GOVERNANCE, RESILIENCE AND SUSTAINABILITY OF LAKES FOR A BETTER SOCIETY

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SERGIO ANTONIO SILVA MUÑOZ
(ACADEMIC EDITOR)

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Foreword

Since ancient times, lakes have provided food and multiple other ecosystem services for humans and other life forms that have subsisted on them. This human-nature relationship involving lakes has transcended numerous generations and has resulted in unique and ubiquitous interdependencies inherent in the concept of sustainability, most notably today within the Sustainable Development Goals (SDGs).

In that regard, there have been several efforts, such as the World Lake Conference, whose origins date to 1984, and today is globally recognized as a place for multi-sectoral participants to exchange their views and experiences on the sustainable management of lakes and their basins.

The 18th World Lake Conference (WLC18) —Governance, Resilience, and Sustainability of Lakes for a better Society— was convened virtually at the University of Guanajuato, Mexico in November 2021. Under the framework of the WLC18, discussions dealt with a wide range of technological, scientific, socio-economic, and cultural issues, among others, related to the sustainable use of lakes, wetlands, and other bodies of standing water, as well as the perennial issues related to in lake and nearshore/lakeshore problems, lake basin activities and global scale challenges.

During the three days of WLC18, 1,032 attendees —from 58 countries of the 5 continents— shared three plenary sessions, seven technical conferences, six special sessions: 128 technical presentations, and the exhibition of 26 posters. Participants ranged from sectors such as education, government, non-governmental organizations, non-profit organizations, financial institutions, citizens at large, and mass media.

As a relevant outcome of the WLC18, the Guanajuato Declaration recognizes that freshwater is essential for all life and socioeconomic development on our planet and that many SDGs will be difficult to achieve without sustainable supplies of freshwater. Since more than ninety percent of all the liquid freshwater on the surface of our planet is contained in lakes and wetlands, it is now imperative to acknowledge their extremely significant role in the global water agenda.

In purpose to adequately address governance, resilience, and sustainability of lakes issues, participants, exchanged global knowledge gained through experiences and foresight gained from diverse transdisciplinary efforts in such areas as the practice of managing of water resources, science, and technology, environment and health, governance, economics, and social ambit, all of which constitute the thematic of the World Lake Conference.

These aforementioned areas also translate into critical issues that include Technology for Sustainable Lake Basin Ecosystem Services, Governance and Economic Components of Integrated Lake Basin Management, Social and Cultural Aspects and Benefits of Lake Basin Management, and Environmental Components and Goals for Sustainable Lake Basin Ecosystem Services.

As a result of recognizing the importance of a rapidly growing transfusion and transfer of knowledge and experiences gained from sources of cutting-edge scientific and technological breakthroughs to fostering the experiences on a global scale is critical for strengthening the science-policy-governance interfaces that have gained in importance, this book presents some representative extended works that were discussed during WLC18.

Special acknowledgment to all who with valuable support and great contributions, through relevant subjects of discussion will be a factor in the implementation of targets and goals encompassed in the SDGs and COPs resolutions regarding the present and future of the global water agenda.

Dr. Sergio Antonio Silva Muñoz
Chair, University of Guanajuato WLC18 Advisory Board,
Provost for Academic Affairs, University of Guanajuato

Chapter 1. Economics

The first chapter of this book comprises work on the analysis of the economic implications of lakes in basins, both locally and globally. The chapter includes aspects on irrigation and trade of water-generated products and issues related to the economic aspects of lake sustainability, such as infrastructure and aquaculture.

Economic valuation of ecosystem services of three reservoirs and their importance for lake governance in Malaysia

Z. Sharip[1], Z. Johar[1], A. Majizat[2], A.N.A. Ghani[3]

Abstract

Economic valuation of ecosystem services is an important research area to support intergrated lake basin management and governance. As such, the economic valuation of ecosystem services was carried out in three reservoirs in the country, namely Sembrong Lake in Johor, Bukit Merah, and Chenderoh Lakes in Perak. The contingent valuation method (CVM) was undertaken to estimate the conservation value of all three reservoirs based on the assessment of the willingness to pay (WTP) for such conservation effort while the travel cost method (TCM) was to estimate the tourism value potential of the reservoirs. Additionally, direct values of water, fish, and flood mitigations were carried out for Sembrong Lake. The WTP per person per year for all three lakes was estimated at RM15.19 for Sembrong, RM17.20 for Bukit Merah, and RM15.76 for Chenderoh, respectively. The total economic values for conservation were RM381.6 million, RM130.7 million, and RM131 million for Sembrong, Bukit Merah, and Chenderoh lake respectively. The TCM analysis indicated that the mean recreation benefits per visitor per year were highest in Bukit Merah (RM294) followed by Chen-

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deroh, (RM197) and Sembrong (RM36). The direct values for Sembrong Lake were RM384.3 million with flood mitigation contributing 62% of the values. Based on this study, the economic values of ecosystem services of the three lakes are substantial and provide a significant welfare contribution to the society. Lake managers and decision-makers should give high priority to the management and conservation of lakes in order to enhance lake ecology that ensures long-term benefits to society.

Keywords: *Contingent valuation, ecosystem services, man-made lakes, travel cost method*

1. Introduction

Lakes provide invaluable services for mankind and living beings. The ecosystem services can be categorised into four categories namely resource provisioning, regulation and maintenances, cultural and supporting. These services are increasingly being evaluated to support decision making and develop management strategies or policies related to the benefits of different service by nature and their trade-offs [1]. Economic valuation of ecosystem services has been identified as important research in the National Blueprint for Lakes and Reservoir Research and Development in Malaysia since 2015 [2]. Such valuation not only enables greater understanding of the ecosystem services but can also enhance the financing pillars of Integrated Lake Basin Management. Valuation of lake ecosystem services is limited in Malaysia; only Tasek Bera was evaluated before year 2000 [3] followed by Putrajaya Lake [4] [5] and Paya Indah Wetland that was evaluated in 2015 [6].

Evaluation of ecosystem services has been widely undertaken worldwide ranging from forest and woodlands, wetland, freshwater system, and marine and coastal systems [7] [8] [9]. Among the categories of services, cultural services were the most widely valuated [8] [9]. In Malaysia, valuation of lake ecosystem services are gaining acceptance and have been extended to evaluate the impact of climate change on lakes [10] as well as assessing the different lake attributes such as in Chini Biosphere reservoir [11]. However, valuation of ecosystem services towards conservation and recreational potential was limited. This study was perfomed to support the development of integrated lake basin management plans for the three selected reservoirs. The aim was to identify the values of lake's main ecosystem services in monetary terms to enable stakeholder prioritised management and conservation efforts.

2. Materials and methodology

2.1 Study area

This study was carried out in three large but relatively shallow reservoirs in Malaysia. The surface area of the reservoir in decreasing order: 33 km^2 (Bukit Merah), 25 km^2 (Chenderoh) and 8.5 km^2 (Sembrong). Chenderoh reservoir is the oldest hydropower reservoir, built in 1930 with a mean depth of 4.5 m. The reservoir also functions as flood mitigation, recreation and aquaculture. Bukit Merah reservoir is the oldest irrigation reservoir in the country, built in 1906 with a mean depth of 2.5 m. The lake has multi-function which includes flood mitigation, domestic water supply, arowana sanctuary and industry and tourism. The sembrong reservoir is the newest among the three reservoirs, built in 1984 and having a mean depth of 3.2 m. The main functions of the reservoir are flood mitigation, and water supply.

2.2 Methodology

This study uses three economic valuation methods comprising indirect economic valuation namely Contingent Valuation Method (CVM), Travel Cost Method (TCM) and direct valuation method.

CVM was undertaken to estimate the conservation value of all the reservoirs based on the assessment of the willingness to pay (WTP) for such conservation efforts. The mean WTP of the double bounded dichotomous choice (DB-DC) contingent valuation method is estimated as the area under the probability function of accepting the price bid posted to the respondent [12], which is as shown in Equation (1):

$$E(WTP) = \int_L^U (1 + e^{\alpha+\beta WTP})^{-1} dbid \quad (1)$$

where $(1 + e^{\alpha+\beta WTP})^{-1}$ represents the probability of saying YES, and upper (U) and lower (L) limits of the integration. The mean is calculated as follows:

$$E(WTP \mid \underline{x}, \beta) = \underline{x}' \lceil -\frac{\hat{\alpha}}{\hat{\delta}} \rceil \quad (2)$$

Table 1 illustrates the description of variables used in the valuation of WTP.

TCM was undertaken to estimate the tourism value potential of the reservoirs; where the 'price' of the site is determined by the time and travel costs incurred by people visiting the site. TCM is estimated based on the Equation 3

$$\widehat{CS} = \frac{1}{-\hat{\beta}_{TC_i}} \quad (3)$$

$\widehat{CS}$ represents the total consumer surplus for the site, and $\hat{\beta}_{TC_i}$ is the coefficient for the travel cost. The total CS of the lake is calculated using Equation 4:

$$TCS = \widehat{CS} * annual\ visitors \quad (4)$$

CVM and TCM were carried out at all lakes where data collection was completed through survey questionnaires and interviews with visitors at the lakes. All data analyses were carried out in STATA Statistical software.

The Direct Value Method (DVM) was only applied for Sembrong Lake due to available data. The direct economic values estimated were water rent, fish rent and flood damages as the following:

i. Yearly harvested fish value from Sembrong Lake based on annual fish catch and price rate that is issued by the Department of Fisheries;

ii. The water value for domestic supply (using the water volume extracted for consumption in Kluang population and water treatment cost); and
iii. The possible flood damage salvaged by the Sembrong Dam (cost for road repair and hydraulic structure based on past flood damages)

Table 1. *Description of variables for CVM.*

Variable	Definition
wtp1	First response on willingness to pay (Yes=1, No=0)
wtp2	Second response on willingness to pay (Yes=1, No=0)
bid1	First bid price
bid2	First bid price
jantina	Gender (Male=1, Female=0)
umur	Age (years)
kahwin	Marital status (Single=1, Married=0)
hh	Household size
income	Monthly income (RM/month)
eduyr	Number of years in schooling (years)
yakin1	Level of confidence in paying to thrust fund (Very confidence=1, Not confidence=0)
jobgov	Type of job (Government and private sector=1, others=0)

3. Results and discussion

The total number of respondents obtained in this study were 105 respondents (Sembrong Lake), 300 respondents (Bukit Merah Lake) and 300 respondents (Chenderoh Lake) respectively.

Figures 1 and 2 shows the education level and age of respondents. Most respondents in Chenderoh and Bukit Merah survey were college or university graduates while those in Sembrong reservoir was secondary school educated (Figure 1).

The age level of respondents in Sembrong lake were older adults at the age of 51-60 while the age levels of respondents in Chenderoh and Bukit Merah were younger adults between the 21-30 years (Figure 2).

Figure 1. *Educational levels of respondents.*

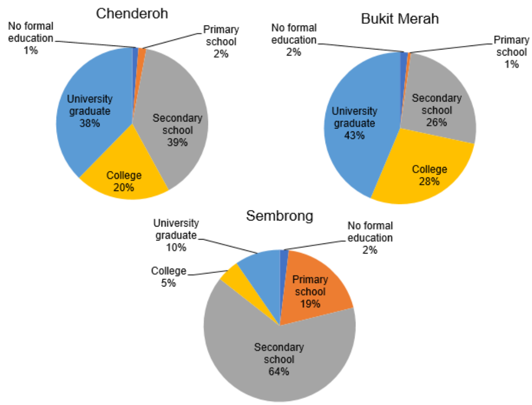
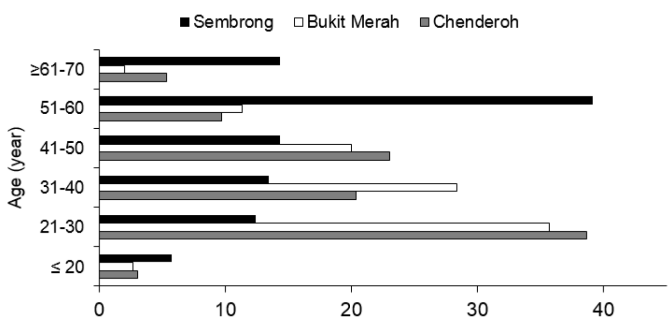


Figure 2. *Age levels of respondents.*



3.1 Contingent valuation methods

Bukit Merah Lake has the highest WTP values compared to Chenderoh and Sembrong lake (Table 2). The total economic value derived from WTP contributed with more than USD90 million for Bukit Merah Lake if the lake is conserved. WTP for Tasik Bukit Merah is affected by income and the level of education of the respondents ($p<0.05$). WTP increased with the increase in income and the education levels of the respondents.

WTP for Chenderoh Lake is affected by age and income of the respondents ($p<0.05$). WTP for Sembrong Lake is affected by marital status ($p<0.05$). Married respondents were more willing to pay for conservation of the lakes.

Table 2. *Economic values for each lake.*

Lake	WTP, RM (USD) /yr	Economic values, RM (USD) million/yr
Chenderoh	15.76 (3.75)	131.0 (31.2)
Bukit Merah	17.20 (4.10)	381.6 (90.9)
Sembrong	15.19 (3.60)	78.6 (18.7)

Note: 1USD=RM4.20

The main reason for the majority of the WTP in Sembrong Lake is to avoid further deterioration of the lake for future generation uses. On the other hand, the reasons for WTP in Bukit Merah and Chenderoh Lake was to enhance the management of the lake and their biodiversity. As for not being willing to pay, more than half of the respondents in all study areas agreed that the maintenance cost should be borne by the government.

Half of the respondents agreed to pay higher tax if the fund is channeled to intensify management and maintenance of Sembrong Lake; this percentage is higher for Chenderoh Lake (62%) and Bukit Merah Lake (72%) of the total respondents. Generally, the Malaysian community depends on the government efforts to manage and maintain facilities including lakes [10]. As such a tremendous amount of funding has interminably been provided by the government towards this end.

In contrast to developed countries such as Japan and USA, community awareness was strong and they became part of the group to undertake management, restoration and maintenance of lakes [13] [14] [15]. Such WTP using CVM surveys has also been undertaken in other Asian and African lakes where a similar positive response of the community willingness to pay for conservation efforts was recorded [16] [17].

The WTP found in these three lakes were much higher than the one recorded in Putrajaya Lake (RM14.60) (Table 3) possibly due to lower sense of belonging of community in the latter. In terms of total economic values, the values in all three lakes were lower than Putrajaya Lake (RM1,027 billion) possibly due to their smaller population compared to Klang Valley.

The WTP in this study was much higher than in some other African lakes such as Chamo Lake and urban lake in the Philippines.

Table 3. *Comparison of WTP in few selected lakes.*

Lake	WTP, USD/yr	Source
Chenderoh, Malaysia	3.75	This study
Bukit Merah, Malaysia	4.10	This study
Sembrong, Malaysia	3.60	This study
Putrajaya, Malaysia	3.50	Majizat et al. 2015
Paya indah, Malaysia	1.70	Siew et al. 2015
Chamo, Africa	0.51	Asmamaw et al. 2018
Urban lake, Phillipines	2.63	Bueno et al. 2016
Dalai, China	10.72	Wang & Jia 2012

3.2 Travel cost methods

The TCM analysis indicated that the mean recreation benefits per visitor were RM36 (~USD9) for Sembrong, RM294 (~USD70) for Bukit Merah and RM197 (~USD47) for Chenderoh, respectively. Higher recreational values for Bukit Merah is due to its various attractive sites. The lake has Laketown Resort and Chalet with Waterpark, Ecopark and Adventure park for different recreational facilities to attract visitors. Additionally, there are also Orang Utan sanctuary island and Arowana sanctuary in different parts of the lake. Similarly, Chenderoh Lake has Tasik Raban Resort and few other traditional chalets besides located nearby the Lenggong Valley which is a UNESCO World Heritage Site. Sembrong Lake lacks tourism facilities and only attracts anglers.

Factors influencing TCM varied between lakes (Table 4). Generally, visitors to Bukit Merah and Chenderoh Lake are mostly families of outside residents that are willing to travel for two hours using a car and van for recreational purposes. Visitors to Sembrong were mostly local anglers that travel by motorcycle and spent longer time for their angling activities.

The main factors influencing TCM for Tasik Bukit Merah and Chenderoh were the travel cost, income, household size and the number of days allocated for recreation ($p<0.05$). Marital status, gender, and the level of education also affected TCM for Bukit Merah. TCM for Chenderoh Lake was also influenced by age, and the job type while TCM for Sembrong Lake is only influenced by the year of education.

Table 4. *Factors influencing TCM for each lake.*

Factors	Chenderoh	Bukit Merah	Sembrong
Average time spent	~ 2 hours	~ 3 hours	~ 4 hours
Mode of transport	Car/van (96%)	Car/van (89%)	Motorcycle (74%)
Travelling time	2 hours (45%)	2 hours (>50%)	30 minutes
Travelling companion	Family (59%)	Family (60%)	Friends (53%)
Distance travel (<50 km)	68.7%	16%	>70%
Main purpose	Recreation (>50%)	Recreation (>50%)	Angling (>55%)

The recreational values from TCM estimation in these three lakes were much lower than the one recorded in Putrajaya Lake (RM304.30).

3.3 Direct values

The direct values for Sembrong Lake were RM384.3 million (USD91.5 million) with flood mitigation contributing 62% of the values. Flooding is one of the common issues in Malaysia, the construction of Sembrong Dam was to mitigate flooding to downstream areas of Batu Pahat. Sembrong Dam has been serving the downstream areas of Batu Pahat since its establishment in 1984. There is no record of major flooding in the areas during the period of 22 years from 1984 to 2006. The only flood occured was in 2006-2007 where the whole Malaysia in general and Johor State experienced the worst flood events [18] [19]. The estimated cost for road repair including bridges and hydraulic structures for Batu Pahat District was RM 13.6 million and RM 63.3 million, respectively. By estimating the total damage from flood, it is only 5% of the total worth of economic loss during the flood occurrence and at a discounted rate of 8% (USD57.2 million).

Figure 3. *(a) Fish composition. (b) Total value of fish in Sembrong Lake.*

The water rent contributes 20.4% while fish rent contributes 17.6%. With daily extraction of 58 MLD of water for domestic supply, the water rent at discounted rates of 8% was estimated at USD18.9 million.

The most dominant fish species in Sembrong lake is *Barbonymus gonionotus* followed by *Oreochromis mossambicus* contributing 68% of the fish harvested by fishermen for this study (Figure 3). *Barbonymus gonionotus* is the most common freshwater Asian carp found in Malaysia. In terms of fish price, the most expensive fish were *Oxyeleotris marmoratus* (USD14.30/kg) followed by *Hampala macrolepidota* and *Hemibagrus nemurus* (USD2.50/kg). Based on the total value of fish and fish harvest in a year, the fish rent at discounted rates of 8% was estimated at RM65.6 million (USD15.6 million). This value is much larger than the fish value recorded in Putrajaya Lake [4] [5] probably due to lake longer existence, larger size and major rivers influence. Sembrong Lake was also occasionally stocked with fish fry by the Fisheries Department to reduce the eutrophication level.

4. Conclusion

Bukit Merah Lake has the highest economic values (CVM and TCM) among the three lakes. The economic values of ecosystem services of the three lakes were substantial and provided a significant welfare contribution to the society. Lake managers and decision-makers should give high priority to the management and conservation of lakes in order to enhance lake ecology that ensures long-term benefits to society.

Acknowledgements

We thank the National Water Research Institute of Malaysia (NAHRIM) for providing funding for this study.

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Lake Cuitzeo, Michoacan, Mexico. Effects of environmental deterioration

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Abstract

Cuitzeo is the second largest lake in Mexico (420 km^2). With 6-8 million years in age [1], it is considered one of the oldest lakes on Earth. Field, laboratory, and documentary research was developed to integrate an environmental diagnosis. The lake is very shallow with a mean depth of 1.6 meters, according to electric conductivity values it is divided into three lacustrine zones: the eastern zone with very low electric conductivity values, the western side with up to 8,850 µS/cm and the central part with intermediate values. Water quality analyses indicate that Cuitzeo is a hypereutrophic aquatic ecosystem, highly turbid, with increasing saprobic conditions. Despite the basin area (3,675 km^2) receives an average annual water rainfall income of almost 4,000 million cubic meters, intensive water overexploitation and high evaporation rates derived from deforestation activities and land use change, cause that Lake Cuitzeo receives less than 10% of water input from the basin. Consequently, during extreme dry seasons up to 70% of the lake surface desiccates [2] and dust storms are present in the western side. Fishery is

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near to collapse due to both intensive fishing and the frequent desiccation episodes, from 1,546 ton/year of fish catch registered in 1993 fish productivity has fallen to 250 ton/year in 2006 [3]. Forty-five years ago, the presence of up to 18 fish species were registered from which 15 were native species. At present only six species are present from which three are native species.

Keywords: *Lake Cuitzeo, environmental diagnosis, lake desiccation, fishery collapse*

1. Introduction

Lake Cuitzeo is located on the boundary of the states of Michoacan and Guanajuato, Mexico. The watershed is 3,675 km^2 in surface, whereas the lake is about 420 km^2, depth reduced from 4.0 m [4] to 0.12 m [3]. The lake has three defined lacustrine basins: the eastern basin with freshwater and the existence of water springs, wetlands, and internal thermal water springs; the central basin with increasing salt and minerals concentration, sewage discharges and very low depth; and the western basin with high values of mineral concentration and pollutants, as well as high instability of water residence and frequent desiccation periods.

Nowadays the average annual storage volume of Lake Cuitzeo is only 255.0 Mm^3. This is the same amount of water as lake Zirahuen which is 42 times smaller in surface area (10.0 km^2).

The Río Grande of Morelia is the main inlet with a theoretical flow of 151.0 Mm^3/year that includes numerous agricultural and urban pollutants. Other tributaries are Querendaro and Zinapecuaro rivers with a total contribution of 40.0 Mm^3/year, apart from other small streams originating in the high mountains [3][5].

Lake Cuitzeo is in an advanced state of hypereutrophication due to its high content of organic matter and high levels of saproby. At present Lake Cuitzeo is known for the frequent dust storms in the western basin, these dust storms contain high concentrations of salt, cysts, bacteria and viruses which are suspended in the air and are dragged to the riverside populations.

In the year 1941, Lake Cuitzeo registered its first drought in 70.0% of its area caused by the construction of the Cointzio and Malpaís dams, the construction of irrigation channels and the reduction of the flow of water in its main tributary. In the year of 1985 the western and central parts of the lake, which constitute 60.0% of the total surface, were completely dry due to the lack of rain that affected the entire country. These sections of the lake have lost the bathymetric relief that characterizes a lake and transformed into plains of saline soils with little drainage. During the dry season, the reduction of the lake surface and the loss of volume of Lake Cuitzeo are reduced from 485.0 Mm^3 (1995) to less than 300.0 Mm^3 (2020), the western area dries up (January-April) [6] [7].

When this process occurs, then the dissolved pollutants in the water tend to settle down on the substrate, inducing the generation of dense dust storms that cover the communities of Capacho, Jeruco, Doctor Miguel Silva and Cuitzeo.

2. Materials and methodology

A detailed environmental, social and economic diagnosis of the basin and lake was made with the aim to identify the effects of environmental deterioration of Lake Cuitzeo and its basin.

An extensive and systematic documentary review of various physical and digital sources was carried out, as well as verbal interviews with the key actors about the management of the Cuitzeo basin.

Simultaneously, a field work was executed and included the weekly collection of interviews, audiovisual and photographic material of the desiccation and recovery of the volume of the lake, in addition to the updating of morphometric parameters.

2.1 Water balance

The estimation of the water balance was based from data collected by Sistema Meteorológico Nacional (SMN-CNA) and the application of the principle of conservation of masses. This establishes that, for any arbitrary volume, and for any period of time, the difference between the tributaries and effluents will be conditioned by the variation of the volume of stored water.

The water balance was estimated using the following expression (Figure 1):

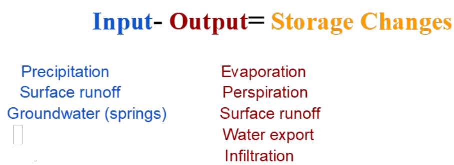


Figure 1. *Water balance equation.*

2.2 Economic impact of dust storms

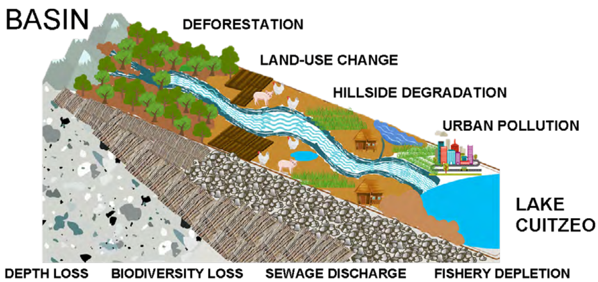
In the case of local effects on public health in Lake Cuitzeo derived from dust storms, the defensive cost method (induced) was used in the western basin, 272 questionnaires were applied, this was the determined sample with 95% of confidence. The collection of information was carried out in the most affected by dust storms, Doctor Miguel Silva and Jéruco (Cuitzeo) and Capacho (Huandacareo) [6].

The defensive costs that were quantified were: cost of doctor visits, medicine costs, and cost of face masks, to determine a total cost per household and then to extrapolate the information. The analysis of the information collected in the field was carried out by different statistical tests, based on descriptive statistics characteristics (mean, mode, median, minimum and maximum) of each variable, nominal, cardinal or metric and bivariate analysis tests were traditionally performed (test of differences of means and correlations). The information is systematized and analyzed with SPSS and GRETL statistical software [6].

3. Results and discussion

The drainage watershed has been under a progressive ecological deterioration including social, economic and environmental issues, in which different problems are identified and to a different degree in the upper, middle and lower basin of Cuitzeo (Figure 2).

Figure 2. *Process of ecological deterioration in the basin of Lake Cuitzeo.*



3.1 Sewage and water quality

In the basin of Lake Cuitzeo 25 municipalities are included, among which the capital of the state, Morelia, is the largest population center and also the one with the greatest impact on the lake. Up to 23.0% of the population of Michoacán lives in the Cuitzeo basin and 26.0% of the state's wastewater is generated. With 850,000 inhabitants, Morelia generates 63,072.0 Mm^3/year of wastewater and 442 ton of phosphorus/year are discharged into the Rio Grande de Morelia.

The lake is a continuous warm polymictic lake. However, the temperature near the surface (15.0 cm deep) can rise up to 4.5°C higher than the underlying water column. The West basin is more turbid (0.06 m) than the Central basin (0.15 m) and East basin (0.20 m) (Table 1).

Maximum concentrations of suspended solids are registered in the West basin (897.0 mg/L), whereas the East basin is less turbid (185.0 mg/L), the Central basin is with intermediate values (632.0 mg/L). Most of the chemical variables indicated relatively extreme values considering the freshwater nature of the lake. This is observed in values of electric conductivity, pH, alkalinity, total dissolved solids, and organic matter. The presence of fecal coliform bacteria is also manifested in high concentrations. The high concentrations of chlorophyll are associated with blue green algae blooms dominated by *Euglena spp*, *Oscillatoria spp*, and *Anabaena spp*.

Table 1. *Water quality parameters of lake Cutizeo by zones [3].*

Parameter	West	Central	East
Transparency (m)	0.06	0.15	0.20
Electric conductivity (µS/cm^{-1})	8850	2750	850
Salinity (‰)	5.8	1.9	0.58
Hydrogen potential (dimensionless)	11.8	9.8	7.9
Total solids (mg/L^{-1})	4703	3085	578.5
Suspended solids (mg/L^{-1})	897.0	632.0	185.0
Biochemical Oxygen Demand (mg/L^{-1})	217.40	167.6	114.8
Chemical Oxygen Demand (mg/L^{-1})	625.00	270.3	123.4
Total phosphorus (g/L^{-1})	1545.00	916.7	247.6
Chlorophyll (g/L^{-1})	40.50	132.0	227.0
Fecal coliform bacteria (NMP org./100 mL)	1949.01	1168.9	480.20

3.2 Water balance

In the 3,675 km^2 of drainage basin of Lake Cuitzeo there is a surface runoff of 2’946,034 Mm^3 with an infiltration rate of 258.18 Mm^3, surface springs and groundwater contribute to water production of about 15.78 Mm^3 and 225.58 Mm^3, respectively (Table 2).

Table 2. *Water balance of the Cuitzeo Lake basin.*

INPUT (Mm^3)		
Precipitation (871.35 mm/año)	3,202.211	---
Surface runoff	2,946.034	85.55%
Subsurface infiltration (8.0%)	256.176	07.44%
Graund water	225.58	06.55%
Water springs	15.78	0.46%
Total	**3,443.57**	**100.0%**
OUTPUT (Mm^3)		
Evaporation (1,771.5 mm/año)	6,510.262	100.0%
Total	**6,510.262**	**100.0%**
HYDRAULIC DEFICIT (Mm^3)	**-3,066.430**	**-47.10%**

However, the construction of the Cointzio and Malpaís dams, irrigation channels and a decrease in the water flow of the main tributary (Rio Grande de Morelia) resulted in a hydrological imbalance, causing severe droughts in the lake and, in turn, negative effects on health and economy of the shoreline human communities.

It is evident a pronounced hydrological imbalance between the amount of annual rainfall on the lake basin and the annual rate of evapotranspiration recorded. The average annual volume of water that comes from the runoff of the basin, with an average annual rainfall of 871.35 mm is 252.0 Mm^3, whereas the evapotranspiration rate is 746.8 Mm^3, which represents a hydraulic deficit of 273.8 Mm^3 of water (Table 3).

Table 3. *Water balance of Lake Cuitzeo.*

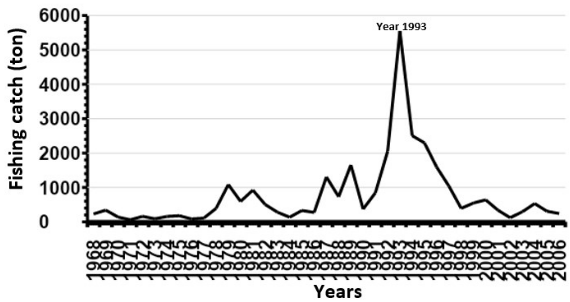
INPUT(Mm^3)		
Precipitation	252.0	53.3%
Rio Grande of Morelia	151.0	31.9%
Rio Querendaro	40.0	08.4%
Rio Zinapecuaro	30.0	06.4%
Total	**473.0**	**100.0%**
OUTPUT (Mm^3)		
Evapotranspiration	746.8	94.5%
Total	**746.8**	**100.0%**
HYDRAULIC DEFICIT (Mm^3)	**-273.8**	**-40.1%**

3.3 Fishery depletion

The lake and its littoral zone is characterized by high primary productivity rates, but very low biological diversity. In 1993 fishing captures in Lake Cuitzeo reached up to 5,546 ton with a yield rate of up to 130 kg/ha, while in 2006 the fish production reached a maximum of only 250 ton [3] with a yield rate of 8.0 kg/ha (Figure 3).

The above was mainly the result of the introduction of exotic species, the progressive process of hypereutrophication of the lake, the introduction of exotic fish species, the frequent desiccation of the West basin where previously the species of "charal" *(Chirostoma jordani)* was abundant, as well as the intense overfishing with long fine mesh nets. Of a total of 19 fish species registered in the year of 1975, only 6 species have survived [8] [3].

Figure 3. *Historical evolution of the fish catches in Lake Cuitzeo [3].*



3.4 Impacts of dust storms

The four municipalities that are the most affected from dust storms are Chucandiro, Huandacareo, Copandaro and Cuitzeo. According to the results obtained by field research made by the University Michoacana of San Nicolas Hidalgo (UMSNH), affected inhabitants spent up to $350,000 US dollars in medical treatment during the desiccation period of four months with the occurrence of dust storms [6], resulting in 97,026 respiratory and 11,288 stomach infection cases [9][10][11].

4. Conclusion

It has been accepted in limnological research that the hypereutrophication process is the last stage of lake ecosystems before extinction [12]. This status includes unstable environmental conditions and the disruption of the original healthy structure and function of the aquatic ecosystem. In Lake Cuitzeo, the hypereutrophication process has been manifested in water unbalance, loss of depth, sediment resuspension, high turbidity, salinization, high nutrient loading, dissolved oxygen depletion, frequent algae blooms, the increase of saprobicity, loss of fish diversity, and depletion of fishery.

Considering that Lake Cuitzeo is located in the boundary with the state of Guanajuato and the Mexican Plateau where water resources are very limited for economic and social development, it is of fundamental importance to induce the Federal Government to declare Lake Cuitzeo as Zone of Ecological Restoration according to the article 78 of the General Law for Ecological Equilibrium and Environmental Protection (LEGEEPA). This decree will support strategic restoration programs including the participation of those affected human communities. The water production and storage in functional aquatic ecosystems is now crucial to face water vulnerability, climate change and loss of productivity capacity in Latin America.

Acknowledgements

The authors thank the fishermen's groups and unions for their openness and contributions in the field work, as well as the organizations, institutions and citizens who, in the face of adversity, continue to fight for the rescue of Lake Cuitzeo.

Special thanks to the members of Panorama Ambiental A.C., for their contribution in research and fieldwork. We also thank the young professionals from the Mexican federal program of Jóvenes Construyendo el Futuro for their valuable work in computing and field work.

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Chapter 2. Environment and Health

In the second chapter, the topics are related to the impacts of climate change, aquatic ecosystems, biodiversity, water quality and sanitation, integrated waste management, quality of life, environmental health, energy, integrated watershed management, risk assessment, circular economy, and works related to lake pollution, as well as local projects for regeneration and restoration of water bodies.

Assessment of climate change in the forest in the spring, historical and future period, Mexico

Ángel Flores Ponce[1], Sonia Tatiana Sánchez Quispe[1], Liliana García Romero[1]

Abstract

Climate change is one of the greatest challenges of our time and places additional pressure on our societies and the environment. It is suggested that its greatest impacts will be long-term and involve complex interactions between natural processes (ecological and climatic phenomena), global social, economic and political processes; This is why the precipitation and temperature series are quantitatively evaluated due to the impact of climate change to obtain droughts and humidity in the forest area La Primavera of Mexico; where it is imperative to carry out hydrological studies to know the current water status due to the importance it has for being a protected natural area, this is because drought is an insidious natural hazard resulting from rainfall levels below what is considered normal and when this phenomenon lasts for a season or for a longer period of time, the precipitation is insufficient to respond to the demands of society and the environment, as well as the humidity caused by precipitation levels above the normal, which can become floods that cause great disasters in their wake.

Keywords: *Climate change, drought, humidity, vulnerability, risk*

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1. Introduction

Water is an indispensable element for the existence of life on our planet, all living beings that inhabit Earth need it to survive. Unfortunately the availability of the water resources on the planet is decreasing, due to the misuse and treatment we give to the waters we use to meet our needs and the climatic variables that limit the availability of water, since there are anomalies in the future series of precipitation and temperature, which generates a decrease in this resource. In recent years there has been exponential talk of these climatic variables, which are considerably affecting important sectors for society.

The concept of climate change arises for the first time in the nineteenth century, as a result of geological studies that found that, since prehistoric times, the Earth had presented variations in climate. For a long time there was discussion about the impacts that human activity could have on such changes, but it was until the 1960's that scientific evidence began to support the notion that activities of anthropogenic origin could actually be affecting the global climate [7].

In Mexico, 90 million inhabitants are supplied with water from the aquifers [5]; given this, there is a need to know the water availability both surface and underground in different areas of studies throughout the country, this availability can be used for the generation of electricity through geothermal plants.

Climate change is an environmental problem with unique characteristics. Since it is of global competence, it is proposed that its greatest impacts will be long-term and involves complex interactions between natural processes (ecological and climatic phenomena), social, economic and political processes of a global nature.

As a particular case, changes in the precipitation and temperature series due to the impact of climate change in the La Primavera forest area, Jalisco, are quantitatively evaluated; where it is imperative to carry out hydrological studies to know the current water status due to the importance it has as an area of protection of flora and fauna, as well as a potential geothermal field.

The La Primavera forest has an area of 40,000 hectares, of which 30,500 are part of the La Primavera Flora and Fauna Protection Area (APFFLP), decreed by the federal government on March 6, 1980. On October 27, 2006, the bureau of the international coordinating council of the MAB program of the United Nations Educational, Scientific and Cultural Organization (UNESCO) incorporated the APFFLP into the global network of biosphere reserves of the MAB-UNESCO; this protected area is one of the most important in the west of the country and constitutes the "lung" of the metropolitan area of Guadalajara [3].

Climate change is no longer seen as a problem that concerns only developed countries. Therefore, it is the task of countries such as Mexico to get involved in its study and try to implement in the short term those policy actions that allow the mitigation of it; in the medium and long term, it is up to Mexico itself to create strategies and plans that allow it to adapt and mitigate climate change in our country. In order to achieve this, it is clear that Mexico needs to work and develop in this line of research.

2. Justification

Climate change is an issue of international importance, as extreme weather events are increasingly recorded, which have left severe damage, both economic, ecological and human.

This problem could undoubtedly affect different economic, political and social sectors anywhere; the magnitude of this affectation will depend on the vulnerability of each area, which means that the climatic conditions will be different for each site and the climatic variables will reflect these affectations in different scales.

Water resources are one of the sectors that denote the utmost concern about the phenomenon of climate change worldwide. Currently the existing water resources are not enough to supply the demands of society; with unpredictable phenomena such as the change in the climate, the situation becomes more worrying.

There are no updated hydrological studies for the La Primavera Flora and Fauna Protection Area; so it is imperative to carry out a set of multidisciplinary studies to know the current situation of the area in question, in such a way that the availability of both surface and underground resource can be obtained, in order to see the impact that these will suffer with this existing climate change.

3. Methodology

The methodology to be followed for the realization of this research is made up of several stages, which are described below.

3.1 Analysis of the area under study

This stage consists of carrying out the geographical analysis of the area under study, the delimitation and characterization of it, since thanks to the recognition of the area to be studied it allows to know the characteristics of this, with which decisions will be made from this information, as well as it will allow us to make a comparison of the studies to be carried out, with those already obtained in previous studies.

3.2 Collection of information and data

In order to carry out the realization of this project it is necessary to carry out a collection of information that is necessary for the realization of all the processes, so it is necessary to consider and analyze what will be the information to be required for the preparation of the studies and know where it can be obtained, therefore, a list of the information that was collected and the sites from which they were obtained is made:

- Precipitation and temperature information. These data are obtained from the weather stations that are located near or within the study basin. For these data, the Computerized Climate database [1] was used.

- Evapotranspiration was calculated from temperature and precipitation data obtained earlier in [1], using Thornthwaite's method.
- Layers of type and use of soil. These are maps in vector format obtained from the website of the National Institute of Statistics and Geography [6], which helped us in carrying out the calculations of the study area.
- Water demands from the agricultural, urban and industrial sectors. This information was obtained in the digital portal of the National Water Commission [2], [9].
- Precipitation and temperature data considering the effects of climate change, for the CPR of 4.5 and 8.5 for short, medium and long term periods, through the ArcMap software, which are available for research work on the website of the National Institute of Ecology and Climate Change [4].

3.3 Carrying out the studies and obtaining results

Once obtained the information of the study area, we proceeded to the realization of the studies of the area to be able to carry out the calculations with the help of programs such as ArcMap and Excel, to obtain the data regarding climate change in our study site with different RCP to near and far study horizons.

3.4 Comparison of hydrological modelling results (current period vs climate change)

Once obtained the modeling of the historical series of the runoff for the La Primavera Flora and Fauna Protection Area, and the modeling of the same but considering the effects of climate change, a comparison of the results could be made. There are two models for historical periods, one considering the effects of climate change and the other simulating the climate that according to the available climatological data occurred. Based on the results obtained from the models, conclusions can be made about the impact that climate change will have for future periods; in this way, measures can be taken to make an appropriate use of water resources under the different climate change scenarios proposed in the models.

4. Results

The results obtained in this work are shown in detail, in addition to the processes that were followed to obtain them.

The stage of hydrological modeling is undoubtedly very important throughout the process, since from here important conclusions emerge that will allow to evaluate some proposed scenarios. To carry out mathematical modeling, it is necessary to present data from different sectors, such as meteorological and hydrometric stations; series of precipitation and temperature generated from climate change models and for each of the scenarios proposed.

4.1 Studio area

As a particular case, the change in the precipitation and temperature series due to the impact of climate change in the La Primavera forest area, Jalisco, is quantitatively evaluated, where it is imperative to carry out hydrological

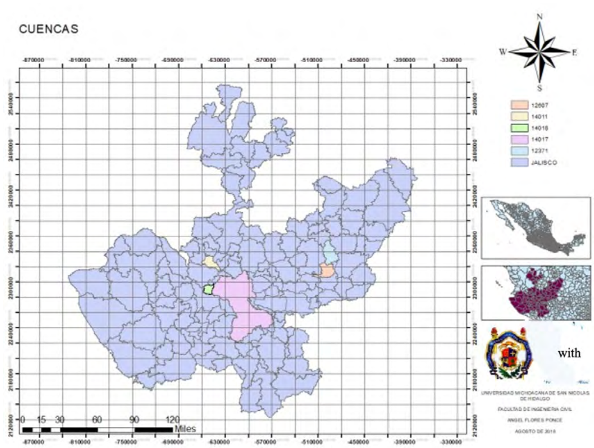


Figure 1. *Location of the study area of the basins surrounding the La Primavera Flora and Fauna Protection Area.*

studies to know the current water status due to the importance it has as an area of protection of flora and fauna, as well as a potential geothermal field.

4.2 Collection and processing of information

Precipitation

Meteorological information was obtained from the selected stations and their respective evaluation was carried out.

Evaluating the consistency of the data means evaluating the quality and reliability of the information to be processed. This evaluation was carried out by means of the following tests:

1. Sequence testing
2. Helmert test
3. Anderson limits
4. Matrix and monthly series

Once these tests were carried out and verified the reliability of the information, we proceeded to the respective filling of data from our meteorological stations "filling of gaps".

Temperature

The same procedure with precipitation was carried out to obtain the meteorological information of the stations with respect to the temperature, to later carry out the filling of gaps in the information and with this to be able to proceed with the obtaining of the evapotranspiration of the area by means of the Thorntwaite method

Underground extraction

In order to know the impact on subsoil water, the volume of extraction per cell that exists in the geological masses of the different aquifers in this region was obtained, and with this information to know the overexploitation of this underground resource.

Table 1. *Analysis of the wells to know their volume of extraction.*

ZONA	POZOS
TOLUQUILLA	1564
SAN ISIDRO	363
AMECA	1952
ATEMAJAC	817
ARENAL	171
TEQUILA	119
AMATITAN	88
CAJITITLÁN	496
M. ACATLÁN	231
TOTAL	5801

Climate change

Climate change information is obtained for both precipitation and temperature for RCPs of 4.5 and 8.5 for short, medium and long-term periods using the same methodology used by:

France
United States
United Kingdom
Germany

This information was obtained from the Precipitation Maps (Figure 2) and Temperature Maps (Figure 3) with the ArcMap operating system and temperature.

Once the climate change data were obtained, they were applied to the historical data to obtain their possibilities of change to different periods.

Table 2. *Methodology of different countries applied to Mexico.*

Figure 2. *Precipitation map for climate change.*

Figure 3. *Temperature map for climate change.*

Table 3. *Monthly climate change to different CPR and different periods.*

In the same way, the comparison is made for the possible changes in temperature and annual precipitation to different periods.

Table 4. *Annual climate change to different CPR and different periods.*

HISTÓRICA					
PRECIPITACIÓN 68.69			TEMPERATURA 18.47		
PAÍS	RCP	PERIODO	VARIABLE CLIMÁTICA	CAMBIO	CAMBIO CLIMÁTICO
MEXICO	RCP 4.5	2015-2039	Precipitación (mm)	-1.19	67.40
			Temperatura media (ºC)	1.30	19.77
		2045-2069	Precipitación (mm)	-2.22	66.37
			Temperatura media (ºC	2.34	20.80
		2075-2099	Precipitación (mm)	-3.06	65.53
			Temperatura media (ºC	2.77	21.24
	RCP 8.5	2015-2039	Precipitación (mm)	-1.50	67.09
			Temperatura media (ºC	1.41	19.87
		2045-2069	Precipitación (mm)		
			Temperatura media (ºC	3.09	21.55
		2075-2099	Precipitación (mm)	-7.50	61.09
			Temperatura media (ºC	5.01	23.47

With the different CPR and the different periods, a graphic comparison is made with respect to the historical values, in order to appreciate the climatic trend of the region.

5. Conclusion

The area of the La Primavera forest, Jalisco, despite being an area of protection of flora and fauna, is in a situation of climate change due to the overexploitation of the water resources of the subsoil, which generates anomalies in the future series of precipitation and temperature, causing a trend of change in the climate, generating future effects to the region.

Figure 4. *Comparison of precipitation at RCP 4.5 at different periods.*

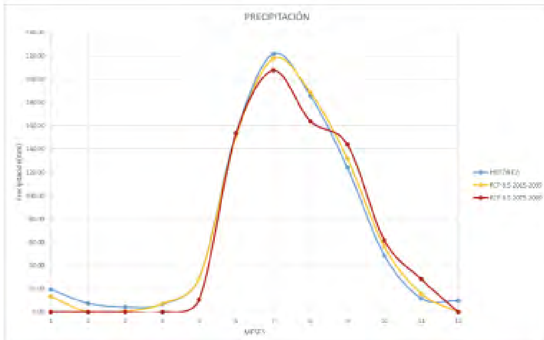


Figure 5. *Comparison of precipitation at RCP 8.5 at different periods.*

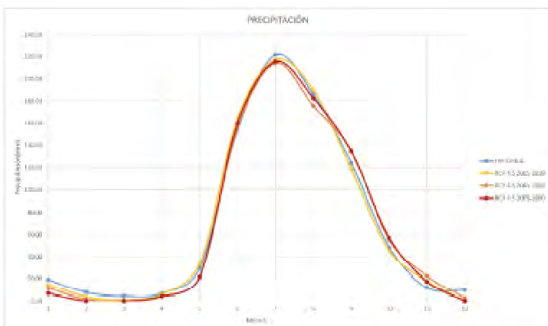
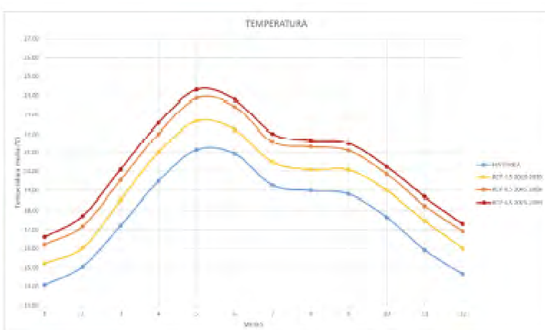


Figure 6. *Temperature comparison at CPR 4.5 at different periods.*



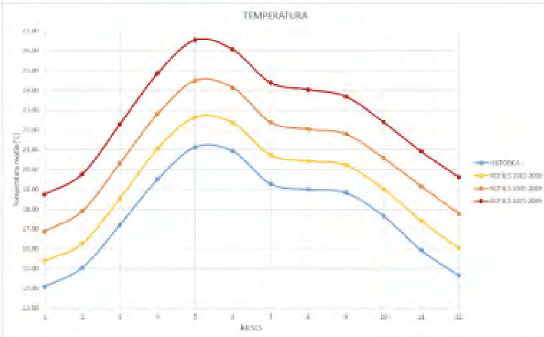


Figure 9. *Temperature comparison at CPR 8.5 at different periods.*

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Bathymetry and sediment estimation in the Laguna de Yuriria, Mexico

Juan Miguel Reyes Cisneros[1]

Abstract

For the Laguna de Yuriria, located in the state of Guanajuato, Mexico, with a maximum water level of 278 million cubic meters and an area close to 6,000 hectares, two bathymetries are identified, one carried out in 2005 and another in 2009, whose surveys were made at different times of the year, with significant differences between maximum depths. Given economic limitations and the need to have updated bathymetry referenced to the limnimetric rule of the Lagoon and to know the current volume and distribution of sediments, in April 2020, a bathymetric and sediment survey was carried out, through the direct measurement at 634 systematically distributed points. To validate the results, the volume of water was calculated based on the generated bathymetry and compared with the volume reported by the National Water Commission (CONAGUA) at that time, resulting in similar data. The estimate of the current volume of sediment was 77.5 million cubic meters. Finally, a model was generated to estimate the volume contained in the reservoir, based on the direct reading of the limnimetric rule.

Keywords: *Sediment, bathymetric survey, Laguna de Yuriria, water management*

[1] Secretary of the Environment and Territorial Planning of Guanajuato

1. Introduction

The Laguna de Yuriria is an artificial lake that is located within the limits of the municipality of the same name in the State of Guanajuato; it is one of the first hydraulic works implemented in America (around 1548), and is considered one of the most important bodies of lacustrine water in Mexico. There is a diversity of migratory bird populations and it is characterized by the presence of several species of the ichthyofauna typical of the Lerma River basin, in addition to being considered in the list of the RAMSAR convention (site No. 1361 and code No. 4MX048) of February 2, 2004 [2]. This reservoir receives water from the Lerma River through a channel called Taramatacheo, fulfilling the role of regulating vessel of the Solís Dam. Currently, a water mirror surface of more than six thousand hectares is estimated and, according to CONAGUA [1], it has a storage capacity at its ordinary maximum water level (NAMO) of 278,789 million cubic meters (Mm3).

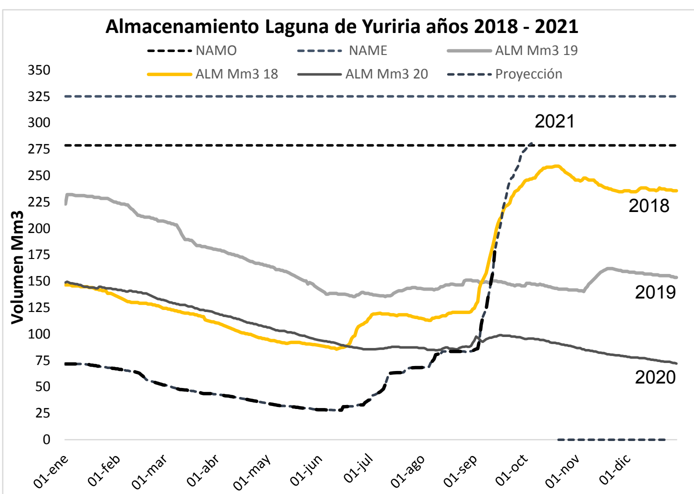
As it is a regulating vessel of the Solís Dam and a source of supply for irrigation of agricultural crops, the water levels respond more to the regulation of the volumes carried out by CONAGUA, than to the dynamics of the rainy season, that is, the high levels that the Laguna de Yuriria reaches are mainly due to the arrival of water that CONAGUA intentionally discharges into it. These levels or volumes can be reviewed in the daily reports in the Hydrometric and Climatological Bulletin in which it presents statistics on the dynamics of the dams and rivers of the different basins of the country as well as of influential meteorological stations. In this sense, when it comes to generating bathymetric cartography, this information is very useful, in addition to readings in the field that, in the case of the lagoon, can be carried out on a limnimetric ruler located at the end of the pier on the Yuriria boardwalk. In this way, when a bathymetric survey is carried out, it is necessary to record the reported volumes and field measurements in order to adjust the depths indicated by the different isobaths in the cartography. In the same way, the volumes reported by CONAGUA can be correlated with the level measurements of the ruler in the field to generate a regression model to make estimates of the bathymetric levels and the volumes of water storage.

2. Materials and methodology

2.1 Background of bathymetry in the Laguna de Yuriria

Based on the information reviewed, there is knowledge of two bathymetries carried out at different times, the first during March 2005, by the National Polytechnic Institute [2] and the second in October 2009, carried out by the National Polytechnic Institute. same institution. The most obvious difference between the bathymetric maps is the maximum depth, with a difference of 2 meters equivalent to 44% with respect to one another, resulting in a depth of 4.5 meters in the dry season of 2005 and 2.5 meters in the end of the rainy season in 2009. It seems that one of the two is wrong, but this difference is due to the condition of the regulating vessel and the manipulation of the levels by CONAGUA. Regarding the shape of the bottom relief, both studies coincide in having a shape tending towards a plain towards the interior of the reservoir, while near the shore the slope is steeper, the latter condition being more pronounced in the 2005 bathymetry.

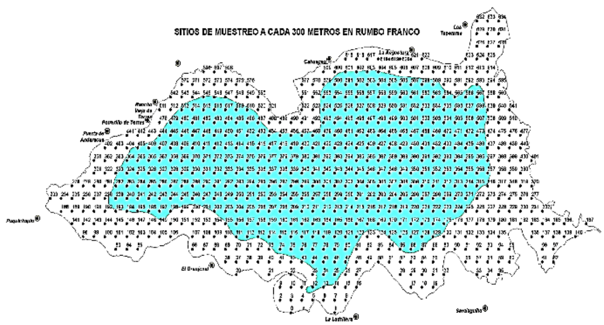
Figure 1. *Water storage in the Laguna de Yuriria during the years 2018 to 2021 (own elaboration with data from CONAGUA [1]).*



2.2 Planning of information gathering in the field

A map of the location of sampling points was generated by means of a grid randomly superimposed on the Laguna de Yuriria polygon at a distance of 300 meters between points, being systematically distributed in 634 points throughout the water mirror. Likewise, the registration formats and the ruler for measuring the depth of the water and sediments were generated, which consisted of a 6-meter-long graduated rod. Finally, the navigation team was prepared and the work team was integrated, which consisted of the boat operator, 1 person in charge of making the measurements and a person in charge of locating the points and recording the data.

Figure 2. *Distribution of sampling sites in the Laguna de Yuriria (own elaboration).*



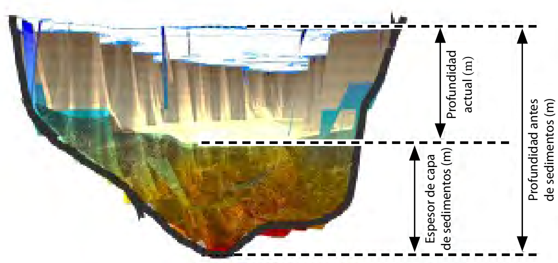
2.3 Navigation and data collection in field

With the point distribution layer loaded in a GPS application on Smartphone, the sampling points were located and the sediment depth and thickness data were recorded in the respective formats. The measurement was made with the rod introduced into the water and subsequently penetrating the sediment at a more or less similar force for each measurement. Likewise, the record of the water level was kept on the ruler located on the Yuriria pier. The information gathering in the field was carried out from April 14th to 30th, 2020, due to the fact that some areas were inaccessible due to the presence of aquatic weeds. Additionally, some zero isobath points were georeferenced on the outskirts of the lagoon.

2.4 Information processing and generation of final products

The field data was emptied into a spreadsheet and imported and processed in a Geographic Information System, obtaining a shape file of points and a raster file, to later obtain the isobaths at every 0.5 meters of depth. From the isobaths, a 3D model of the relief of the lagoon was generated in the program. Likewise, the volume of stored water and sediments in the bottom were estimated, with the Geographic Information System.

Figure 3. *Measurement parameters: current depth and before sediment; sediment layer thickness (own elaboration).*



3. Results and discussion

3.1 Bathymetric estimation model

A simple bathymetric map, product of information measured at a given moment, is not enough to understand the dynamics of the water levels of a reservoir subject to frequent variations, since according to the season of the year and the diversity of climatic behavior between several years, these levels vary considerably, this situation being very evident in the Laguna de Yuriria, even more so because it is a regulating vessel. To solve this deficiency of the bathymetric study, a combination of available parameters was carried out to develop a statistical analysis that would allow, on the one hand, to estimate the storage volume of the reservoir based on direct readings of the limnimetric ruler of the jetty, in addition to compensating and estimate the value of the deepest isobaths with that same reading or, on the contrary, based on the daily report of storage volumes reported by CONAGUA [1], to be able to estimate the depth.

A linear regression model was generated based on 35 readings of the rule in a period from February 25th, 2019 with a volume reported by CONAGUA of 207,169 Mm3 until May 28th, 2020 with a volume of 95,189 Mm3 [1]. With this model, the volume of water is estimated based on the direct field reading of the limnimetric ruler. Likewise, two graphs were generated to perform readings of the estimated variables based on the reading of the rule: volume and depth in a given isobath. It should be noted that like any estimate, it has a certain range of estimation error, the model can be perfected, but at the moment it provides a quick and simple account of the current situation, this information being useful for decision making.

Storage volume estimation model with data from 2019 and 2020.

$$Y = -43.877 + 79.207\ X \quad R^2 = 0.990 \quad (I)$$

Where:

Y = volume of water Estimated (Mm3)
X = Measurement of the ruler in field (m)

Figure 4. *Graphic model for estimating the volume of water storage (Mm3) in the Laguna de Yuriria (own elaboration).*

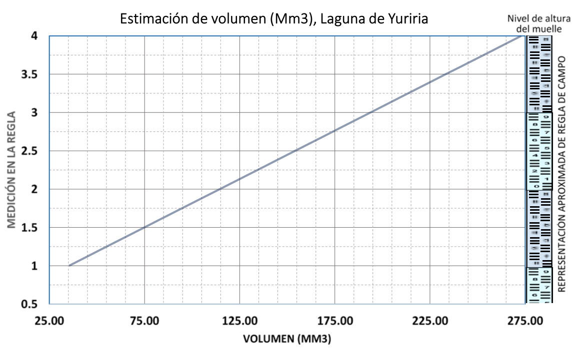
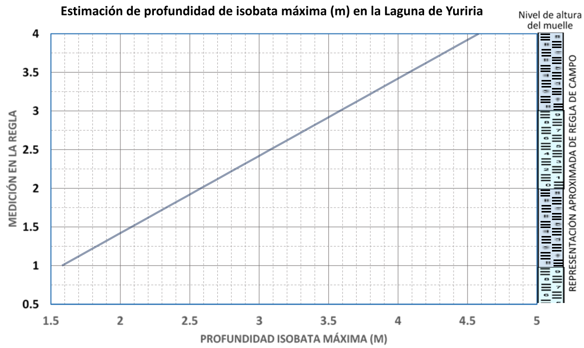


Figure 5. *Graphic model for estimating water depth (Mm3) in Laguna de Yuriria (own elaboration).*



3.2 Map generation

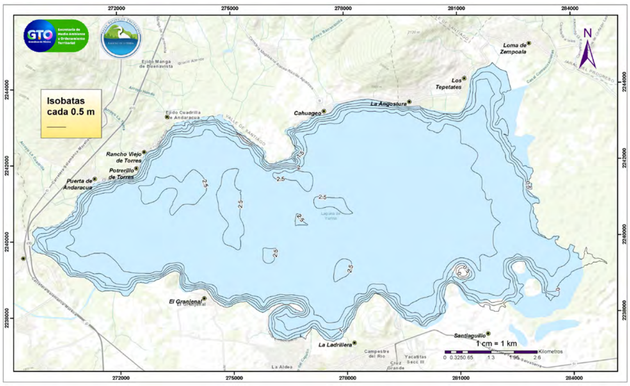
The graphic representation of the bathymetric survey is essential as a tool for interpreting the information. In this sense, as graphic products of the bathymetry, cartography represented two-dimensionally in isobaths and three-dimensionally in 3D elevation models was generated. Specifically, the following maps were generated:

- Bathymetric map updated and referenced to limnimetric rule.
- Bathymetric map before sediments.
- Map of volume of accumulated sediments (inverted three-dimensional).

Considerations. It is important to mention that field measurements are not exempt from a certain level of error since the precise location of the points in the water is not possible with the type of boat and equipment used; likewise, depth measurements may also have a certain level of inaccuracy due to the waves generated on the water surface, which makes a static reading difficult. Due to the above, it was decided to generate the isobaths at every 0.50 meters of depth with the purpose of mitigating said error.

The total area of the lagoon calculated based on the reference polygon used to generate this map is 6,600 hectares of water mirror, excluding the massifs of tular and reedbed in the extreme east and west. The volume estimate based on the level curves generated turned out to be 111,034 Mm3, similar to that reported by CONAGUA [1] for April 14th, 2020 of 112,581 Mm3, so it is deduced that the survey is reliable, under the assumption that Both data are estimates.

Figure 6. *Bathymetric map resulting from the Laguna de Yuriria (own elaboration).*



Map 7 shows the depth to the bottom of the sediments reaching more than 5 meters. The estimation based on the level curves of the volume of water + sediments, turned out to be 188.60 Mm3, which discounting the current volume, results in an accumulation of sediments of 77.565 Mm3. This last data can increase if the existence of another layer of sediments with greater compaction is confirmed.

Figure 7. *Bathymetric map without sediments of Laguna de Yuriria (own elaboration).*

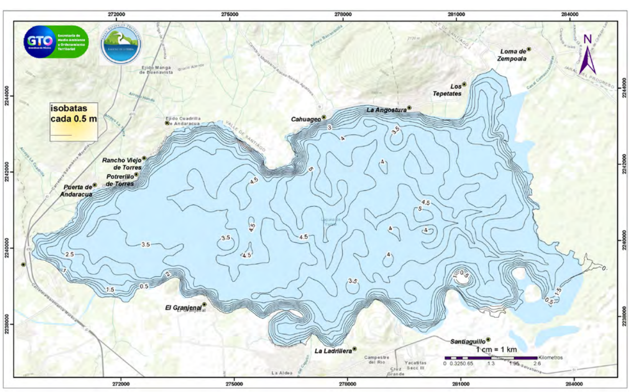


Figure 8 represents the thickness of the sediment layer, inverted and projected from the surface upwards, for which the contour lines represent height. The 77,565 Mm3 of sediment are distributed throughout the reservoir, with thicknesses of more than 2.5 meters, mainly in the most central parts. These volumes and the distribution of the sediments give an idea of the great challenge that cleaning up the bottom of the lagoon represents.

Figure 8. *Thickness map of the sediment layer in the Laguna de Yuriria (own elaboration).*

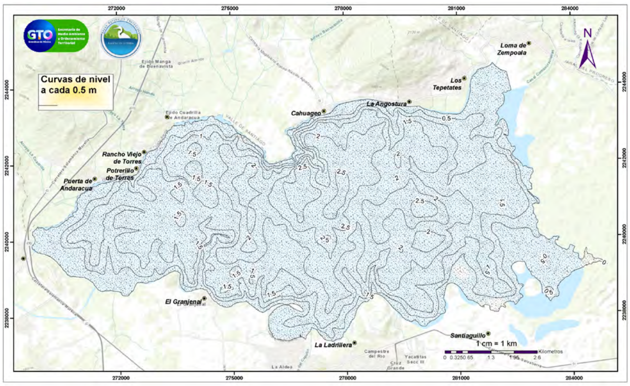
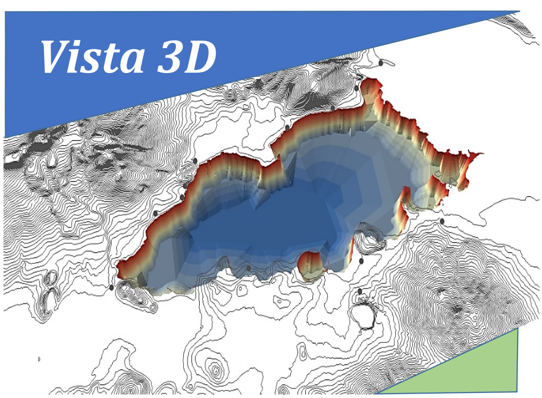


Figure 9 shows the three-dimensional view of the bathymetric level of the lagoon. The maximum depth at the time of measurement is a little over 2.5 meters with an estimated volume of water of 111,034 Mm3. It should be noted that in this illustration the relief was exaggerated so that greater detail of the bottom topography could be appreciated.

Figure 9. *3D bathymetric map of Laguna de Yuriria (own elaboration).*



The relief of the floor after the layer of sediments is very irregular and does not follow the ravine-shaped pattern, in addition it still has flat parts, which suggests the possibility that there are lower layers of sediments with a higher level of compaction (see figure 10). The storage capacity without sediment increases by 77,565 Mm3, equivalent to the current volume of accumulated sediment. It should be noted that in this illustration the relief was exaggerated so that greater detail of the bottom topography could be appreciated.

Figure 11 illustrates the three-dimensional view of the thickness of the layer of accumulated sediments inverted, that is, projected from the surface upwards, achieving thicknesses of more than 2.5 m. The model represents

Figure 10. *3D bathymetric map without sediments in the Laguna de Yuriria (processing own).*

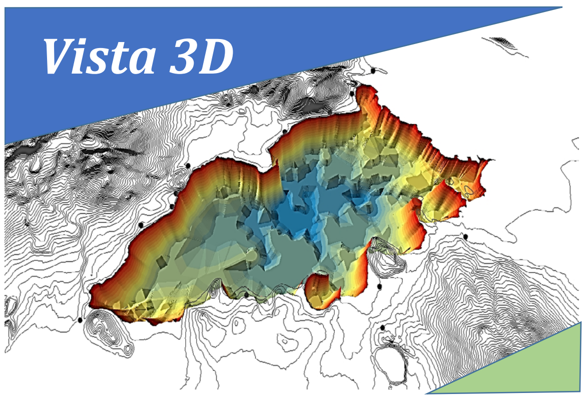
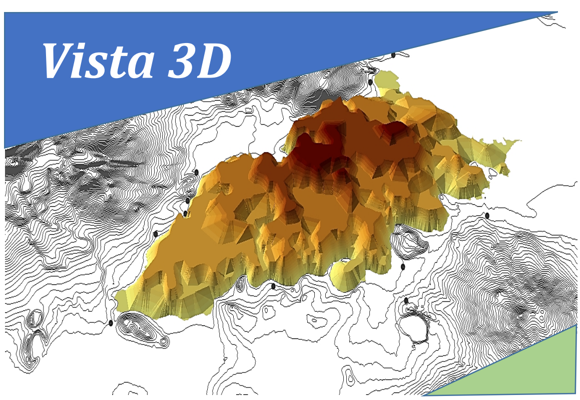


Figure 11. *3D inverted representation of sediments accumulated in the Laguna de Yuriria (processing own).*



an estimated volume of 77,565 Mm3 of sediment. It should be noted that in this illustration the relief was exaggerated so that greater detail of the bottom topography could be appreciated.

4. Conclusion

The estimated storage volume was similar to that reported by CONAGUA, with a difference of less than 2%. The storage capacity of the Laguna de Yuriria without sediment would increase by 27.1%, equivalent to 75.56 million cubic meters corresponding to the volume of sediment. It is important to feed back and adjust the storage volume estimation model, with recent readings, starting from the current abundant volumes.

Acknowledgements

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Citizen science on water quality monitoring in Laguna de Bay, Philippines: towards a sustainable transformative strategic plan in environmental monitoring

M.G.B. Maribao[1], R.F. Fadri[2]

Abstract

This study focused on exploring and understanding the social drivers of environment-based initiatives of citizen scientists in the Philippine setting, particularly at Laguna de Bay. The study employed the qualitative phenomenological research design anchored on the worldview philosophical assumptions of the advocacy/participatory approach in generating themes: bounded involvement, social responsibility, envisioning ecological integrity, knowledge and interest disparities, social inequality, financial impediment and unequal apportions, finding niche and sustenance, optimizing participatory actions, and individual empowerment. With the objetive of proposing a sustainable, transformative strategic plan for environmental monitoring, this study aims to bridge gaps and eliminate barriers in water quality monitoring by involving motivated citizens with concern towards the lake water and becoming engaged in plans or programs that benefit from their efforts. Given the implications, citizen scientists must be empowered to achieve sensible public goals and promote further ecological integrity that could be handed down through generations.

Keywords: *Citizen science, water monitoring, transformative strategic plan, Laguna de Bay, environmental monitoring*

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1. Introduction

In a time when public engagement in community–based initiatives calling for action as well as seeking assistance from experts to rehabilitate environment and restore natural habitats to its closest pristine form, citizen science heeds for this call. As described by Dickinson and Bonney (2015), "citizen science provides the theory, framework, and practice behind providing the general public with opportunities to engage in and contribute to the scientific process". According to Garbarino and Mason (2016), citizen science has allowed scientists to create research teams even without funding. The team members collate data and, exploring wide areas, examine sets of data, and yield large sampling. For decades, people have been involved in managing their environment; biodiversity campaign projects; and water quality monitoring activities. Publiclab.org (2016) in Wildschut (2017) disclosed that there are people who are willing to help in solving problems related to the environment and democracy that "*neoliberalism*" fails to solve. Irwin (2018) further stated that even as the aspirations of citizen science become broader in scope, it encounters a lot of barriers such as recruiting enough volunteers to participate sustainably and acquiring quality data. Despite reality that community-based science should be given a significant capacity coupled with the outgrowth of citizen science–related studies, sadly, it is still an under-realized opportunity. Loose et al. (2015) in Geoghegan et al. (2016) highlighted that there is a necessity of comprehending and outsmarting barriers in practicing citizen science in different cultural contexts.

The Philippines is known for its vast resources and water bodies surrounding it. Laguna de Bay and other lake waters are constantly monitored, engaging community people nearby it to participate in environment-based activities geared towards protecting its water. Both government and non-governmental initiatives were launched and in progress to rehabilitate and restore this natural resource. Various activities of citizens' actions have been done in safeguarding the lake from *multiple risks of ecological deteriorations.* However, there is limited information documenting citizen science-based events as well as the challenges that volunteers undertake. this prompted the researcher to explore the social drivers of citizen scientists and other community enthusiasts in Laguna de Bay. An under-realized and less explored discipline is in need of a clear understanding to tap its potential and strengthen its limits in gearing up participatory science in the country. This study hoped to refine ongoing explorations on how continued participation on earth stewardship is influenced, by way of revisiting and designing policies for a sustainable monitoring of environment. The insights gained from the analysis of testimonies would promote citizen science in the country while maximizing participation and retention in monitoring Laguna lake waters which can be handed down through generations.

2. Methodology

This paper used qualitative phenomenological research design anchored on the worldview philosophical assumptions of advocacy/participatory approach. Creswell (2011) described the approach as "a way of delivering a call for participants, increasing awareness or promoting agenda for change to better their lives". This study explored driving forces of lifelong participation of citizens in monitoring water conditions in the Philippines. The researcher identified the essences of citizen scientists' experiences about participating in water monitoring at Laguna de Bay via key informant interview of selected co-participants from four sites in the lake. Members of *Bantay Lawa* and Fisheries and Aquatic Resource Management Council (FARMCs), whom are called lake guards, comprised the nineteen (19) co-participants with ages ranging from 43 to 61.

An interview protocol was used to guide the flow of discussion. The instrument is composed of five (5) open-ended questions that revolve around topics concerning motivations, barriers and challenges, received benefits as co-researchers they participate in safeguarding the lake water. When clarifications of responses were necessary, follow-up questions were raised.

2.1 Data Gathering and Thematic Analysis

An approval was acquired from the central office of Laguna Lake Development Authority (LLDA). Assistance was provided by the Community

Development Division (CDD) personnel of the LLDA to arrange and finalize interview schedules. During the actual interview, the purpose of the study was clearly stated and content of the informed consent was shown and explained in detail to every co-participant emphasizing the implications of the succeeding activity. The participants were observed as they go about their regular routine monitoring of the lake water while having a non-formal conversation to establish rapport. With this approach, the researcher was able to immerse into the overall experience of the co-researchers as citizen scientists. All interviews were conducted at the lake guards' headquarters within two (2) months with few interrupted schedules.

All interviews were audio-recorded, transcribed verbatim, analyzed, then coded and sorted to draw out the themes. A final thematic map was made based on insightful analysis of the themes. A proposed transformative and sustainable strategic plan for monitoring Laguna de Bay was designed drawn out from analysis and reflection on the testimonies.

3. Results and discussion

After a careful evaluation of the significant statements, nine central themes emerged in this study: bounded involvement, social responsibility, envisioning ecological integrity, knowledge and interest disparities, social inequality, financial impediment and unequal apportions, finding a niche and sustenance, optimizing participatory actions, and individual empowerment. Each of the central themes has subthemes. Three central themes concerning motivations were identified: Bounded Involvement (Theme 1); Social Responsibility (Theme 2); Envisioning Ecological Integrity (Theme 3).

The first theme, *Bounded Involvement,* further unfolds into three subthemes: familial stewardship, financial involvement, and sense of commitment and dedication. This theme has given a concrete understanding of the volunteer citizens' "birthright" to lake monitoring since the practice have been handed down through generations. Most of the volunteer citizens in Laguna de Bay were raised and trained as fishermen. They witnessed how their parents acted as stewards unconditionally, taking care of the lake water's vast property and biodiversity.

The second theme, *Social Responsibility,* was further emphasized into two subthemes: community engagement and service to others and the sense of awareness. This theme reflects the social issues confronting volunteer citizens and members of community watch groups. Community engagement ensures that people in the community have access to valued social settings and activities. These activities allow community members to feel that they can contribute meaningfully to the community and develop functional capabilities to fully participate. Collaborative programs initiated by the lake management office, such as clean-up drives, have provided community members opportunities to become empowered as individuals and community with strong moral and environmental values.

The third theme, *Envisioning Ecological Integrity,* has two subthemes: love of nature and epitomizing environmental stewardship. The unfailing compassion for the lake and citizen scientists' altruistic behavior could enhance the lake water's capacity to adapt to changes and continually provide for future generations' needs. Consequently, how these volunteers envision the lake regarded as one primary reason for their continued participation. This theme has shown the determination and passion extended by volunteer citizens and community watch groups to safeguard the lake.

Community watch groups' participation has been eyed as good intermediaries to provide information and assist both agencies and community people in monitoring lake water quality, fish yield, and combatting illegal fishing related activities. However, barriers and challenges of broader context relative to leadership support, communication, policy implementation, and allocation of resources are perceived to hamper continued participation.

In the analyses of fisher folks' viewpoints, three significant themes emerged concerning barriers and challenges: Knowledge and Interest Disparities (Theme 4); Social Inequality (Theme 5); Financial Impediment and Unequal Apportions (Theme 6).

The fourth theme, *Knowledge and Interest Disparities,* unfolds into two subthemes: disparate notions on lake water status and conflict of interest. This theme illustrates the nonconforming cognition and beliefs on lake water quality status and practices of citizen scientists, academic scientists, and decision-makers. Most of the citizen scientists in Laguna de Bay felt that inequality issues remain in the organization and administration. They even associate unequal opportunities to their educational attainment and status in life, consequently, how they are being dealt with by professional scientists and decision-makers. Ideally, the creation of community watch groups was to address the acute conditions in the lake water. However, as plans and programs progressed, they were dubious about experts and decision-makers' prevailing motives. This scenario causes them to become anxious about their social status.

The fifth theme, *Social Inequality,* developed into two subthemes: distrust of authority and political interventions. This theme describes the socio-political economic realities in the administration, organization, and active supervision of agencies concerning citizen scientists' socio-economic realities experienced. For citizen scientists of Laguna de Bay, sensible judgments on critical issues pertinent to lake water monitoring are skewed continuously by people with biases, hidden motives, or agendas. These were evident in their narratives about certain events where veracity and actions are required.

The sixth theme, *Financial Impediment and Unequal Apportions,* discusses disproportionate provisions of aids and resources, fragmental allocations, and considerations of work-related hazards faced by citizen scientists in safeguarding the lake. Inadequate funding and fragmentary allocation of resources have always been a challenge for most projects and programs initiated by either private or public agencies. Citizen scientists' tasks require equipment and materials for efficient monitoring, they need to be aided with sustained support from stakeholders. However, some volunteers encountered budget-related constraints, deficits, and delayed honoraria in most instances. Their frustrations over the inequitable allocations and scarce resources were also revealed as they narrated their experiences in performing their duties.

Benefits may encourage citizen scientists to continue volunteering. These are rewards for their seemingly untiring involvement in safeguarding the lake from polluters and violators. In the fisherfolks' standpoints, one central theme emerged from citizen scientists' benefits: Finding Niche and Sustenance (Theme 7).

The seventh theme, *Finding Niche and Sustenance,* further unfolds into three subthemes: development of interpersonal skills, sense of direction, and security benefits. This theme depicts the citizen scientists' role in protecting the environment, which provides sustenance for their living. However, with the status of overpopulation and relocations combined with the people's desire for selfish gains, the lake has never been the same. Citizen scientists accepted the realities of paying the price for the unjust utilization of the lake's resources, hence, protecting it from further damage. The lake is undeniably resilient for this kind of unfair use. It has continuously provided sustenance for its people that even the succeeding generations look forward to in the future.

The infusion of citizen science in environmental monitoring at the grassroots level through a carefully planned strategy could provide community volunteers the edge to engage themselves in the scientific enterprise, that is, democratizing science to influence policies and processes involving the environment and health. Upon analyses of citizen scientists' statements, a central theme has emerged: Optimizing Participatory Actions (Theme 8).

The eighth theme, *Optimizing Participatory Actions,* displays the importance of infusing citizen science in environmental monitoring at the grassroots level. Citizen scientists can learn, innovate, and even mitigate everyone's welfare measures. However, these attributes will naturally arise and can only be further developed to support conscientious people and agencies' sensible plans. The combined reasonable actions of all stakeholders could enhance the citizen scientists' innate qualities and capabilities. Moreover, the assurance of being prioritized, without any political color could inspire citizen scientists to protect the lake religiously. Hence, the intent to participate in monitoring activities and remain in the field without hesitation or anxiety is likewise possible. When perseverance, ingenuity, and trust with empathy through a transformative approach are combined, citizen science can address broader societal impacts.

In the final part, the forms of support and training that citizen scientists wish to have to scale-up their capacity to monitor activities and sustain their interest in participating were explored. After careful analyses, a single theme has emerged, that is, Individual Empowerment (Theme 9).

The ninth theme, *Individual Empowerment,* has two subthemes: development of leadership and scientific skills and adequate supplemental subsidies. This theme recounts the significance of empowering citizen scientists through support and training to scale-up environmental monitoring and sustain continued participation. Moreover, these themes bring citizen science implications to the future of sustainable, transformative strategic planning for environmental monitoring. Community watch groups in Laguna de Bay have been perceptive of their limitations. Though they may have contextual and local knowledge of the lake water and the traditional means of protecting it, their strong sense of disposition becomes clouded with doubts and anxieties when faced with politically-related instances and scientific concerns. Therefore, they are aware of the necessary training and support to facilitate leadership and scientific skills and eventually boost their innate confidence. Such training includes law enforcement, planning, clean-up of lake water, proper solid waste disposal, determining physicochemical and biological parameters.

Table 1. *Summary of emergent themes.*

MAJOR THEMES	SUBTHEMES	CS SOCIAL DRIVERS
Bounded Involvement	A) Familial Stewardship B) Financial Involvement C) Sense of Commitment and Dedication	MOTIVATIONS
Social Responsibility	A) Community Engagement and Service to Others B) Sense of Awareness	
Envisioning Ecological Integrity	A) Love of Nature B) Epitomizing Environmental Stewardship	
Finding Niche and Sustenance	A) Development of Interpersonal Skills B) Sense of Direction C) Security Benefits	BENEFITS AND OPPORTUNITIES
Knowledge and Interest Disparities	A) Disparate Notions on Lake Water Status B) Conflict of Interest	BARRIERS and CHALLENGES
Social Inequality	A) Distrust of Authority B) Political Interventions	
Financial Impediment and Unequal Apportions		
Individual Empowerment	A) Development of Leadership Skills and Scientific Skills B) Adequate Supplemental Subsidies	SUPPORT AND TRAININGS
Optimizing Participatory Actions		CS capacity Improvement for sustained participation and strategic planning

4. Conclusion

The lived experiences of citizen scientists reflect what usually transpires at the bottom level in an organization. The researcher elucidated that the potential success of engaging ordinary citizens in protecting the environment is impeded due to miscommunications between them and the policymakers and experts; and the limited provisions of support, training, and funding. On one hand, their motivations stem from various reasons such as interest, satisfaction, awareness, community welfare, commitment, and rewards. Agencies should expand opportunities to engage community people in order to strengthen their capabilities. Therefore, citizen scientists' inclusion in the planning process could warrant promising collaborative efforts in environmental monitoring, resulting in optimized participatory actions. Their disposition and strong will to learn and be trained is a positive sign that experts should appreciate. Their potentials must not be wasted; therefore, adequate supplemental subsidies should be at hand.

Acknowledgements

The researchers would like to extend their gratitude to the members of *Bantay Lawa* and Fisheries and Aquatic Resources Management Council (FARMC), and other fisher folks of *Laguna de Bay* for the willingness to participate in this research endeavor; the Community Development Division (CDD) of the Laguna Lake Development Authority (LLDA) for the assistance and support; and the University of Perpetual Help System DALTA (UPHSD) – Las Pinas Campus, Philippines.

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Comparative analyses of Ostracoda (Crustacea) species from lakes

Okan Külköylüoğlu[1]

Abstract

Nonmarine ostracod species can inhabit a variety of inland waters of lotic and lentic ecosystems. In order to subsume species distribution and their habitat preferences along with their occurrence patterns, 81 lakes were studied. 130 species were found from 26 of 81 lakes in which monthly and/or seasonal samplings were achieved. In average this means five species per lake. 110 ostracods were reported only one or two times. Species with higher occurrence frequencies displayed cosmopolitan characteristics that they have wide ranges of ecological tolerances to different environmental variables (e.g., temperature). Based on species occurrences, lakes in similar geographic regions exhibited positive correlations ($p<0.05$). Accordingly, similarities were higher among the Anatolian lakes than lakes in Europe while lakes (e.g., Lake Mendota (USA), Lake Petén Itzá (Guatemala)) showed very weak correlation to other lakes studied. Indeed, these lakes were clustered in different branches in Twinspan analyses which also illustrated that some indicator species (e.g., *Cypridopsis vidua, Heterocypris salina, Candona acuta*) played critical role on this separation. Three lakes (Abant (Turkey), Fehér (Hungary), Swidwie (Poland)) with oligotrophic-me-

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sotrophic characteristics were clustered together where *Notodromas monacha,* a very rare ostracod species known to prefer high oxygenated waters, was common. It is also important to mention that most of the species are swimmer, which provides them to move actively within and among the water bodies. Thus, being the first study on the literature with an extensive research, results suggested that some species can be used as indicators of lake environments.

Keywords: *Non-marine ostracod, ecology, distribution, diversity and richness*

1. Introduction

Species of the class Ostracoda (Crustacea) are one of the most abundant invertebrate aquatic animals (ca. 65K species) and are well preserved arthropods (0.3 to 5 mm length) since Cambrian (ca. 540 Mya), but first true ostracods appeared during the Ordovician Period (485 to 443 million years ago), and colonized inland waters in the Carboniferous Period (359 to 299 million years ago) [1-3]. Ostracods are widely distributed over the world and can be found in marine, brackish and freshwater habitats, including lakes, ponds, pools, springs, underground waters, streams, creeks, canal and troughs. Overall, distributional range of the group lies from about 5000 m deep in the oceans to over 5000 m a.s.l. [4]. Although it is not well known for many species, ostracods seem to prepare certain kinds of habitats and ecological conditions. Thus, each species tends to have species-specific habitat preferences [5-7]. Accordingly, current knowledge about species habitat preferences can be attributed to the reconstruction of past histories for the habitats. Application of this perspective corresponds to the studies on specific habitats such as lakes. Thereby, gaining knowledge about ostracods habitat preferences along with the ecological conditions they tolerate is important for understanding the changes on the habitats and species assemblages through time. Hence, lakes are one of the most specific aquatic bodies where ostracods may show regular seasonal occurrence patterns as long as the conditions are suitable and/or fluctuate within the species tolerance ranges. The aims of the present study were to 1) determine ostracod species inhabiting lake ecosystems, 2) analyze clustering relationships of these ostracods, 3) use Ostacod Watch Model, and 4) introduce concept of pseudo-richness, and concept of cosmoecious species.

2. Materials and methodology

Data used in this study have been collected from the literature and combined with some unpublished data. I choose specific studies done in the natural lake (but also see the text). In each study, standard sampling methods have been used for ostracods (see details in [9-10]). Thus, 26 of 81 lakes with ostracods were selected based on sampling methodology (i.e., monthly, seasonal sampling). To explicate the data, different statistical analyses were used including Twinspan analysis and Similarity Percentage analysis (SIMPER) (in Community Analysis Package 4.0, 2007) used to show clustering relationship along with influential factor(s). Cluster analyses and Species richness along with Plot of Henderson were run for estimating species richness and diversity (in Species Diversity and Richness program version 4.1.2). Co-occurrence analysis was tested to show co-occurrence patterns among the species in R-team [11]. Finally, Ostracod Watch Model [12] was used to see seasonal occurrence patterns of the species. In all analyses, adult specimens were used while damaged and unidentified species (and juveniles) were not included into the analyses.

3. Results and discussion

Total of 130 species were found from 26 (21 lakes and 5 reservoirs) of 81 lakes in which monthly and/or seasonal samplings were achieved. 110 ostracods were reported only one or two times. 15 of 130 species contributes more than 90% of diversity (Table 1). Five species (*Cypridopsis vidua* (17x occurred), *Limnocythere inopinata* (14x occurred), *Darwinula stevensoni* (13x occurred), *Physocypria kraepelini* (12x occurred), *Neglecandona neglecta* (11x occurred)) covers >50% of diversity. Numbers of species accumulation curve was found in accordance with the estimated curve

(Fig. 1).Based on species occurrences, lakes in similar geographic regions exhibited positive correlations ($p<0.05$). Accordingly, similarities were higher among the Anatolian lakes than lakes in Europe while lakes (e.g., Lake Mendota (USA), Lake Petén Itzá (Guatemala)) showed very weak correlation to other lakes studied. Twinspan analyses illustrated some indicator species (e.g., *Cypridopsis vidua, Heterocypris salina, Candona acuta, N. neglecta*) played critical role on clustering relationships (Figure 2). Three lakes (Abant (Turkey), Fehér (Hungary) [13], Swidwie (Poland) [14] with oligotrophic-mesotrophic characteristics were clustered together where *Notodromas monacha*, a very rare ostracod species known to prefer high oxygenated waters, was common. Species with higher occurrence frequencies displayed cosmoecious species characteristics that they have wide ranges of ecological tolerances to different environmental variables and wide distribution. Results suggest that ostracod species show different seasonal occurrence patterns depending on lake (or habitat) type. Also, species with swimming abilities seem to prefer lentic aquatic bodies while non-swimmers are bottom-dependent in lotic habitats.

Table 1. *SIMPER results show contribution of 15 most abundant lake ostracods. Unassigned average similarity = 19.319.*

Name	Ave. Abund	Ave. Simil	Contri %	Cumul %
Cypridopsis vidua	0.654	3.461	17.92	17.92
Limnocythere inopinata	0.538	2.591	13.43	31.35
Darwinula stevensoni	0.50	1.951	10.09	41.45
Physocypria kraepelini	0.462	1.383	7.15	48.61
Neglecandona neglecta	0.423	1.319	6.83	55.44
Ilyocypris bradyi	0.385	1.288	6.66	62.11
Candona candida	0.423	1.256	6.50	68.61
Cypria ophtalmica	0.385	1.071	5.54	74.15
Heterocypris salina	0.231	0.641	3.32	77.47
Prionocypris zenkeri	0.307	0.564	2.92	80.39
Ilyocypris gibba	0.269	0.500	2.59	82.98
Eucypris virens	0.269	0.467	2.42	85.41
Heterocypris incongruens	0.231	0.366	1.89	87.30
Cyprideis torosa	0.192	0.355	1.84	89.15
Potamocypris variegata	0.192	0.298	1.54	90.69

Fıgure 1. *Henderson plot of species accumulation and estimate for species number.*

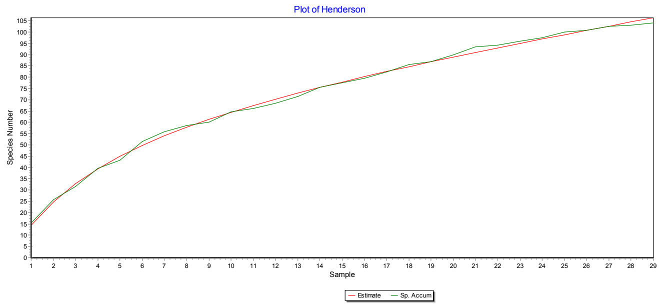
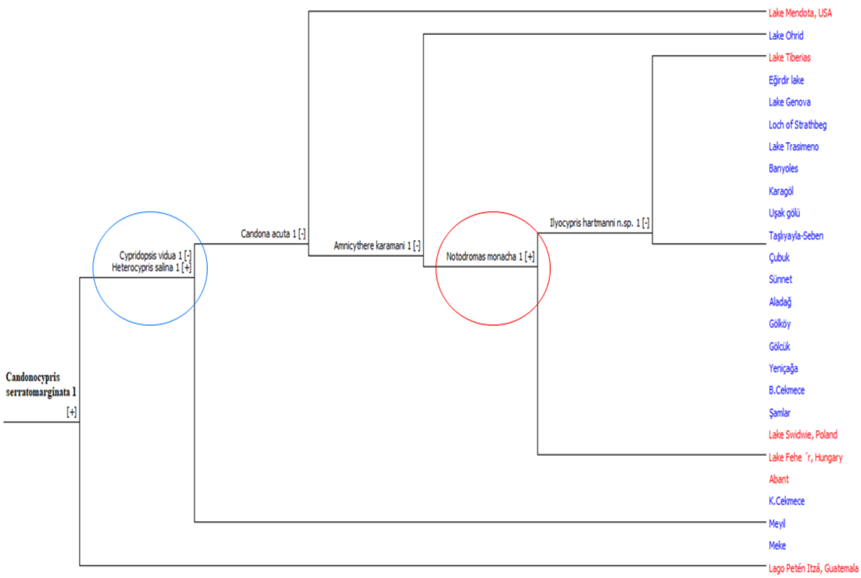


Fıgure 2. *Twinspan analysis show indicator species circled.*



Among the species, *Ilyocypris inermis* (not shown in Table 1) and *N. neglecta* appear to have more tendency for co-occurrences than other species pairs. This is probably because of their habitat preferences that both species are bottom-dependent due to lack of swimming setae on their second antenna. This may provide them to share the same habitat. Indeed, species with similar habitat preferences tend to show similar seasonal occurrence patterns. However, it should be pointed out that almost all of these common species are known to have similar cosmoecious characteristics than species with wide ecological tolerances and wide geographical distribution) [6, 15-6]. Thus, water quality measures can be estimated for the lakes based on the ratio of noncosmopolitans (or cosmoecious) to cosmopolitans

(Pseudorichness ratio = noncosmopolitans (or cosmoecious) / cosmopolitans) (6).

Implication of this ratio:

1) $NC / C > 1$,

numbers of cosmopolitan $<$ numbers of noncosmopolitan

2) $NC / C = 1$, equilibrium point

3) $NC / C < 1$,

numbers of cosmopolitan $>$ numbers of noncosmopolitan.

4. Conclusion

Determination of ostracod species assemblages from the lakes (or any other habitats) can be useful for interpretation of the past and current aquatic conditions and helpfull to estimate future possibilities. Aforementioned ratio of pseudorichness along with using cosmoecious (or cosmopolitan) species can be applied for understanding the dominancy and/or rareness of the species diversity and richness of the habitats. Such information is also useful to reconstruct past historical conditions in those areas. Future studies on specific habitats are need to provide solid evidences.

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Diversity and molecular phylogeny of freshwater sponges from Thane Region of Northern Maharashtra, India

D. K. Kakavipure[1], P. P. Shinde[1]

Abstract

The Western Ghats, which is one among the 25 global hotspots of biodiversity, extends for over a length of 16,000 km. lying parallel to the Indian coast. The distribution and taxonomy of fresh water sponges (Porifera) in the Western Ghats Region of India has not received widespread attention. In an initial effort to begin the systematic taxonomic distribution of fresh water sponges, two lakes and one river from the northern part of the Western Ghats were identified. The selected collection sites were Tansa lake (19° 58' N, 73° 25' E), Varhala Devi lake (19° 20'N, 73° 00'E) and Pinjal river (19° 37' N, 73° 60 E). From every collection site, 2 sponge species were collected and identified by using morphological characters. The sponges collected from Varhala Devi lake were identified as *Ephydatia sp.* and *Eunapius carteri*. The sponges from other two locations are being identified. The molecular phylogeny analysis of all the sponge species is also being attempted. This investigation highlights the presence of fresh water sponges; the most primitive metazoan in the Western Ghats of Thane region and opens up new research avenues to understand the ecological significance of this little known group of animals.

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Keywords: *Western Ghats,* Ephydatia sp. Eunapius carteri, *Varhala, Tansa, Pinjal.*

1. Introduction

Sponges are the most ancient multicellular animals, having existed for more than 580 million years (Müller et al., 2004). At least 15,000 species are classified into the phylum Porifera, which is divided into three classes, the Hexactinellida, the Demospongiae, and the Calcarea, based on the nature of their mineral skeleton. Sponges have colonized most aquatic habitats from polar seas to tropical waters and approximately 150 species (spongillids) have become adapted to freshwater (Manconi & Pronzato, 2002). Freshwater sponges include six extant families which belong to the suborder Spongillina (Porifera). The taxonomy of freshwater sponges is problematic and their phylogeny and evolution are not well understood. Some of the earlier noteworthy work on fresh water sponge taxonomy was carried out by Annadale N. (1908), Khera S. and Chaturvedi Y. (1976), Tiiu Rovere (2006), Kakavipure D.K. and Yeragi S. G. (2008), Jakhalekar S.S. and Ghate H.V. (2013, 2018). It was studied by a few researchers. Five different sponge specimens were collected from 3 fresh water bodies. All the specimens were used for DNA extraction. The DNA was quantified and further amplified by using specific PCR primers. Out of 5 specimens, only one sponge DNA gave amplification. This PCR product was sequenced further and the sequences were analysed by using BLAST. In this investigation, phylogenetic analysis of fresh water sponge specimens was carried out by using ribosomal ITS sequences. A method reported by Itskovich et al. (2008) was followed for this analysis.

1.1 Analysis of freshwater sponges

Fresh water sponges were collected from the following locations:
Tansa lake (19° 58’ N, 73° 25’ E)
Varhala Devi lake (19° 20’N, 73° 00’E)
Pinjal river (19° 37’ N, 73° 60 E)

1.2 Morphological identification of sponges collected from different locations

Varhala Devi lake:
Ephydatia Sp.
Eunapius carteri

Tansa lake:
Corvospongilla bhavanagarensis (Soota, Pattanayak and Saxena)
Corvospongilla lapidosa (Annandale)

Pinjal river:
Radiospongilla cerebellata (Bowerbank)
Corvospongilla lapidosa (Annandale)

Ephydatia Sp.

Eunapius carteri

Corvospongilla bhavanagarensis

Radiospongilla cerebellata

Corvospongilla lapidosa

2. Materials and methodology

Authors have sequenced the 18s ribosomal ITS region of one individual of freshwater sponge and RAPD analysis of one individual of freshwater sponge carried out.

2.1 DNA isolation protocol

DNA Extraction from 6 samples of freshwater sponges was carried out using G1N10 GenElute Mammalian Genomic DNA of Sigma-Aldrich. The ethanol preserved tissue (20 mg) was transferred to sterile distilled water in 1.5ml microfuge tube and left at room temperature for 15 minutes. The distilled water was completely drained and 180 μl of Lysis solution T was added followed by 20 μl of Proteinase K solution. The tissue was ground using tissue grinder.The mixture was vortexed and incubated at 55°C for 30 minutes. 20 μl of RNase A solution was added and the mixture was incubated for 2 minutes at room temperature to obtain RNA-free DNA.

The cells were then lysed using 200 μl of Lysis solution C and vortexing for 15 seconds thoroughly. The mixture was further incubated at 70°C in a water bath for 10 minutes. Column preparation solution (500 μl) was added to each preassembled GenElute™ Miniprep Binding Column and Centrifuged at 10,000 rpm for 1 minute. 200 μl of 96-100% ethanol was added for DNA binding and mixed by gentle vortexing. Entire lysate was loaded on the prepared column and the column centrifuged at 10,000 rpm for 1 minute. The flow through was discarded. The column was washed by loading 500 μl of diluted wash buffer and centrifuged at 10,000 rpm for 1 minute. Washing was repeated with extra centrifugation for 2 minutes. The column was transferred to new microfuge tube and 200 μl of elution buffer added. The column was incubated at room temperature for 5 minutes and then centrifuged at 10,000 rpm for 2 minutes. The DNA was stored at 4°C for further use.

Agarose gel electrophoresis was performed to check the presence of DNA using 0.8% Agarose.

2.2 DNA quantification protocol

DNA concentration was determined using Quant-iT ™ dsDNA BR Assay Kit of invitrogen. Quant-iT™. Working solution was prepared for 5 samples and 2 standards by diluting the Quant-iT ™ dsDNA BR reagent 1:200 in Quant-iT ™ dsDNA BR buffer in a plastic container. Working solution (190 µl) was dispensed in 2 Qubit assay tubes for standards and 198 µl was dispensed in each sample tube. 10 µl of each of the two standards were added to the respective standard tubes and 2 µl of each of the sample was added to the respective sample tubes. The tubes were vortexed and incubated at room temperature for 2 minutes. The Quant-iT ™ dsDNA BR was chosen on Qubit ™ fluorometer and calibration done using the two standards. Sample readings were taken and calculated for 2 µl. The results were obtained in µg/ml. The concentrations of DNA isolated from 6 samples are shown in Table 1.

Table 1. *The quantity of DNA obtained from 10 mg of frozen sponge samples.*

S. no.	Sample name	DNA conc^{n}. µg/ml
1	*Ephydatia* Sp.	20.2
2	*Eunapius carteri*	18.6
3	*Radiospongilla cerebellata*	21.8
4	*Corvospongilla lapidosa*	23.2
5	*Corvospongilla bhavanagarensis*	16.9
6	*Corvospongilla lapidosa*	12.1

The DNA obtained from different sponge specimens were used for PCR amplification.

2.3 PCR amplification

Molecular phylogeny was carried out on a Biometra thermal cycler by using 5X qARTA.Taq Master Mix (2.5mM MgCl2) from Qartabio (QTMM2.5-200) and primers from MWG-Biotech. The composition of PCR mixture is mentioned in Table 2. The details of PCR programme is mentioned in Table 3.

Amplification of ribosomal ITS gene

Primers used: FW13 and 1278 (Table 4)

DNA amplified: Pinjal 1

Table 2. *PCR Reaction mixture.*

Component	Volume
5X PCR mastermix	10 µl
Forward primer (10pM/µl)	2 µl
Reverse primer (10pM/µl)	2 µl
Template DNA (80ng/µl)	1 µl
Nuclease free water	35 µl
Total volume	**50 µl**

Table 3. *PCR conditions.*

<table>
<tr><th>Temp.</th><th>Duration</th><th>No. of cycles</th></tr>
<tr><td>94°C</td><td>2 min</td><td>1</td></tr>
<tr><td>94°C</td><td>1 min</td><td rowspan="3">40</td></tr>
<tr><td>55°C</td><td>1 min</td></tr>
<tr><td>72°C</td><td>1 min</td></tr>
<tr><td>72°C</td><td colspan="2">8 min</td></tr>
<tr><td>4°C</td><td colspan="2">End point</td></tr>
</table>

Table 4. *Primers used for molecular phylogeny of Pinjal.*

Primer	Sequences 5’-3’
FW13	TACACACCGCCCGTCGCTACTA
1278	CTYYGACGTGCCTTTCCAGGT

Agarose gel electrophoresis was performed using 1.2% Agarose.

2.4 Sequencing of PCR products

Out of 5 DNA samples obtained from 5 sponge samples, only one DNA (Pinjal 1) showed amplification. This PCR product was sequenced at Eurofins India Ltd., Bangalore, India. Forward primer FW13 was used for sequencing this product.

2.5 BLAST analysis

The sequences of PCR products were analyzed by using Basic Local Alignment Search Tool (BLAST). Nucleotide-nucleotide BLAST was carried with facility of National Center for Biotechnology Information(NCBI).

(http://www.ncbi.nlm.nih.gov/BLAST)

3. Results

PCR product of approximately 1060bp was obtained. The sequences of Pinjal River sponge specimen (Pinjal 1) showed 99% similarity with the sponge *Radiospongillacerebellata*, reported earlier by Itskovich et al., 2008.

3.1 Phylogenetic analysis using ribosomal ITS sequences

Sample Code: PINJAL 1
Nucleotides sequenced: 656
>PINJAL 1

AAAGTCGTAACAAGGTTTCCGTAGGTGAACCTGCGGAAGGAT
CATTACCGTACCTTTCGGGGAAACCGTTCCCTGGATCCACTGT
GCACCAAGGCTGCGGCCCGCCAAAAACCGCGTTTGGGGAGGTC
GCCCTCGGGTTCGAGGGCGACGCGAGTCGGCGAGAGAGATC
CCCCCGCCGACCTCCCCCGACGCGGAGGGCCGCAGTTCG
TATTTTTTACACTCTTTGAACTTTGGCGTCGTAACGGGTT
GAAGTTTTTGCATTGTCGAGGAGACAACGTACGAAAGCGTCT
GAGACAACTTCTAACGGTGGCCCTCGGCTCGTGCGTCGAT
GAAGAACGCAGCAAACTGCGATACGTAGTGTGAATTGCAGAAT
TCCGTGAATCATCGAGTCTTTGAACGCAAATTGCGCCCTCG
GTTCGAAGCCGGGGCACGTCTGTCTGAGCGTCCGTTTCGTTTC
GCGTCTCTCGTCCGGGATCGTTTTCCAAAATTCGATCCGGACG
GGAGCAGCGGGTTGAGGCGTCGTCCGCAAGACACGCGGGCGTC
CCTTGAAGTGCGAAGCGCTCCGGTTCGAAGGACCACCTCCTCG
CGAGTGCCCTTCCACCTTGCGCGTCGGGAACTCGACGATGA
CAAGGGAAGAGGGGCCTGGCGAGGGAAGG

Phylogenetic analysisusing Ribosomal ITS sequences

Sample Code: PINJAL 1
Nucleotides sequenced: 656
Program: NCBI/BLAST/blastn

Table 5. *Gene Accession No; Phylogenetic neighbours and % similarity.*

S. No	**Gene Accession No.**	**Phylogenetic neighbours**	**% Similarity**
1	EF151938.1	*Radiospongillacerebellata* voucher BW0112 18S ribosomal RNA gene,	99
2	EF151953.1	*Radiospongillacerebellata* voucher Jp3 18S ribosomal RNA gene,	99
3	EF151952.1	*Radiospongillacrateriformis* voucher Jp5 18S ribosomal RNA gene,	86
4	EF151954.1	*Radiospongilla sendaj* voucher Jp2 18S ribosomal RNA gene,	87
5	GU250966.1	*Ephydatia*sp. VI-2010 voucher torehol_2 18S ribosomal RNA gene,	84
6	AM950186.1	*Ephydatia* sp. n. 2 PW-2008 18S rRNA gene (partial),	84
7	AM950185.1	*Ephydatia*sp. n. 2 PW-2008 18S rRNA gene (partial),	84
8	AM950184.1	*Ephydatia* sp. n. 1 PW-2008 18S rRNA gene (partial),	84
9	FJ719109.1	*Ephydatia* sp. OB-2009 isolate Tore-Chol 2 18S ribosomal RNA gene,	84
10	AM950183.1	*Ephydatia* sp. n. 1 PW-2008 18S rRNA gene (partial),	84

The details of these microbes can be searched on http://www.ncbi.nlm.nih.gov/Web site with the help of accession number.

3.2 Random amplified polymorphic DNA (RAPD) analysis of *Radiospongillacerebellata* (Pinjal 1 sample)

RAPD PCR protocol

The DNA isolated from Pinjal 1 sample was subjected to polymerase chain reaction (PCR) amplification with 12 random 10-mer primers (Synthesized by Eurofins-MWG-Operon, Bangalore, India) (Table 6). Amplification of genomic DNA was carried out in 25 μl reaction mixture containing 1μl (60 ng/ μl) genomic DNA as template, 25μl PCR master mix (Sigma P4600

ReadyMix Taq PCR Reaction Mix, with MgCl), 2 µl primer (concentration 10pM) and 22 µl of nuclease free water (Table 7). DNA amplification was performed in a DNA thermal cycler (Biometra, Germany). PCR conditions were as follows. First cycle of 5min at 94°C for template denaturation, followed by 40 cycles of 1 min at 94°C, 1 min at 34°C, 2 min at 72°C. An additional cycle of 7 min at 72°C was used for final primer extension. For OPM01, OPN05, OPP01, OPQ01 primers, annealing temperature was 37°C. (Table 8). Amplified products were analyzed by electrophoresis on 1.4% agarose gel.

Agarose gel electrophoresis

Agarose gels were prepared using an agarose concentration appropriate to the size of DNA fragments to be separated. For genomic DNA 0.8% concentration of agarose gel was used whereas for PCR product 1.4% agarose gel was used. Agarose was added to a 1X TAE buffer (Fermentas # B49) and melted in a microwave oven. Care was taken to ensure even mixing and complete dissolving of the agarose. A gel insert tray was sealed with tape and a gel comb inserted. The agarose was cooled to 55°C before pouring onto the gel insert tray. Care was taken to ensure that all bubbles were removed before the gel set. The tape was removed from the gel insert tray and the gel comb was carefully removed. Electrophoresis 1X TAE buffer was added in order to cover the gel and to load the DNA samples. DNA samples or PCR products (10µl of the sample with 2µl of the gel loading dye) were added to the sample wells in the agarose gel using a micropipette. DNA ladders of different sizes (5µl) were loaded in first and the last well. Care was taken not to damage the sample wells with the micropipette during the procedure. Loading dye (Fermentas # R0611) as well as DNA marker (GeneRuler™ Express DNA Ladder of Fermentas #SM1553 were used from Fermentas Company. Electrophoresis was carried out at 85mA and 180 volts for approximately 1 hour by observing dye front. The gel was stained in solution containing 5µl of ethidium bromide in 50ml of distilled water for 15-20 minutes and observed under UV transilluminator for DNA bands. Photographs of the gel were taken.

Preparation of RAPD report

Photographs of the gel was taken and analyzed further. Using Microsoft Power Point the report was prepared with the photograph, and the table for primers as well as the individual band size as obtained with reference to the ladder. The results are given in separate file.

Table 6. *Details of RAPD primers used in the study.*

Name of primer	**Primer sequence**	**Range of amplifications (bp)**
OPA-01	CAGGCCCTTC	1300 - 1400
OPA-09	GGGTAACGCC	400 - 900
OPA-13	CAGCACCCAC	300 - 1500
OPD02	GGACCCAACC	350 - 1200
OPD-08	GTGTGCCCCA	350 - 1750
OPD-20	ACCCGGTCAC	600 - 1200
OPM01	GTTGGTGGCT	600 - 1150
OPN05	ACTGAACGCC	750 - 850
OPP01	GTAGCACTCC	750
OPQ01	GGGACGATGG	850 - 1100
UBC456	GCGGAGGTCC	850 - 1000
UBC457	CGACGCCCTG	850 - 1000

Table 7. *Composition of PCR reaction mixture used for RAPD PCR.*

Component	**Volume**
2X PCR mastermix	13 µl
Random primer (10pM/µl)	2 µl
Template DNA (60ng/µl)	1 µl
PCR water	9 µl
Total volume	25 µl

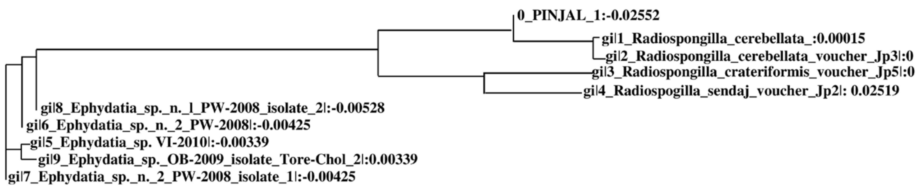
Table 8. *PCR conditions used for RAPD PCR.*

Temp.	**Duration**	**No. of cycles**
94°C	5 min	1
94°C	1 min	
34°C*	1 min	40
72°C	2 min	
72°C	7 min	1
4°C	End point	

For OPM01, OPN05, OPP01, OPQ01 primers, annealing temperature was 37°C.

4. Discussion and conclusion

This investigation highlights the presence of fresh water sponges; the most primitive metazoan in the Thane district of Western Ghats and opens up new research avenues to understand the ecological significance of this little-known group of animals. Further studies are required to make a diversity database of freshwater sponges from Western Ghats with their molecular phylogeny. Like marine sponges, this group also can be explored for the production of bioactive metabolites. It is possible to isolate novel microorganism from these sponges, which can be used as a source for discovering therapeutic molecules.



Phylogenetic tree showing genetic distance between Pinjal 1 sponge sample and its phylogenetic neighbours.

Acknowledgements

We acknowledge the management, PAJBSU Mandal, Principal, Dr. Ashok D. Wagh, Dept. of Zoology, B.N.N. College, Bhiwandi, for their moral support throughout the research work. We are thankful to Dr. Archana N. Thakur, Director, CODON Life Sciences, Goa and Dr. S. G. Yeragi, K. J. Somaiya College, Mumbai, for their encouragement and valuable support.

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Ecological screening on health condition of fish population in Lake Ohrid (R. North Macedonia), through histopathological biomarkers

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Abstract

Histopathological biomarkers can be indicators for the effects on organisms by various anthropogenic pollutants and represent reflection of the overall health of the entire population in the ecosystem. The alterations in cells and tissues in vertebrate fish are recurrently used biomarkers in many studies, but such changes occur in all vertebrates and invertebrates inhabiting the aquatic basins.

Liver and gill pieces of 178 individuals of fish, collected from 5 localities of Lake Ohrid, were excised and processed for standard histopathological analysis. The obtained results revealed pathological changes in the liver and gill tissue.

Keywords: *histopathology, liver, gill, Lake Ohrid*

1. Introduction

Lake Ohrid is one of Europe's deepest and oldest lakes and preserving a unique aquatic ecosystem that is of worldwide importance. The lake itself

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has very transparent water with maximum transparency of 22m in winter. This is a result to its oligotrophic state and low production of organic matter.

The most striking feature of Lake Ohrid hydrography is that it is almost exclusively fed by underground water from more or less abundant karstic sources, mainly along the eastern shore of the lake [2] [1].

The karstic springs of Lake Ohrid are a most interesting hydrogeological phenomenon, as they introduce heterogeneity and variability of many hydrogeological, ecological and other parameters.

Tributaries of Lake Ohrid are a minor water source. At the northern side of Lake Ohrid, the only outflow forms River Crn Drim, which discharges to the Adriatic Sea.

Approximately two-thirds of surface area of Lake Ohrid belong to the R. North Macedonia and about one-third to R. Albania. In 1979, Lake Ohrid and its surroundings have been listed by UNESCO since 1979/1980 as Natural and Cultural Heritage of the Ohrid region [8].

The extraordinarily high degree of biodiversity and endemism in many groups of Lake Ohrid organisms has long been recognized, with most of the relevant studies conducted in the first half of the twentieth century. The importance of the rich endemic Lake Ohrid biota for maintaining biodiversity of the area and for understanding patterns and processes of evolution is unquestioned. Unfortunately, the lake suffers from increasing anthropogenic pressure and some endemic species presumably have gone extinct, making evolutionary studies increasingly difficult [3]. Still pelagic zone remains immune to the anthropogenic pressure that threatened these waters in previous decades [4]. Population in the Lake Ohrid catchment has more than dubled (+100 000 inhabitants) since the late 1940s. Moreover, up to 50 000 tourists visit the area annually. These changes in the nutrient balance of the lake could be expected despite the installation of a limited sewer and treatment system in the 1970s and its improvement since 1995. [5].

Adverse effects may be due to regional population growth, but also due to global phenomena such as climate changes. Pollution, especially within the littoral zone near inflows of tributaries, habitat degradation and decreasing fish populations were identified as major problems. In the future, even irreversible changes of the ecosystem must be anticipated, if the trophic state of Lake Ohrid is significantly changing [6]. Anthropogenic influence is visible in littoral zone of Lake Ohrid, e.g. the increasing P load measured at some locations during the tourist season. Thus, it is important to provide regular monitoring of essential indicators for the lake ecology in all larger groups of karst aquifers and in order to qualify the groundwater input [7].

2. Materials and methodology

During the summer period of 2018, in Lake Ohrid have been caught a total of 178 pieces of fish, which were classified in 11 different species: *Barbus peloponnesius (Syn. Barbus rebeli), Chondrostoma ochridanum (Syn. Chondrostoma nasus), Rutilus ohridanus, Leuciscus cephalus, Alburnus alborella (Syn. Alburnus scoranza), Pachychilon pictum, Gobio ohridanus, Alburnoides ohridanus, Rhodeus sericeus (Syn. Rhodeus amarus), Scardinius knezevici, Carassius carassius (Syn. Carassius gibelio).* Out of each specimen there have been dissected a piece of the liver and gill for histological analysis, which, thereafter has been processed on the standard procedure for development of histological preparation. They have been analyzed under a microscope and the registered tissue lesion has been photographed.

3. Results and discussion

There was been conducted a histological analysis of the samples of liver and gills from the natural population of fishes, whish inhabits the Lake Ohrid. The caught specimens of fishes were with satisfactory external look, active and without any external changes. But, histopathological analyses display us presence of different pathological changes in liver and gill tissues of the investigated specimens.

The analysis of the histological preparations of liver from the investigated specimens indicated presence of many types of tissue lesion, as an inflammatory processes (Figure 2), necrosis (Figure 4), steatosis (Figure 3) and hemoragia (Figure 1) at the level on hepatocellular parenchyme. On a level of hepatic bile tract were evidenced bile duct proliferation, bile duct epithelium necrosis, etc.

Figure 1. *Hemoragia on the level of hepatocelular parenchima.*

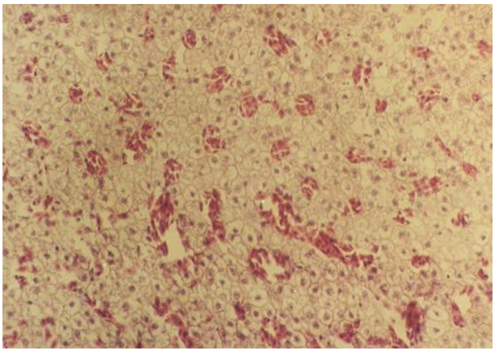


Figure 2. *Inflamation around blood vessels (H&E x 100).*

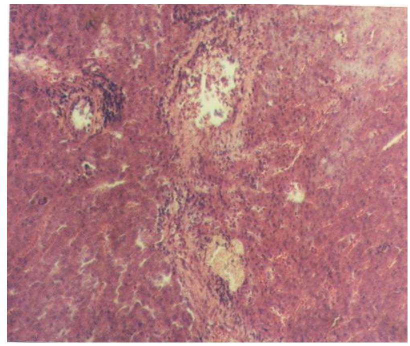


Figure 3. *Liver tissue with microsteatosis (H&E x 100).*

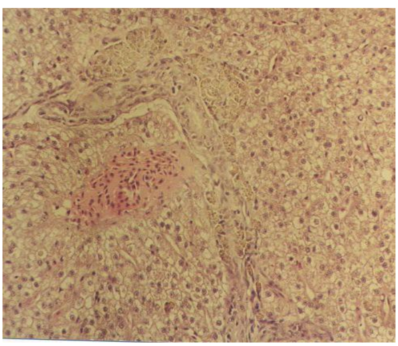
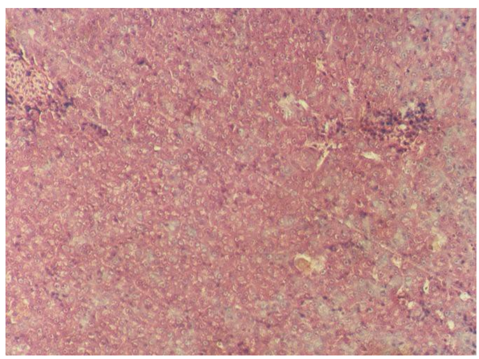


Figure 4. *Necrosis on the level of hepatocelular parenchima (H&E x 100).*



The gills, which participate in many important functions in fishes, such as respiration, osmo regulation and excretion, remain in close contact with the external environment, and are particularly sensitive to changes in the quality of the water, are considered the primary target of the contaminants.

Microscopic analysis of histological preparations of fish gills tissue displayed a presence of progressive changes like a hypertrophy of the lamellae epithelium, regressive changes, necrosis, lamellar disorganization and inflammatory changes.

It is important to note that the response of histopatological biomarkers depend on the frequency of the release of pollutants and type and degree of contamination. In most cases, stressed environment corresponds to chronic or subacute conditions. Histological lesions reinforce the high potential of histopathological lesions to reveal chronic exposure of fish to pollutant [10]. The histopatological analyses of fish organs has been used as a tool for evaluation of the toxic effects of toxicants to the fishes, the severity of histopathological changes depend on toxicant dose and the time of exposure of fishes to toxicants [15][16].

Contamination of freshwater ecosystems often originated from domestic wastewaters and agricultural runoff, as well as from anthropogenic activities such as industrial production and mining and smelting operations [11] [14].

Higher content of organochlorine pesticides was found in fish muscule tissue of barbel fish (*Barbus peloponnesius*) from Lake Ohrid, than in sedimen samples as a result of the bioaccumulation and the lipophilic character of this group of pollutants [9]. Even though the detected organochlorine pesticides are not present in dangerous concentrations, still as organic pollutants with high persistency, bioaccumulation and toxicity, they represent quite a risk for the biotope and biocenose, and through them for the human as the higest level in the trophic pyramid [12] [13].

4. Conclusion

A wide range of toxic effects of xenobiotics in the water have been demonstrated in aquatic animals in nature. In conclusion the present study showed that histopathological biomarkers of toxicity in fish organs are a useful indicator of environmental pollution. The organ and tissue damage in the investigated fishes are due to the direct toxicity of the xenobiotics on the fishes populations.

Acknowledgements

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Hepatic capillariasis in the Mediterranean barbell (*Barbus meridionalis petenyi* Heck.) from Lake Ohrid. *Folia Veterinaria*, Vol. 47(1): 35-37.
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Effects of water quality on the volume of fisheries production in Laguna Lake, Philippines

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Abstract

With the series of fish kills experienced by Laguna Lake in recent years, it is vital to understand which specific factors caused these events. According to the Laguna Lake and Development Authority (LLDA), these were mainly due to the increased nitrate levels and decreased dissolved oxygen (DO) levels in the lake, which are indicators of lake water quality degradation. This study aimed to determine the relationship between different water quality parameters and the volume of freshwater fish production in Laguna from 2016 to 2019. The study examined seven water quality parameters: ammonia biochemical oxygen demand (BOD), DO, fecal coliform, inorganic phosphate, nitrate, and pH, and their correlation with the fish production volume. Results, however, showed that only fecal coliform has a strong correlation with fish volume (r=-0.9488). Nitrate and DO, on the other hand, displayed moderately strong correlations (r=-0.5735; r=-0.4161), while other parameters were insignificant. This suggests that aside from the usual water quality parameters analyzed, fecal coliform concentration may also be a crucial indicator of lake degradation, possibly affecting fish production.

Keywords: *Freshwater fish, water quality, Laguna Lake, fecal coliform*

1. Introduction

Laguna de Bay, the largest freshwater lake in the Philippines, accounts for about 17% and 44% of the national and municipal fisheries production, respectively. [1] About 40% of its fish production contributes to the total fish supply of Metro Manila and nearby provinces, producing approximately 85,000 tons of fish annually. [2] According to the Association of Laguna Lake Fish Producers (ALLFP), the lake is suitable for aquaculture due to two main factors: its natural cleansing capacity due to saltwater inflow, and the minimal use of commercial feeds for fingerlings. [3] With this, there is consequently an abundance of livelihood opportunities for fishermen, thereby resulting in the construction of fish pens and cages within the lake since the 1970s. In June 2017, the lake was reported to have about 14,000 hectares of fish pens, exceeding the suggested carrying capacity of 9,200 hectares.[4] This then led to the dismantling of these fish pens by the Laguna Lake Development Authority (LLDA) in accordance with President Duterte's directive in his 2016 SONA: to dismantle fish pens to promote equitable access to the lake's fishery resource. [3] [4] [5]

Pen aquaculture in the lake was claimed to pollute the lake through eutrophication by the national government. However, according to Dr. Emil Q. Javier, Chair of the Coalition for Agriculture Modernization in the Philippines, this was an exaggeration and not based on facts [3]. This was further supported by the latest comprehensive assessment submitted to the UN-sponsored Global Millenium Ecosystem Program, stating that aquaculture (pen and cage) contributed only to about 0.5% of the lake's eutrophication, whereas, 79% is from domestic sources, 16.5% from agricultural run-off, and 4.5% from industrial effluents. [3] [5] This indicates that the lake's degrading water quality leading to several fish kill events [6] [7] may not be caused by the overabundance of fish pens and fish production, but due to other external factors.

These factors may include other extreme levels of different physicochemical parameters of water quality such as fecal coliform, dissolved oxygen, ammonia, biochemical oxygen demand (BOD), and pH. A study in Indonesia revealed that high fecal coliform concentration recorded during the high tides seasons showed that their river water was not safe for human use and consumption. [8] The same study suggested that as some impaired waters were unsafe for human consumption, so are they detrimental for some fishes and other aquatic organisms, especially at extreme levels of concentration of physicochemical parameters like fecal coliform. Supporting this are studies from West Africa [9] and France [10], which revealed significant correlations between the physicochemical parameters of both natural and artificial bodies of water and freshwater fish population. Results have shown that improved water quality due to reduced anthropogenic activities led to increased fish populations.

Laguna Lake has accumulated high concentrations of pollutants due to the overabundance of fish pens, domestic wastes, agricultural run-offs from irrigation systems, and other industrial effluents, therefore tampering with the water quality parameters of the lake. This study, therefore, aimed to determine the relationship between different water quality parameters of Laguna de Bay and the volume of fisheries production in the lake. This may then provide trends of fish population in relation to the levels of the different water quality parameters in the lake that can be used by fish pen owners and other researchers as reference. Finally, results may also be used by local government agencies in devising rehabilitation plans and strategies to improve the lake's polluted state.

2. Materials and methodology

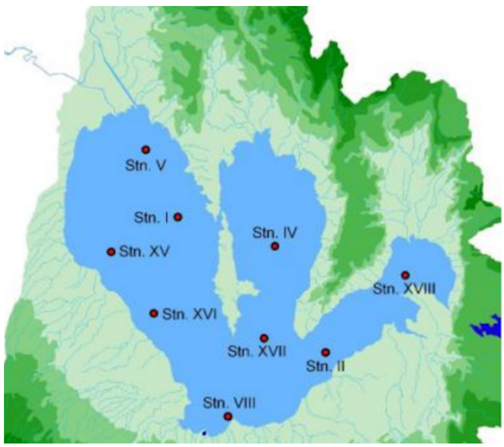
The work is an observational study that made use of currently existing data on water quality parameters (namely ammonia, BOD, DO, fecal coliform, inorganic phosphate, nitrate, and pH) of Laguna de Bay, as well as the volume of overall fisheries production in the province of Laguna from the year 2016 to 2019. The correlation of each water quality parameter with fisheries production was then analyzed.

2.1 Data sourcing

Data on water quality parameters were sourced from Laguna Lake Development Authority's (LLDA) official monthly reports. These data were collected in certain sampling stations scattered across the lake (Figure 1). The data values were then averaged per station and per year.

Fisheries data was then collected from the official website of the Philippine Statistics Authority (PSA).

Figure 1. *Monitoring stations in Laguna de Bay (LLDA, 2012).*



2.2 Statistical treatment

To determine the strength of the correlations, Pearson's correlation coefficient (Eq. 1) was used, and to assess the significance of the correlations, the t-test (Eq. 2) for r was utilized. The t-test was performed at a probability level of 0.05 and 3 degrees of freedom, giving a critical t-value of 3.182.

$$r = \frac{n\Sigma xy - \Sigma x\ \Sigma y}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (y)^2]}} \qquad (1)$$

$$t_{r_{xy}} = \frac{r_{xy}\sqrt{n-2}}{\sqrt{1-r_{xy}^2}} \qquad (2)$$

3. Results and discussion

The different statistical properties of the water quality parameters (max, min, mean, and standard deviation) per station were gathered and listed. The BOD values from all stations ranged from 0.5 mg/L to 9.0 mg/L with an outlier of 70.0 mg/L. The mean BOD values of the stations ranged from 2.0 mg/L to 3.7 mg/L. On the other hand, the DO values ranged from 4.0 mg/L to 17.2 mg/L, with station mean values from 7.8 mg/L to 8.7 mg/L. The coliform values of all stations had extreme outlying values in the early months of 2016. As such, the statistical values were skewed with values ranging from 1.8 MPN/100mL to 3500.0 MPN/100mL and mean values from 157.9 MPN/100mL to 303.3 MPN/100mL. The pH values ranged from 6.3 to 9.8, with station means from 8.3 to 8.6. The stations all had a minimum ammonia value of 0.001 mg/L with an outlying maximum of 1.540 mg/L. The station mean values ranged from 0.031 mg/L to 0.145 mg/L. Similarly, all stations also had a minimum nitrate value of 0.001 mg/L with an outlying maximum of 4.434 mg/L The mean values ranged from 0.114 mg/L to 0.291 mg/L. Lastly, the phosphate values range from 0.001 mg/L to 0.805 mg/L with mean values ranging from 0.074 mg/L to 0.174 mg/L.

It was found that, overall, the study was not able to reject the null hypothesis stating that there is no significant relationship between water quality parameters and fisheries production. However, close to significant correlations were found between fecal coliform and fisheries production over

Table 1. *Pearson's correlation coefficients between the water quality parameters and freshwater fish production.*

Water Quality Parameter	r-value
BOD[a]	0.3311
DO[b]	-0.4161
Fecal Coliform	-0.9488
pH	0.2907
Ammonia	0.0109
Nitrate	-0.5735
Phosphate	0.0931

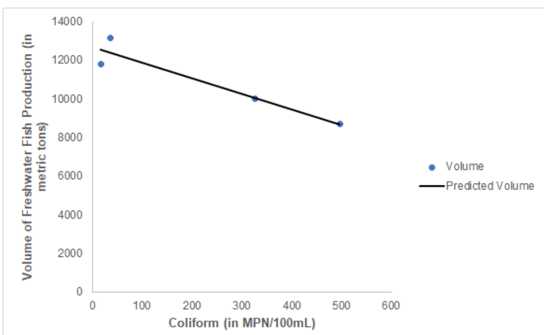
[a] BOD – (Biochemical Oxygen Demand)
[b] DO – (Dissolved Oxygen)

the years. Similarly, the p-values for nitrate and DO showed slightly strong correlations, while the rest of the water quality parameters showed weak to no correlations at all. The Pearson's correlation coefficient of each parameter was analyzed (Table 1), and fecal coliform was the only parameter found to have a strong correlation out of all the parameters.

3.1 Fecal Coliform

The statistical analyses showed that fecal coliform had the strongest correlation with fisheries production volume. However, the calculated p-value for fecal coliform was 0.0512 and could not reject the null hypothesis. Although it presented a statistically insignificant result based on the hypothesis, which may have been due to the sample size, the Pearson's correlation test resulted in an r-value of -0.949, showing a strong negative correlation between fecal coliform and fisheries production (Figure 2). Additionally, results showed a very strong correlation with a t-value of -4.247.

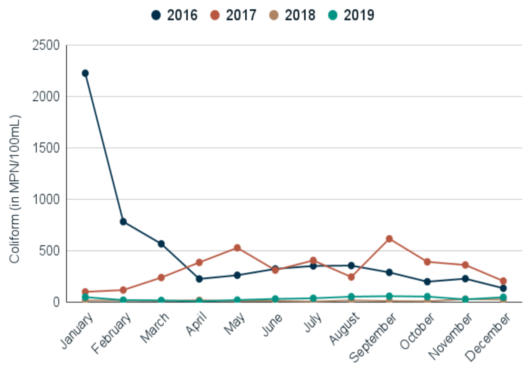
Figure 2. *The effect of total fecal coliform on the volume of freshwater fish production.*



The levels of fecal coliform within the lake have been fluctuating through the years. As seen in Figure 3, there were fluctuating levels of fecal coliform in the lake. A study from Egypt discussed the varying levels of total coliform, fecal coliform, and E. coli in tilapia and mullets during different times of the year (e.g., summer, spring, etcetera), which supports the study's results indicating the fluctuating levels of fecal coliform throughout a year. [11]

Furthermore, this mentioned how coliform bacteria threaten fisheries production as fish can spread diseases and bacteria once they're infected, supporting the study's results suggesting that fecal coliform has a significant effect on fish health and growth.

Figure 3. *Monthly variations in fecal coliform concentrations for 2016-2019.*



Consequently, the effect of the fish health deterioration due to fecal coliform may pose severe threats to human health, especially to the consumers of the fish producers around the lake. A study from Kenya revealed that fecal coliform is one of the indicators of bacterial quality, fish health, and public health. [12] Their results show that, due to domestic sewage discharge, Lake Naivasha's water quality deteriorated, causing the levels of total coliform, fecal coliform, and E. coli in the fishes to exceed the acceptable limit recommended by the Food & Agricultural Organization (FAO) and World Health Organization (WHO). This then indicated that the consumption of fish from this lake posed health risks to humans.

Furthermore, a related study about Laguna Lake supports the idea that water quality deterioration may be caused by factors other than fish production. [13] Their results show that fecal coliform dominantly came from sewage (37.65-49.4%) and human sources (24.4-29.22%). This further supports the UN-sponsored Global Millennium Ecosystem Program's report on lake eutrophication caused by 79% domestic waste, possibly containing fecal coliform. They concluded that sewage contaminated waters pose a serious health risk to the residents in the area.

3.2 Nitrate and dissolved oxygen

Nitrate showed a moderately high negative correlation with an r-value of -0.573 and a slightly significant correlation given its t-value, -0.990. With a p-value of 0.427 at a significance level of 0.05, it can be deduced that the correlation of nitrate with fisheries production is not statistically significant. These results suggest that decreased nitrate levels do not necessarily affect fish health and growth, which is contrary. Multiple studies show that excessive amounts of nitrates are harmful to fish and the aquatic environment, as they may promote the growth of algae, causing eutrophication.

On the other hand, DO had a p-value of 0.584, a t-value of -0.647, and an r-value of -0.416. This indicates a low negative and insignificant correlation with fish volume and that decreased DO levels do not necessarily affect the volume of fisheries production in Laguna de Bay. However, a 2017 study showed that critically low or high DO levels are detrimental to fish health. [14] These may inhibit fish growth by slowing down the development of fish embryos and hypoxia.

3.3 Other water quality parameters

The other four water quality parameters showed weak correlations. BOD had a p-value of 0.667 and a t-value of 0.496, implying that the levels of BOD do not have a significant effect on fisheries production in Laguna de Bay.

Also, pH, meanwhile, had a p-value of 0.709 and a t-value of 0.430, still indicating a not significant correlation. Data gathered showed an average pH level of around 8. A study by Canada found that in high pH waters (9.5), this affects the fish's gill functions, specifically the ion-exchange processes. [15]

Phosphate had a p-value of 0.907 and a t-value of 0.132, implying that phosphate does not significantly affect the volume of fisheries production in Laguna de Bay. A 2015 study attributes the excess supply of phosphate to the process of eutrophication as with nitrate. [16] They have also pinned the cause of excess phosphate levels to fish feeds, specifically those that go uneaten and fish excrements.

Lastly, ammonia had a p-value of 0.989 and a t-value of 0.016, exhibiting the least correlation with fisheries production among the water quality parameters investigated. Recorded ammonia levels were less than what is recommended by DENR. Studies found that ammonia is, in fact, toxic to fish and makes fish unable to extract energy from feed efficiently.

4. Conclusion

In summary, all the water quality parameters showed no significant correlation with the volume of fisheries production in Laguna de Bay, although fecal coliform looked promising. These findings could possibly be attributed to the small sample size of only four years of data. The problem might also lie in the excessive averaging of water quality data. Although, this averaging was necessary to properly correlate it to the available data on fisheries production.

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Effects of the water physicochemical conditions on the water mercury levels of Palawan Quick Silver Mines, Inc., pit lake and Tagburos River in Sta. Lourdes, Puerto Princesa City, Philippines, during the dry season using multivariate analysis

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Abstract

The study aimed to determine the factors that affect the mercury levels and determine the similarities of the pit lake and Tagburos River (in terms of water quality) during the dry season in Sta. Lourdes, Puerto Princesa City using multivariate analysis. The first factor correlated to pH, electrical conductivity, total dissolved solids, turbidity, and salinity, which were associated with ions, particulate matter, dissolved organic matter. The second factor was correlated to water total mercury and oxidation-reduction potential, which was associated with the Hg speciation.

The water physicochemical condition was used to explain the low levels of Hg in the pit lake and the river. The sediment contains cinnabar in which Hg is in a stable state, and leaching of Hg was nearly impossible considering that both water sources' pH was alkaline. Accumulation of Hg in the pit lake water may be possible over time. Still, the interaction of Hg and dissolved organic carbon, however, was dominant. A net increase in Hg content in the water could be insignificant. Photochemical and biogeochemical reactions transform Hg-DOC interaction labile forms such as Hg^0 and organomercury forms which are volatile leaving the water with lesser Hg concen-

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tration. With the strong correlation of TDS and EC toward DOC, the Hg-DOC interaction was likely the most dominant chemical interaction in the water.

Keywords: *Mercury, dissolved organic carbon, sediment, Hg-DOC, photochemical reduction, cinnabar*

1. Introduction

The Palawan Quick Silver Mines, Inc. (PQMI) was an open-pit mercury mine that has operated for 20 years since the 1950s. Because of the low metal prices and strict regulation on mercury, PQMI halted operations. The area was left unrehabilitated until 2015. Flooding converted the pit into a lake where background mercury levels on the sediments can reach 400 mg kg^{-1} of total Hg. Although the sediments contain high levels of Hg, the water Hg level was very low, as reported by various authors (Samaniego et al., 2019; Grey et al., 2003).

The level of Hg in the waters of the pit lake and the adjacent Tagburos River were worth investigating because of the anomalies identified (low Hg level in the water vs. high Hg in the sediments). Samaniego et al. (2019) reported that the primary cause of very low Hg levels in the waters of the pit lake and the river were the very low solubility of HgS in the sediments and the neutral to alkaline pH of the water, which were not favorable for leaching of Hg. Moreover, suspended particles from the mine benches were believed to have contributed to the water's Hg concentration.

Nevertheless, authors claim that a particular substance controls the fate of Hg in the water. The dissolved organic carbon (DOC) is a fraction of the total organic matter with a particle size of 0.45 μm. It has a high affinity to Hg ($10^{7.05}$ to $10^{19.3}$) (Rossotti and Whewell 1977; NIST 2004). The high affinity of DOC to Hg means the Hg-DOC bond is very stable under thermodynamic considerations. Because of the high electron density of DOC, it acts as an electron donor to the oxidized form of Hg to be reduced into zero valent Hg (with the aid of UV radiation by the mechanism called photoreduction) becoming more labile and volatile leaving the water lesser in Hg concentration. The pit lake and the river had very high DOC levels, as Grey et al. (2003) reported, ranging between 2.1 to 16 mg/L. It is plausible to use DOC as one of the substances that causes this anomaly.

Samaniego et al. (2019) and Grey et al. (2003) had reported the Hg levels in the pit lake and the river. Still, none of these studies explicitly explained the reason for the low Hg level in both water bodies but only baseline data. This study, however, explored the possibility of explaining the phenomenon by using simple water physicochemical data and relating these data to the Hg level of the water bodies using multivariate analysis. Multivariate analysis was an appropriate tool for describing this phenomenon since environmental data contain multiple parameters and they are usually not normally distributed.

This paper seeks to explain the low levels of Hg in both water bodies despite the sediments having high Hg levels and plant accumulated Hg concentration was increased. Moreover, it seeks to compare both water bodies in terms of their water physicochemical conditions.

2. Materials and methodology

2.1 Study Site

The study was conducted at the Palawan Quick Silver Mines, Inc. (PQMI) pit lake located in the village of Sta. Lourdes, Puerto Princesa City, Palawan, Philippines. The site belonged to Type III climate classification: no pronounced dry and wet seasons with short dry season during November to April and wet season during the rest of the year. The month of February has the lowest rainfall volume according to the 30 year long term rainfall data from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA).

The PQMI is located within the Tagburos River watershed which flows adjacent to the pit lake and drains to the Honda Bay which is several kilometers from the lake. Residential/build-up area is also located a few meters beyond the PQMI buffer-zone. Activities such as scrap-metal buy and sell business, vegetable farming, and firewood production were the common socio-economic activities observed in the area. The Tagburos River spans 4,879 meters from Sta. Lourdes, Puerto Princesa City to Honda Bay which flows through the communities of Sta. Lourdes and Tagburos.

The mine benches are located at the northern part of the pit lake which lacks vegetation. It was believed that during heavy rains, run-off which may contain suspended particles with Hg and other pollutants could flow towards the northern portion of the lake. Half of a kilometer north of the pit lake is the Puerto Princesa City's Sanitary Landfill.

2.2 Sampling

Samples were collected as a grab at the designated sites in the pit lake and the river. About 21 samples from the lake (7 samples at each sampling location with three replicated samples) and nine samples in the river (3 samples each for upstream, middle stream, and downstream) were collected in each sampling location. The sampling scheme at the lake was different from the river such that samples at the lake were taken at the three pre-determined vertical sections of the lake (strata) at the south (approx. 18 m deep) and north (approx. 13 m deep) parts of the lake. On the other hand, only the surface section was sampled at the middle part of the lake because of its relative depth (1.7 m). The water samples from the river were taken at the surface, considering its relative depth, approximately 1 m.

2.3 Physicochemical analysis

Water pH, oxidation reduction potential, dissolved oxygen, electrical conductivity, total dissolved solids, salinity, and turbidity were measured in situ using AP 800 Aquaprobe Water Monitoring Instrument Multiparameter Probe. For the Hg determination on the water and the sediments the methods Standard Methods for the Examination of Water and Wastewater (APHA 2012) (with modifications). Method 747 1B: Mercury in Solid or Semisolid Waste (Manual Cold Vapor Technique) was used to determine sediment Hg_T (USEPA 2007) were used respectively.

2.4 Data analysis

The data underwent z-scoring before factor analysis and generalized linear model analysis using IBM SPSS Statistics 26 software.

3. Results and discussion

The summary of the water physicochemical data of the lake and the river is presented in Table 1. Both water bodies' pH was classified as alkaline with values ranging from 7.10 to 8.42; ORP values were reducing in nature implying the presence of electron rich substances dissolved in the water with values ranging between -11.2 mV to -25.6 which were variable across the sampling locations for both water bodies; EC and TDS values were high and consistent for the pit lake but highly variable for the river (323 μS/cm to 686 μS/cm and 211 mg L-1 to 445 mg L^{-1}, respectively) . Dissolved oxygen values were variable across the lake and the river (1.23 mg L^{-1} to 14.03 mg L^{-1}) Salinity values were very low indicating that both water bodies are freshwater basins (0.11 PSU to 0.29 PSU) and turbidity values were very high in the pit lake (40.6 NTU to 59.6 NTU), compared to the river (4.50 NTU to 7.80 NTU) being more polluted than the river.

Mean water Hg values ranged between <0.02 ug/L to 1.03 ug/L and mean soil total Hg values between 22.20 ug/L to 130.57 ug/L. Mann-Whitney U test revealed that the water total Hg across all sampling locations was comparable except at the bottom section of the lake, where the water Hg level was statistically highest among the samples collected. Meanwhile, sediment mean total Hg was highly variable which only explains the inherent lithology of the area.

Factor analysis revealed two important factors with a total variance explained of 80.15%. Factor 1 had a total variance of 61.57% with a strong correlation to pH, EC, TDS, salinity, and turbidity, collectively called ionic parameters and suspended matter. Meanwhile, Factor 2 had a total variance explained of 18.58% with a strong correlation to Hg and ORP, which were collectively called Hg speciation (Table 2).

Factor 1 dictated the discrimination of both water bodies, while factor 2 only adjusted the distances of each sampling location from the score plot

Table 1. *Water physicochemical data of the PQMI Pit Lake and the Tagburos River in Sta. Lourdes, Puerto Princesa City, Palawan, Philippines.*

Parameter	**Pit Lake**	**River**
pH	7.64 to 8.42	7.10 to 7.25
Mean	8.05	7.18
SD	0.30	0.08
ORP (mV)	-11.2 to -24.4	-18.20 to 25.6
Mean	-18.54	-22.57
SD	5.17	3.88
DO (mg/L)	5.79 to 14.03	1.23 to 7.76
Mean	8.05	3.88
SD	3.13	3.43
EC (µS/cm)	646 to 686	323 to 578
Mean	672.00	469.00
SD	13.39	131.46
TDS (mg/L)	417 to 445	211 to 371
Mean	434.71	303.33
SD	9.96	82.80
Salinity (PSU)	0.26 to 0.29	0.11 to 0.24
Mean	0.27	0.19
SD	0.01	0.07
Turbidity (NTU)	40.6 to 59.6	4.5 to 7.8
Mean	50.99	6.60
SD	8.36	1.82
Water Hg (µg/L)	0.02 to 1.03	<0.02
Mean	0.18	<0.02
SD	0.38	0
Sediment Hg (µg/g)	46.7 to 130.57	25.2 to 54.07
Mean	79.32	37.85
SD	44.93	14.76

TABLE 2. *Factor loadings of the water physico-chemical parameters. The parameters with values greater than 0.700 (encoded in bold font) were correlated to their corresponding factors.*

Variables	**Factor**	
	1	2
Total dissolved solids (TDS)	**0.955**	0.147
Electrical Conductivity (EC)	**0.950**	0.135
Salinity	**0.926**	0.149
Turbidity	**0.926**	-0.111
pH	**0.887**	-0.051
Dissolved oxygen (DO)	0.564	0.433
Water Hg (Total)	0.307	**-0.817**
Oxidation-reduction potential (ORP)	0.442	**0.745**
Total Variance Explained (%)	**61.57**	**18.58 (80.15)**

to place the clustering of the sampling locations (Figure 1). The sampling locations for the lake are clustered as one separate cluster. The same happened to the river sampling locations. The implication of the clustering was the current water quality of each water body explained their differences, not Hg alone, since Hg had very low significance to the discrimination.

The generalized linear model was used to generate a linear model for the study (Equation 1). The mercury, ORP, EC, TDS, and salinity were selected to avoid collinearity with the rest of the parameters. The model below was the generated model from the set of variables mentioned:

$$\widehat{ORP} = 1.101(TDS) - 0.655(Hg) - 3.69(EC) - 68.046(salinity) - 37.205 \quad (1)$$

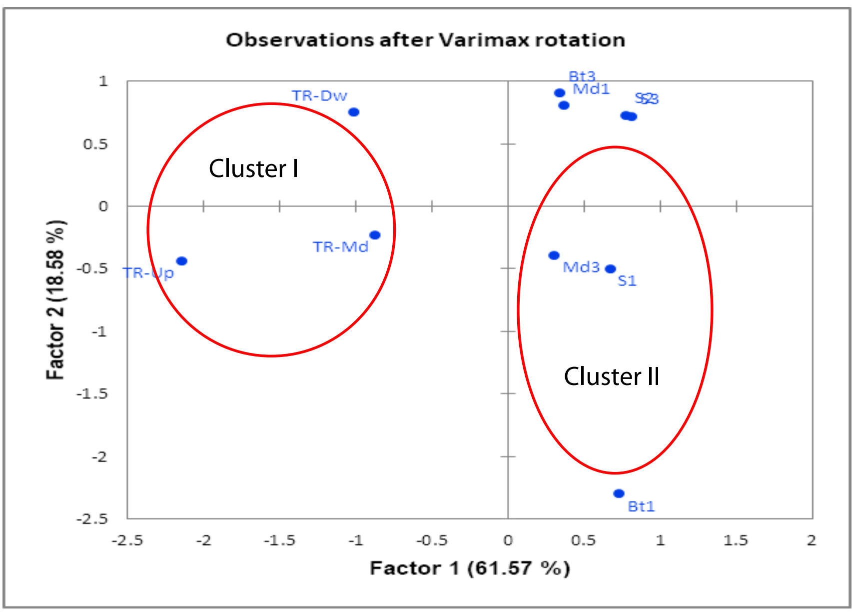
Each variable had a significant effect on the response variable ($P<0.01$) except salinity. The computed Akaike's Information Criterion (AIC) is 159.89 and deviance value of 9.72, the mean absolute and mean bias errors were 12.58% and -1.98%, respectively, which was the most accurate model generated by running analyses using different parameter combinations.

The model tells us the kind of chemical environment the water basins possess. Higher Hg levels mean higher ORP (more positive value), which makes the water oxidizing in nature and mercury stays in its divalent form. Since both water bodies are reducing in nature (negative ORPs), Hg ions would be reduced (Hg^0).

The statistical analyses zeroes in into the three significant water chemical parameters this study obtained: the ORP, EC, and TDS. Dissolved organic matter has high correlation to EC and TDS (Monteiro et al., 2014) which means that the high values of EC and TDS in the water samples were related to the high DOC concentrations in the water. We compared Grey et al. (2003) data to the data this study had obtained. Independent t-test revealed that the data obtained 16 years ago had no significant difference ($P<0.05$) from the data obtained in this study. The EC was used to explain the Hg-DOC interaction. There was no correlation between EC and Hg since the Hg form that binds with DOC is Hg^{2+}, and the obtained Hg data in the study was total Hg. Regardless, the interaction of Hg to DOC became apparent when we used the data of Grey et al. (2003) on the Hg for filtered and unfiltered water. The filtered water Hg level ranged between 4 to 8% of the total concentration of Hg, while unfiltered samples had a high percentage between 91 to 96% of the total Hg level. Moreover, DOC values in the filtered samples were non-existent and values can reach up to 15.00 mg L^{-1} in non-filtered water samples.

The DOC reduces chelated Hg^{2+} with the aid of ultraviolet radiation from the sun by photochemical reduction mechanism into Hg^0, which happens more often at the surface water. The volatile Hg^0 will eventually volatilize from the water leaving the surface water with a lower Hg concentration, hence the very low concentration of Hg in the water despite the sediments contained high amounts of mercury (Celo et al., 2006; Li and Cai 2012; Zhang 2006; Saiz-Lopez et al., 2018).

Figure 1. *Score plot of the sampling locations where two distinct clusters were apparent. Cluster 1 belonged to the river sampling locations, and Cluster 2 belonged to the pit lake sampling locations. There were no overlapping clusters, which means that the two water bodies' discrimination was mutually exclusive in terms of physicochemical conditions during the dry season.*



Aside from its reducing nature, DOC weakens the Hg-S bond when the DOC binds to Hg on the surface of the cinnabar. The strong binding energy of DOC to Hg weakens the Hg-S bond pulling the Hg ion towards DOC: DOC leaches Hg from its ore, making Hg-DOC one of the most important chemistries in the environment to understand mercury's fate and toxicity (Waples et al., 2005; Ravichandran et al., 1998). This explains the presence of dissolved mercury ions in the water despite the alkaline nature of the water. Overtime, the cycle of dissolution, volatilization, and precipitation of Hg by DOC takes place: DOC primarily controls the fate of Hg in the water.

4. Conclusion

We investigated the effect of the selected water physicochemical parameters on the water Hg levels of the PQMI pit lake and the Tagburos River. The result of the analysis revealed a relationship between the level of Hg to the chemistry of the water, which determines its (Hg) fate. The leaching of Hg from the sediments may not be plausible in an alkaline environment, but the presence of the electron-rich DOC aided preventing Hg from leaching from its ore and eventually transforming Hg into more labile form, thus the low Hg concentration in the lake and the river's water.

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Emergency countermeasures against overgrowing invasive amphibious plants and their low-density control in Lake Biwa, Japan

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Abstract

Aquatic and amphibious plants become seriously invasive pests in many lakes of the world. *Ludwigia grandiflora* (water primrose) and *Alternanthera philoxeroides* (alligator weed) are typical examples of recent invasive proliferation in many waterbodies in Japan. Lake Biwa, the Japanese largest lake and one of the ancient lakes of the world, is not an exception. In this paper, the active countermeasures having been taken toward their invasions are historically reviewed.

1. Introduction

Proliferation of aquatic weeds is one of the environmental issues in lakes located in the tropical and temperate zones. Some floating plants such as water hyacinth *Eichhornia crassipes* and water lettuce *Pistia stratiotes* are typical examples known as aquatic "green monsters" overgrowing over wa-

[1] Lake Biwa Museum, Kusatsu Japan / Nature Conservation Division of Shiga Prefecture, Otsu, Japan.

ter surface of the lakes in tropical regions. In addition, emerging plants of tropical origins have become problematic through covering water surface with dense floating mats formed by stems and leaves elongating along and entangling under water surface in temperate lakes, exemplified by water primrose *Ludwigia grandiflora* [1] and *L. peploides* [2] in Europe and North America and alligator weed *Alternanthera philoxeroides* in China, Australia, U.S.A., etcetera. [3]

In recent years, these two species have also overgrown in a temperate lake, Lake Biwa, the largest lake of Japan known as one of the ancient lakes of the world, inhabited by not a few endemic species. In this paper, the emergency countermeasures against these overgrowing plants for their low-density control are historically reviewed. Most of the contents are based on recent reviews [4]~[7].

2. Ecological characteristics and invasiveness

Both water primrose and alligator weed have high abilities to overgrow and disperse through connection of water. They predominate in shoreside habitats forming floating mats (Figure 1) below which dissolved oxygen in the water column is dramatically decreased. Both species are able to widely disperse owing to vegetative propagation; even small pieces of stems and leaves can propagate. They also have amphibious habit to grow both underwater and on land. Usually, their distribution is restricted to aquatic habitats simply because their propagation depends on transportation by water movement. If they are placed on land somehow, they can survive for years as terrestrial plants.

These invasive weeds are supposed to cause several ecological and social damages. They compete with native plants growing in the shoreside habitats, and exclude fish and benthic animals living under their floating mats. They prevent setting fishing gears and cruising boats (Figure 2). They intrude into farmlands and consequently cause serious damage in agriculture. Finally, they expand their distribution in downstream directions and the suffering areas are enlarged, thereby. Unfortunately, these unwelcome impacts have gradually come true.

Figure 1. *Water primrose covering the water surface of a satellite lake of Lake Biwa.*

Figure 2. *A boat surrounded by floating mats of water primrose and alligator weed.*

3. Intrusion and establishment

In 2005, Invasive Alien Species Act was enacted and Designated Invasive Alien Species (referred to IAS, hereinafter) were selected as the targets of regulations. Finding of Senegal tea plant, *Gymnocoronis spilanthoides*, on the eastern shore of the southern basin of Lake Biwa in summer of 2007 was the first case in which a plant species selected as IAS was newly found in and around Lake Biwa. To realize effective removal immediately after finding at the early-stage, researchers and NPO members formed a volunteering team in an attempt to eradicate Senegal tea plant in the Lake Biwa region.

Immediately after detection of Senegal tea plant, alligator weed was first found to form large floating mats in Jinjo-numa, a satellite lake along the eastern shore of the northern basin of Lake Biwa in 2007. This weed is known as the worst invasive aquatic plant of the world, and had already established in the Japanese lakes near Tokyo such as Kasumi-ga-ura, where the last World Lake Conference was held in 2018. The floating mats were partly removed by the volunteering team in 2008, and the remainder was mechanically collected, using an aquatic weed harvester by Hikone City in 2009. But alligator weed was also found in several localities outside of the satellite lake, including the shoreside of Lake Biwa, and gradually expanded its distribution including the southern basin of the lake.

Following alligator weed, water primrose intruded into Lake Biwa, with its earliest coverage area of 142 m^2 in 2009. Water primrose rapidly expanded its distribution all along the southern basin, and large floating mats grew along the lake shore and in the satellite lakes by 2012, reaching as large as 18,000 m^2 in 2012, replacing with the alligator weed which had already established.

4. Intensive removal

4.1 Preliminary Manual Removal Project

The project to control water primrose started in 2013, when it was the last year of "Alien Watcher Project" over 5 years. This project was operated under the urgent program of Ministry of Health, Labour and Welfare to encourage employment. Water primrose growing in a satellite lake on the eastern side of the southern basin of Lake Biwa was selected as the target of manual, by-hand removal (Figure 3). Nearly 19,000 m^2 of water primrose was removed by this project, but the total coverage area in and around the lake decreased by 10,000 m^2 only. It became apparent that it is impossible to overtake the rapid growth of water primrose only by manual human labor and that it is necessary to employ mechanical removal.

Figure 3. *Intensive manual removal of heavily growing water primrose.*

4.2 Establishment of local council

A local council to control invasive aquatic plants in Lake Biwa was established in March 2014, the end of FY 2013, joined by Shiga Prefecture, several cities surrounding Lake Biwa, environmental NPOs and fisheries cooperatives.

The council has been mostly funded by Shiga Prefecture and partly supported by the grant for biodiversity restoration from Ministry of the Environment.

The council started the projects to control invasive amphibious plants in and around Lake Biwa, including mechanical removal of large floating mats of water primrose. The council members collaborate in necessary activities required to control the invasive amphibious weeds.

4.3 Installation of mechanical removal

Due to their largeness, floating mats of water primrose were planned to remove with the aid of specialized machines.

One removal method, proposed by a local construction company, is to use "swing yarder" or a backhoe specialized for forestry work [Figure 4]. A specially-made rake is placed on the other side of floating mats and is drawn closer by winding the wire connected to the rake. The attachment called "grapple" at the end of the arm grabs up the collected weeds and loads them onto the bed of a truck for further transportation to a drying yard.

Figure 4. *A backhoe "swing-yarder" originally used for forestry work, with a specially made rake.*

The other removal method, applying the ordinary method for collecting submerged plants in Lake Biwa, is to use "aquatic weed harvester" or a workboat specialized in collecting aquatic weeds [Figure 5]. This type of workboat is commonly used in many countries of the world for harvesting aquatic weeds. The collected weeds are temporarily stored on the deck below the operator's cabin, and are finally placed onto an approaching boat. The boat transports the collected weeds to the port, where weeds are lifted up by a crane and are loaded on a truck bed to transport them to a drying yard.

Figure 5. *A workboat called "aquatic weed harvester" usually used for collecting submerged weeds.*

4.4 Lessons from unexpected rebound after removal

In FY 2014, large floating mats of water primrose were intensively removed and its total coverage area in the end of the fiscal year could be reduced from the previous year for the first time.

It had been expected that water primrose will regenerate from remaining plant bodies such as roots and stems to some extent. However, its rebounding regeneration in FY 2015 after intensive mechanical removal in FY 2014 was far beyond our expectation.

In addition, not a few large floating mats newly appeared in many localities, supposedly growing from propagules scattered by unusual disturbance and rising of the lake water level by a strong typhoon in September of 2013.

Then, we learned the following two principles are important for their effective removal and low-density control.

The first principle is careful removal in combination of mechanical operation and manual, by-hand removal to minimize the remaining parts such as roots and stems. Growing amphibious weeds can be actually decreased, thereby.

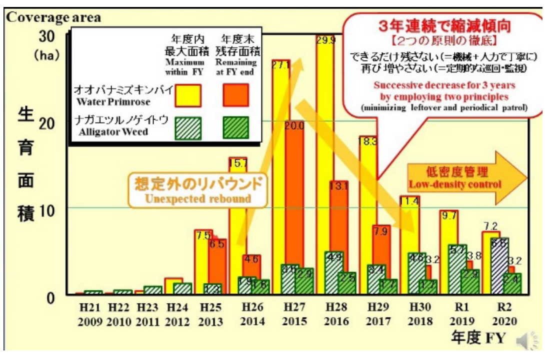
However, we have also realized that it is impossible to remove the weeds completely through removal activities only. In addition, pieces of weeds or floating mats may be drifted from other areas. Thus, the second principle was employed to carry out periodical patrols to carefully remove regenerating or drifted weeds after removal. The recovery of weeds can be largely prevented through this aftercare.

In addition to these two principles, it was important to carry out strategic removal, following priorities based on supposed risks. We considered the following risks for giving priorities. First, whether the growing sites will become the sources of dispersal and expansion of weeds. Rivers, streams and canals, and water gates are selected as candidate sites. Second, whether the fisheries activities and cruising boats will be prevented. Some satellite lakes, bays, and ports are selected. Third, whether the problems in ecological conservation will take place. The distribution data of other animals and plants are important to evaluate conservation value. In particular, coastal vegetations with endangered species are selected as the sites of high priority.

4.5 Achievement of low-density control in and around Lake Biwa

By following these two principles and risk-avoiding priorities, the coverage area of water primrose could be dramatically decreased and that of alligator weed could be kept almost stable from FY 2016 to 2018. After FY 2018, the coverage areas of both amphibious weeds have been stably maintained and in "manageable conditions", in which large-scale floating mats with the size large enough to require mechanical removal and without serious dispersal risks do not remain at the beginning of fiscal year, have been achieved (Figure 5).

Figure 5. *Annual change of coverage areas of water primrose and alligator weed in and around Lake Biwa.*



5. Necessary processes after removal

5.1 Acquisition of yard for temporary placing

It should be stressed that removal itself is not a final goal of the control. Because of their invasiveness, their treatment is strictly regulated by Invasive Alien Species Act not to irregularly disperse them. In addition, they will become general wastes, immediately after removal from the wild. Then, their treatment is strictly regulated by Waste Management and Public Cleansing Act. Accordingly, they should be properly disposed within the municipalities where they were generated.

Since the collected weeds should be treated as the general waste from business activities once they are removed in the project and they should be disposed within the local municipalities where they were collected, therefore, it is important to secure a suitable yard to keep the collected weeds for reducing their weights and drying for further incineration.

After the first step of removal which requires development of removal techniques and patrolling systems, it is necessary to secure the places for temporarily keeping them for drying or reducing weights. Then we need to follow rules of disposing which are often restricted by physical abilities of local incineration factories. Consequently, it is necessary to develop novel methods to facilitate the treatment after removal.

5.2 Development of methods for effective removal and withering

In terms of containment of weeds, some issues still remain to be solved. First, there are some hard targets to remove completely; that is, weeds whose roots are growing among piled rocks of artificial lake shore or growing among other emergent plants. Second, the novel methods to effectively process removed weeds are to be developed instead of drying and reducing weights for incineration and disposing other than incineration.

Now, we are trying to develop novel methods to treat so-called "hard targets" such as the weeds growing on land or with other plants. Artificial lake shore covered with piled rocks is a typical example. We are now preparing for the method for withering them to cover the ground with rubber sheets to shade sunlight.

The weeds rooting among other emergent plants are another example. We are trying to remove the roots entangling with other plants with water-jet of a submersible pump, which can be applied to artificial shore with piled rocks as well.

5.3 Development of methods for processing removed weeds

Because it takes a lot of efforts (in terms of labor, time and money) to reduce weights and water contents before incineration, we are trying to develop techniques to process the removed weeds more efficiently.

It is important to simplify the treatment of removed weeds for their drying, reducing weights and disposing. The techniques under development are methanol fertilization to make liquid fertilizer, complete composting in a special plant, and special carbonization in a factory.

5.4 Dissemination on their invasiveness in agriculture

In Japan, rice cropping in paddy fields is predominated to the extent to form the typical landscape. It is important to make known that ordinary agricultural activities to grow the rice plant may favor the spread and proliferation of these amphibious weeds, unfortunately. For example, ploughing and mowing may break weeds into small pieces with regenerating ability and scatter them all around the fields; weeds may successfully enter into new rice paddies by shared operation of cultivating machines or dredging ditches with weeds' growing; filling water in paddies may explode active growth of the weeds, and insufficient usage of herbicide may promote their selective survival among other weeds.

5.5 Development for suitable governance in environmental policies

Finally, I will point out the relationship between the project executors and the land owners and managers. Regarding project execution, the projects are usually carried out as invasive species controls for ecological conservation. Generally, social incentives are not high enough and financial support is limited, unfortunately. Regarding land owners or managers, it is common that land owners do not suffer from direct or actual damages from the invasive species. Further, in Japan, land owners are not legally responsible for invasive species management.

6. Epilogue

It is fortunate that Lake Biwa should be our "mother lake", and is locally accepted as our cherished treasure. Owing to such friendly relationship of the local residents and governments with the lake, a variety of activities for invasive species control are publicly accepted and have been carried out intensively. Some of our experiences could be useful as a good lesson to other lakes of the world.

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Impact of tropical cyclone Titli and Fani on spatial distribution of marine benthic community of Chilika Lake, India

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Abstract

During the months of October 2018 and May 2019, two cyclones, namely "Titli"& "Fani", stroked the coastal Odisha province with damaging intensity. The cyclones consecutively triggered the preponderance of 297 marine benthic animals belonging to various groups such as sponges, soft and hard corals, crabs, lobsters, reef based fishes, and shell fishes in Chilika Lake. Multivariate statistical analysis technique showed that the entire lake acts as three different ecological units. Quantitative aspect of macrobenthos showed a greater variance between month and sectors. The Shannon Wiener Diversity Index (H') found higher and lower values in the outer channel and in Northern sector respectively. The relative abundance exhibited that the amphipod and polychaeta group responded significantly to the natural turbulences in the lake. In addition to this, the strong cyclone generated waves and currents from Bay of Bengal attributed to probable entry of various reef based benthic organisms into the Chilika Lake through inlet.

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Keywords: *Tropical cyclone, Chilika lake, NMDS, macrobenthic community, population density and biomass*

1. Introduction

Natural physical disturbances such as tropical cyclones are broadly responsible of damage, disturb and restructure of the coastal and marine ecosystem (Bacheler et al., 2019). Extreme impacts of tropical storm have imposed a sudden and sometimes fatal impact on the residing biota, such as fish and benthos, including coral reef by damaging the reef structure from moderate to large scale depending upon the intensity of the storm. Most particularly the sea level rise, wind induces wave surge, there is a fresh water runoff due to heavy rain and catchment flux to the coastal embayment such as estuaries, lagoons, creeks etc. usually disturbing with augmented concentration of suspended solid and hiked nutrient content (Harmelin-Vivien, 1994).

Stupendous changes usually occur in the coastal and marine ecosystem due to physical disturbances due to tropical cyclones such as (i) high turbidity due to significant influx of silt laden freshwater from catchment, (ii) increased sedimentation, (iii) sudden but temporary changes in environmental parameters viz. salinity or dissolved oxygen (DO), (iv) loss of bottom vegetation, such as sea grass due to the disturbance, (v) wide dispersion of sediment along with the contaminants because of strong wave surges, (vi) changes in the "*ecotone*" regime, which can be conceptualised as the temporary conversion of saline regions to fresh water habitats and vice versa in shallow water ecosystems (Mallin and Corbett, 2006; Engle et al., 2009, and Gaonkar et al., 2013).

Consequences of physical disturbances as witnessed in post storm scenario are innumerable. Published literature suggested that mass mortality of marine biota could have been caused by tropical cyclones considered as the direct impact (Harmelin-Vivien, 1994). The indirect impact, for instance, damage of body forms & disease to marine life, loss of food and spoil of feeding ground such as coral reefs, is devastating, of which deleterious effects may be felt at slow pace but whose drastic consequences may be experienced in the short future (Harmelin-Vivien, 1994; Paerl et al., 2001). Coastal lagoons are ephemeral, in geological time scale, located in the juncture of land and ocean interface (Mahapatro et al., 2013; Mahapatro, 2017). These are the shallow coastal dynamic structures having complex ecosystem functioning, highly productive, immensely rich in biodiversity (for instance, Chilika Lake), and provides large scope for the exploitable fisheries resources (Mahapatro et al., 2013; Mahapatro, 2017). Such ecosystems are the immediate victims of any kind of natural or anthropogenic disturbance that may be reflected through loss in biodiversity and sharp decline in the exploitable fisheries resources (Mahapatro et al., 2013; Mahapatro, 2017).

The Lake Chilika has been affected by the occurrence of many cyclones in the past decades. In the last couple of years major tropical cyclone "Titli" (Figure 1a) and Fani (Figure 1b) had taken place within a gap period of seven months. Cyclone Titli had landed at Palasa region of north Andhra Pradesh. This was considered as a very severe cyclonic storm on October 9th 2018, as declared by Indian Meteorological Department (IMD), New Delhi. Its speed was equivalent to a category 3 hurricane on the Saffir–Simpson Scale (SSHWS), having the maximum wind speed of 195 km/h sustained for one minute and a maximum of 150 km/h sustained for three minutes. At the same time, huge rain fall and different wind patterns had been felt over the Chilika Lake. The second cyclone, was named Fani, was observed on May 3rd 2019 and landed at Puri of Odisha coast, India. The IMD, New Delhi, described Fani as extremely severe cyclonic storm, whereas Saffir–Simpson Hurricane Wind Scale (SSHWS) described this cyclone under "Category Five". It exhibited a maximum wind speed of 185 km/h and 230 km/h that sustained for three minutes and one minute respectively. Both cyclones acted significantly to disturb the Chilika lake ecosystem by churning the water column by re-suspending the bottom sediment through wind mediated large waves, fresh water influx from catchment and marine water ingress from the Bay of Bengal. Review of literature suggests that the knowledge on impact of tropical cyclone upon benthic marine life in shallow coastal lakes is scanty (Mahapatro et al., 2018a & 2018b, Mahapatro et al., 2019, Mahapatro et al., 2020a & 2020b, Mahapatro et al., 2021).

With this research gap the present study aims to enumerate the impact of two successive tropical cyclones, i.e. Cyclone Titli and Cyclone Fani on the marine benthic life of Chilika and the resilience of the benthic community to accommodate such natural unprecedented climatic phenomena.

2. Materials and methodology

2.1 Study area

Chilika Lake is a brackish water coastal ecosystem (Figure 1c) ecologically divided into four sectors: northern sector (fresh water region), central sector (brackish water region), southern sector (brackish water & marine water region), and outer channel area (the marine water region). The shape of the lake is bean shaped & well-connected with Bay of Bengal in the east through a couple of tidal inlets. These inlets are responsible for periodical exchange of tidal waters and sediment in the outer channel area. According to Mahapatro (2017), Mahapatro and Kadam (2018), and Mahapatro et al. (2021), the outer channel of Chilika is a highly biodiversity rich province since it harbors numerous microhabitats such as (i) sea grass & seaweed bed, (ii) molluscan reef bed, (iii) mangrove vegetation, (iv) sand dune vegetation, (v) intertidal mudflats, (vi) subtidal shallow region, and (vii) diminutive creeks. Combination of all these microhabitats within the outer channel area provides immense habitat support for the congregation of wide range of flora & fauna (Mahapatro, 2017; Mahapatro and Kadam 2018, & Mahapatro et al., 2021).

Field sampling to Chilika lake was carried out for a longer period that was started from 2007 to 2020. Specific attention for sample collection was paid immediately after the passage of both of the cyclones. Benthic sample collection from all the four sector of Chilika Lake was carried out during September 2018 (pre cyclone Titli), October 2018 (cyclone Titli) and November 2018 (post cyclone Titli). However, to understand the recovery of marine fauna after disturbed condition, another sampling was carried out during April 2019.

After 7 months of cyclone Titli, another cyclone emerged during May 2019 from Bay of Bengal, named Fani. Therefore, a similar strategy had been followed. By keeping the occurrence of cyclone Fani in focal consideration, the sampling was taken during four months: April 2019, termed as pre cyclone Fani, May 2019, cyclone Fani, and June post cyclone Fani. Another sampling was carried out after the sixth month of occurrence of Fani, i.e. on the month of October 2018, to understand the recovery rate of marine fauna.

Sediment sample collection was made from 24 sampling points (six sample stations from each sector) prefixed through GPS. A hand operated grab sampler was used for the collection of samples of bottom sediment. Wet sieving process was made through a 0.5 mm mesh size to collect the macrobenthos samples. The individual number of macrobenthos was counted and the abundance expressed as no. per square meter and the wet biomass expressed through the grams per square meter area. Specific attention had been provided to collect the mega benthic marine fauna from the lake premises after the occurrence of the two cyclones Titli & Fani. Mega benthic marine fauna of Chilika was collected during frequent field visits to shoreline areas of sea front. Some marine fishs samples were collected for identification from the fishermen's net as well as by catch based discarded fish and shell fishes were kept. Soft coral and hard corals, sponges, sea urchins, star fishes, seahorshes, etc. were collected from the shoreline survey in the outer channel area — Bay of Bengal provinces. A primary database on available mega benthic marine fauna has been prepared to enlist the observed marine fauna after the occurrence of couple of tropical cyclone.

2.2 Sample analysis

The observed data has been presented in terms of population density (no. per square meter area) and biomass (gram per square meter area). Relative abundance expressed in% was calculated to know the dominant macrobenthos group. The Shannon-Wiener Diversity Index was calculated on benthic species richness to understand the changes in the species diversity during the cyclone and post cyclone periods. Nonmetric Multidimensional Scaling (NMDS) was made by using PRIMER Software.

3. Results and discussion

Population Density and Biomass: The macrobenthic abundance and biomass has been studied for the months of September 2018, October 2018, November 2018, and April 2019, May 2019, June 2019, and October 2019 expressed in Figure 2(a&b). The results showed that higher values of macrobenthic abundance & biomass were recorded during November 2018 and June 2019, having 3,449 and 3,078 number per square meter area. Similarly, the observed biomasses were 350 & 215 grams per square meter area respectively for the same month. Both population density and biomass were larger after the occurrence of cyclone Titli and Fani.

From Table 1 it is revealed that as much as 297 macro & mega benthic species have been documented from Chilika lake premises after the consequences of the super cyclone Titli and Fani. Most of the unidentified species were grouped under a miscellaneous section. The benthic demersal fishes amounted up to 72 species. Some of the reef based organism, such as marine sponges, soft coral, hard coral, sea pen, sea urchin, sand dollar were recorded for the first time during the study period. Table 2 exhibited the species diversity index (H') that showed outer channel area have shown higher species diversity after the successive cyclones. However, less diversity value was found in the northern sector.

The relative abundance of macrobenthic groups can be viewed in Figure 3 This study revealed that Amphipod becomes the dominant group during both the cyclones Titli and Fani, having a percentage share of 36% and 58% respectively. Others group have shown higher values of percentage share in the month of November 2018. Interestingly, the polychaeta percentage share was found to be increasing in the next month after the disturbance. For instance, Titli occurred in the month of October 2018, during which period in the macrobenthic polychaeta was 19%, later increased up to 25% during November 2018. Similarly, the polychaeta contribution was found to be 7% only during May 2019 where as during June 2019 it became 12%. It reflects that physical natural disturbances occurred in Chilika lake have imposed a positive impact on the benthic polychaeta group. Similarly, Isopoda percentage increased from 1% to 8% in the month of October 2018 and

November 2018, respectively. However the percentage share of the same group isopoda during May 2019 and June 2019 exhibited no significant variation and the values of percentage sharing fall of 5% and 4% respectively.

Gastropods and bivalves are among the most important macrobenthic groups of Chilika Lake. During the present study, it had been found that cyclone affected October 2018 both gastropods and bivalves percentage share was 17% and 15% respectively, whereas during November 2018 it was reduced to 0% and 7% respectively. But after six months, during April 2019 it was recovered to the previous condition having the recorded value of gastropod and bivalves of 15% and 18% respectively. A reverse trend is observed in the relative abundance during the month of May 2019 and June 2019 when compared with the values of October 2018 and November 2018. During May 2019 the gastropod and bivalve share was recorded at 9% and 8% only. However the study further observed that there was considerable increase in the percentage share during June 2019 among the gastropod (17%) and bivalves (26%) respectively. But, same trend was not observed in the study portaining to cyclone Titli. Although the intensity of cyclone Fani was stronger than Titli, response of benthic community of Chilika was found to resemble the disturbances of Titli. It seems that the benthic community of Chilika exhibited group specific resilience over the natural physical disturbances.

Figure 4 (A to I) exhibited some of the images of reef based organisms collected from Chilika Lake after both cyclonic periods. Some of the reef based organisms such as sponges, gorgonids (soft coral), *Polycyathus sp.*, (hard coral), sea pen (*Pennatulacea*), sea horse hippocampus species and many of the unidentified demersal and reef associated fishes, shellfishes, echinoderms including numerous unidentified specimens, were noticed. Occurrence of typical reef dwelling marine fauna in the Chilika Lake premises is certainly attributable to the synchronized ingress of water and sediment from Bay of Bengal through lagoon inlet during tropical cyclone. Lagoon inlet position and tidal incursion plays pivotal role for the migration of marine species. Many research works such as Mahapatro et al., (2012), Mahapatro et al., (2016), Mahapatro et al., (2015a & 2015b), Mahapatro et al., (2018a & 2018b), Mahapatro et al., (2019), Mahapatro et al., (2020a & 2020b), Mahapatro et al. (2021) have recorded the newly occurring marine fauna in Chilika lake after opening of the lagoon inlet. Further studies suggested that most of the marine species have migrated from Bay of Bengal to the Chilika Lake due to the opening of lake inlets during tidal incursion. From the images of Figure 4 J, K & L, it has been observed the gradual disintegration of an exposed starfish due to heavy rainfall in the intertidal sediment. Later on the disintegrated body parts of starfish was fragmented even more and carried away by the water current. This finding reflects the negative impact of tropical rainfall on marine macrobenthos community structure and mortality due to cyclonic storms (Harmelin-Vivien, 1994).

The NMDS plot calculated for month and sector can be viewed from Figure 5 (a & b). From the Figure 5 (a) we can see the heterogeneous grouping among the months affected by the cyclone Titli & Fani. However, Figure 5 (b) revealed that the population density and biomass of four sectors showed major differences between northern sector and outer channel area. The NMDS study further revealed that the entire lake acts as three different units (Mahapatro, 2017) during tropical cyclone condition. First the fresh water province (northern sector), second is the marine province (outer channel area) and third one is the brackish water unit (central and southern sector).

4. Conclusion

Present study exhibit group specific resilience in the benthic marine fauna to tropical cyclone induced natural turbulences in Chilika Lake. Outer channel area of the lake exhibited higher species diversity value. Heavy rainfall acted negatively to some marine benthic invertebrate such as starfish in the intertidal region. Tropical cyclone is triggering the temporal and spatial heterogeneity on the quantitative aspects of macrobenthic fauna. It is likely that the strong cyclone generated waves and current in the Bay of Bengal have supported the synchronized migration access of marine macrobenthic community into the Chilika through the lake inlet. However, a long term study is required on priority basis to substantiate the findings.

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Table 1. *Sectoral distribution of marine species in Chilika Lake.*

Serial No.	Major macrobenthic groups	Northern Sector (Species)	Central Sector (Species)	Southern Sector (Species)	Outer Channel (Species)
1	Poriferans	1	4	5	6
2	Cnidarian	1	5	7	8
3	Polychaeta	20	36	35	39
4	Benthic Crustaceans	15	29	28	29
5	Bivalves	12	29	37	40
6	Gastropod	18	32	35	43
7	Echinoderms	0	0	1	8
8	Benthic/ demersal fishes	12	20	36	72
9	Miscellaneous unidentified	8	19	29	52
	Total number	**87**	**174**	**213**	**297**

Table 2. *Secotral and monthly variation of Shannon Winner Diversity index of Chilika Lake.*

Month/Sector	Northern sector	Central Sector	Southern sector	Outer channel	Overall
October.2018	1.4	1.92	1.68	2.15	1.79
November.2018	1.17	2.35	2.01	2.69	2.07
May.2019	1.2	1.12	1.85	2.25	1.61
June.2019	1.5	1.5	2.1	3.03	2.03

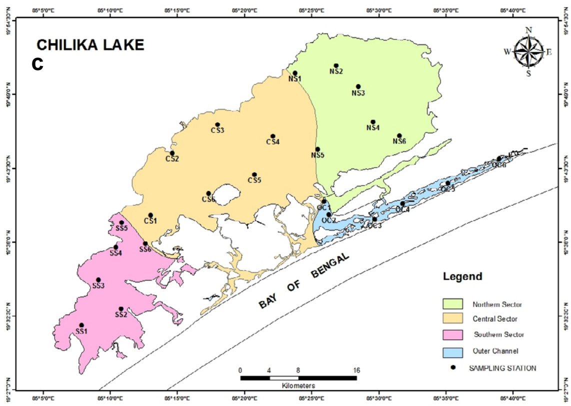
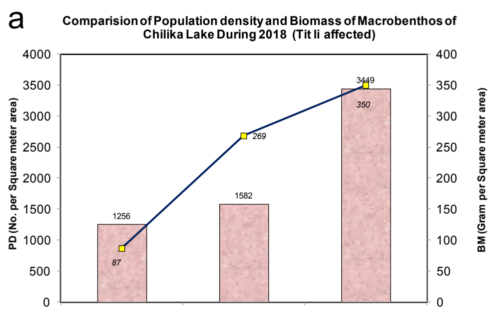


Figure 1. *Image showing the cyclonic track of a) Titli (October 2018) and b) Fani (May 2019) c) sampling map of Chilika Lake showing 24 stations.*



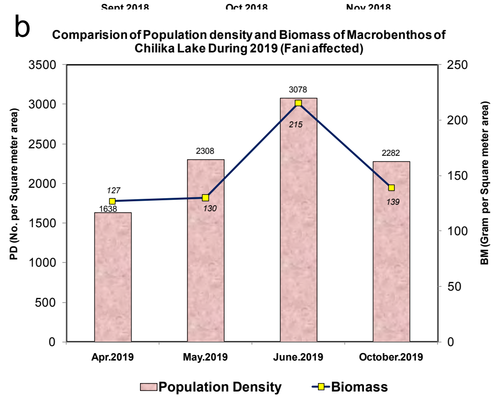


Figure 2. *Image showing population density and biomass of macrobenthos with respect to month: a) 2018; b) 2019.*

Figure 3. *Image showing relative abundance (%) macrobenthic community of Chilika Lake.*

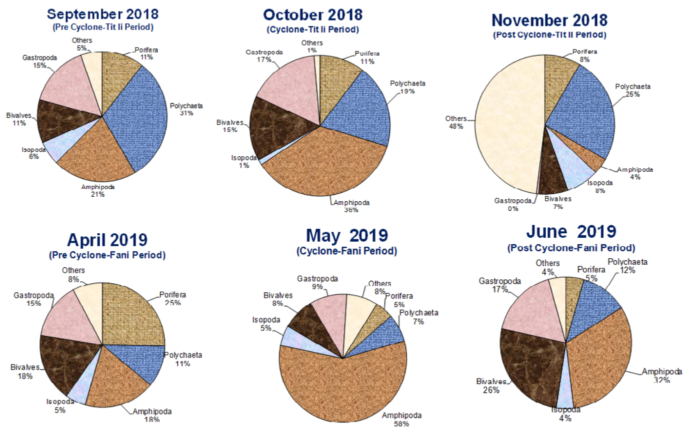
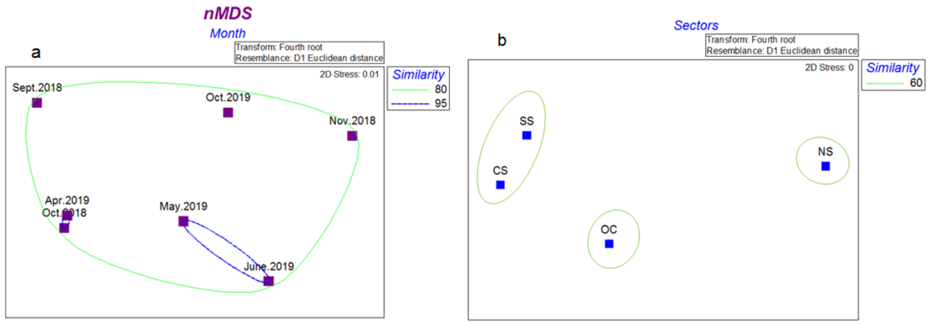


Figure 4. *(A to I) Reef based marine benthic community of Chilika Lake recorded after the tropical cyclone.* Figure 4: *(J, K & L) shows the impact of heavy rainfall on a starfish of Chilika Lake and its sequential disintegration after death.*

Figure 5. *NMDS plot calculated for Month (a) and Sector (b) of Chilika Lake.*



Improving the sediment environment in the lake basin by conservation of the understory of the forest area in the basin of Lake Biwa, Japan

Toshiaki Mizuno[1]

Abstract

In the basin of Lake Biwa, the total forest area is about 2,015 km^2. In recent years, it is considered that the sediment flux volume into Lake Biwa has increased due to the deer having eaten up the understory of the forest since 1999, and the heavy rainfall increase due to climate change in the basin. Moreover, it is considered increase of the sediment flux volume is one of the causes of the adverse situation of endemic species of Lake Biwa such as the Salmonidae. However, there was no study that estimated the sediment flux volume from the forest area in the basin of Lake Biwa. Therefore, we applied the latest existing research results of sediment runoff and analyzed how much the yearly sediment flux changed before and after 1999 as a scenario assessment based on the hypothesis by the simulation analysis. As a result, it was suggested that after 1999, yearly sediment flux may be 2 times higher than that before 1999. Finally we discuss about the imoportance of preserving the understory of the forest area in the basin of the lake as a means of adaptation climate change.

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Keywords: *Deer, forest, scenario simulation, sediment flux, understory coverage rate*

1. Introduction

The area of Lake Biwa is about 670 km^2, and the catchment area is about 3,170 km^2. There are coniferous and hardwood forests throughout the catchment area. The total forest area of Shiga Prefecture, including almost the entire catchment area of Lake Biwa, is about 2,015 km^2(Figure 1).

Lake Biwa is one of the rare ancient lakes in the world and is thought to have existed for 4 million years. Therefore, there is a uniquely evolved freshwater ecosystem, and it is thought that 16 species of endemic types of fish inhabit the Lake Biwa basin ([1]Mizuno 2020). According to research, the endemic type Ayu (*Plecoglossus altivelis altivelis*, Figure 2) have been differentiated for about 100,000 years ([2]Takeshima 2016). It has also been pointed out that Char (*Salvelinus leucomaenis japonicus*, Figure 3) has also undergone a unique evolution in the water system of Lake Biwa ([3]Kiko 2011). Since these Ayu and char spawn in fresh gravel riverbed, these fish are affected by mud sediment flux from the forest area.

Forests in the Lake Biwa basin are composed of artificial forests of coniferous trees (Figure 4) represented by the Japanese cedar and the cypress, and hardwood (broad-leaved) trees (Figure 5) such as oak. Sasa (small dwarf bamboo) and bracken are typical plants in the understory of the forest. The forests in the basin of Lake Biwa are inhabited by Japanese mammals: for example, Japanese black bear (*Ursus thibetanu japonicus*), Japanese macaque (*Macaca fuscata fuscata*), Japanese deer (*Cervus nippon*), Japanese wild boar (*Sus scrofa leucomystax*), Japanese badge (*Meles anakuma*), Japanese red fox (*Vulpes vulpes japonica*) and Japanese raccoon dog (*Nyctereutes viverrinus viverrinus*).

Among them, the increase in the number of Japanese deer inhabitants has become a social problem. With the increase in deer, there are many places where the understory coverage rate of forests has exceeded 60% in the past due to Sasa, etc., but now it is less than 30%. The decrease in understory coverage rate due to the increase in deer is considered to be one of the causes of sediment-related disasters on forest slopes. However, there is no data on changes in the amount of sediment flux that has flowed into Lake Biwa.

Therefore, in this study, the following hypothesis was established: The sediment flux amount volume flowing into Lake Biwa was different before and after 1999, when the deer increased rapidly. The purpose of this study is to clarify the amount of change in the sediment flux flowing into Lake Biwa in the hypothetical scenario. Finally, based on the results, we discuss the conservation of the understory of the forest in the basin for climate change adaptation.

Figure 1. *The map of the basin of Lake Biwa (References: This map is based on the digital map of GSI Maps published by Geospatial Information Authority of Japan).*

Figure 2. *The Lake Biwa Basin endemic type Ayu* (Plecoglossus altivelis altivelis).

Figure 3. *The Lake Biwa Basin endemic type Char (*Salvelinus leucomaenis japonicus; *the Echi River Type).*

Figure 4. *Typical forests of coniferous trees with the understory in the Lake Biwa Basin (Oshinohara, Yasu City).*

Figure 5. *Typical hardwood forest in the Lake Biwa Basin (Suzuka mountains, Higashiomi City).*

2. Materials and methodology

2.1 Study area and period of data

In this study, we targeted at the forest area of the Lake Biwa basin in Japan. Since prefectures are the unit of the statistical data, the statistical data of forest area in Shiga prefecture was used for the simulation model of calculation and analysis.

In this study, we used the forestry statistical data of Shiga prefecture from 1992 to 2020 as basic data for simulation model analysis[4]. According to past deer population research paper[5], it was considered that fewer deer inhabited in the Lake Biwa basin in the period from 1992 to 1999, whereas the deer population increased in the Lake Biwa basin in the period from 1999 to 2020.

2.2 Estimating forest area of each coverage rate caused by deer feeding damage

In the Forestry Statistics Handbook of Shiga Prefecture, the actual area of damage caused by deer forestry is recorded as statistics. In Shiga prefecture, it was 49 ha or less before 1999. However, in 2001, the damaged area exceeded 102 ha and 100 ha, and in 2003 it reached 224 ha and 200 ha. In the forestry industry in Shiga Prefecture, the area damaged by deer was the largest in 2012 at 281 ha. Therefore, in this study, the damage index due to deer was calculated by the following simulation model formula using the numerical values of forestry statistics, assuming that 2012, which accounted for the largest damaged area, was 100%.

$$DDI(\%) = DA / DA2012 \times 100 \quad (1)$$

DDI: Deer damage index for each year (%)
DA: Damaged area in each year
DA2012 : Damaged area in 2012

In 2012, the result of a close examination of the area of the forest understory vegetation by coverage rate due to deer feeding damage in the deciduous broad-leaved forest zone was 14,8550 ha. The area with a coverage of 60% or more was 62,682 ha, 42.2%, the area with a coverage of 30-60% was 46,278 ha, 31.2%, and the area with a coverage of less than 30% was 39,590 ha, 26.7%.

In this study, we assumed that the deer damage index of understory forest was 100% in 2012. Moreover,we assume the forest area ratio with the understory coverage ratio of less 30% was linked to the ratio of the deer damage index of understory. We showed the linkage by the simulation model equation.The area of the forest which coverage rate was less that 30% was estimated by the simulation model equation.

$FA_{less30}\% =$
$TFA\times ((26.7 / 100) \times DDI / 100))$ (2)
$FA_{less30}\%$: Forest area of understory coverage rate less 30% (km^2)
TFA : Total forest area (km^2)
DDI : Deer damage index for each year (%)

Since deer aims at areas with abundant vegetation and cause damage, assuming that the area ratio of 20-60% coverage remains unchanged at 31.2%, the area was estimated by the simulation model equation.

$FA_{30\text{-}60\%} = TFA\times (31.2 / 100)$ (3)
$FA_{30\text{-}60\%}$ Forest area of understory coverage rate of 30-60% (km^2)
TFA : Total forest area(km^2)

Since the forest area with an understory vegetation coverage of more or 60% was the remaining area above, the area was derived by the following formula.

$$FA_{\text{more or } 60\%} = TFA \times (1 - (31.2 / 100) - ((26.7 / 100) \times DDI / 100))) \quad (4)$$

$FA_{\text{more or } 60\%}$: Forest area of understory coverage rate more or 60% (km^2)

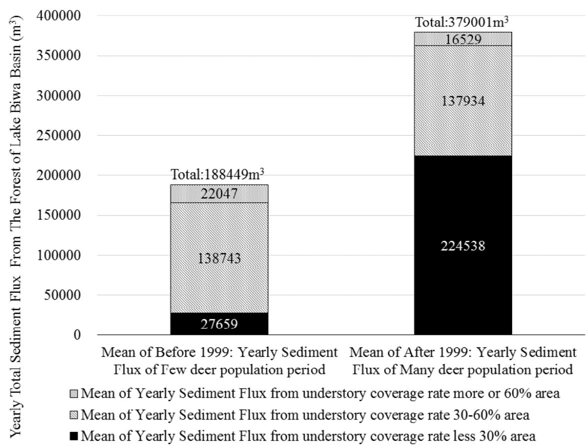
TFA : Total forest area (km^2)

DDI : Deer damage index for each year

2.3 Sediment production rate

According to the sediment production rate research paper by Mizuno et al. (2021[6]). From the Poisson mixed regression analysis results, the annual sediment production per 1.0 (km^2) was 595.9 ($m^3/km^2/year$) when the understory coverage was less the 30% without the random effects of rainfall. Second, when the understory coverage was 30–60%, the annual sediment production per 1.0 (km^2) was 219.2 ($m^3/km^2/year$). Third, when the understory coverage was more than or 60%, the annual sediment production per 1.0 (km^2) was 16.3 ($m^3/km^2/year$).

Figure 6. *Mean of before and after 1999: Yearly total sediment flux from the forest of Lake Biwa Basin.*



2.4 Estimated annual change in the total amount of sediment flux flowing into Lake Biwa from the forest area

The total amount of sediment flux flowing into Lake Biwa was calculated by the following simulation model formula which was summarized (2), (3), (4).

$$TSF= FA_{less30\%}\times 595.9_{(m3/km2/year)} + FA_{30\text{-}60\%}\times 219.2_{(m3/km2/year)} + FA_{more60\%}\times 16.3_{(m3/km2/year)}$$

TSF: Total amount sediment flux flowing into Lake Biwa (m^3)
$FA_{less30\%}$: Forest area of understory coverage rate less 30% (km^2)
$FA_{30\text{-}60\%}$ Forest area of understory coverage rate of 30-60% (km^2)
$FA_{more60\%}$: Forest area of understory coverage rate more or 60% (km^2)

2.5 Aggregation, calculation, charting and statistical analysis

Aggregation, calculation and charting were done in Microsoft Excel. The basic statistical aggregation and the Welch two sample t test was calculated using the R Commander of the statistical software R (version 3.6.1) and R Commander (version 2.7-1).

3. Results

Based on the scenario, the annual sediment flux flowing from the Lake Biwa basin was tabulated for the period before 1999 when only there were few number of deer inhabiting it and the period after 1999 when there were many number of deer inhabiting.

Before 1999, the average annual sediment flux flowing into Lake Biwa was 188,449 m^3, the median was 181,670 m^3, the minimum range was 167,201 m^3, and the maximum range was 215,896 m^3.

After 1999, the average annual sediment flux flowing into Lake Biwa was 379,001 m^3, the median was 394,588 m^3, the minimum range was 254,671 m^3, and the maximum range was 472,329 m^3.

After 1999, the average annual sediment flux flowing into Lake Biwa was 2.01 times that before 1999. As the result of Welch's t-test for the mean before and after 1999, t = -12.151, df = 26.006, p-value = $3.168e^{-12}$ <0.01, and a statistically significant difference can be confirmed at the 1% significance level.

Before 1999, the average annual sediment flux flowing into Lake Biwa from forest areas with less than 30% understory vegetation was 27659 m^3, the median was 20653 m^3, the minimum range was 5738 m^3, and the maximum range was 56124 m^3.

After 1999, the average annual sediment flux flowing into Lake Biwa from forest areas with less than 30% of understory vegetation was 224,538 m^3, the median was 240,764 m^3, the minimum range was 96,131 m^3, and the maximum range was 320,598 m^3.

After 1999, the average annual sediment flux flowing into Lake Biwa from forest areas with less than 30% understory vegetation was 8.12 times than before 1999. As the result of Welch's t-test for the mean before and after 1999, t = -12.185, df = 26.049, p-value = $2.908e^{-12}$ <0.01, and a statistically significant difference can be confirmed at the 1% significance level.

Before 1999, the average annual sediment flux from 30-60% of the forest area to Lake Biwa was 138,743 m^3, the median was 138,774 m^3, the minimum range was 138,537 m^3, and the maximum range was 138,924 m^3.

After 1999, the average annual sediment flux amount of understory vegetation flowing into Lake Biwa from 30-60% of the forest area was 137,934 m^3, the median was 137,861 m^3, the minimum range was 137,588 m^3, and the maximum range was 138,419 m^3.

After 1999, the average annual sediment flux in which understory vegetation flows into Lake Biwa from a forest area of 30-60% was 0.99 times than before 1999. As the result of Welch's t-test before and after 1999 was t = 11.313, df = 22.62, p-value = 8.718e-11 <0.01, and a statistically significant difference was confirmed at the 1% significance level.

Before 1999, the average annual sediment flux flowing into Lake Biwa from forest areas with 60% or more of understory vegetation was 22,047 m^3, the median was 22,244 m^3, the minimum range was 21,235 m^3, and the maximum range was 22,657 m^3.

After 1999, the average annual sediment flux that flows into Lake Biwa from forest areas with 60% or more of understory vegetation was 16,259 m^3, the median was 16,057 m^3, the minimum range was 13,886 m^3, and the maximum range was 20,121 m^3.

After 1999, the average annual sediment flux in which understory vegetation flows into Lake Biwa from a forest area of 60% more or was 0.75 times that before 1999. As the result of Welch's t-test before and after 1999, $t = 12.35$, $df = 26.247$, p-value = 1.928e-12 <0.01, and a statistically significant difference was confirmed at the 1% significance level.

4. Discussion

The annual amount of sediment flux from the forest area flowing into Lake Biwa was twice as different when the deer population were few and when the deer population ware many.

The amount of sediment flux is also related to the inflow of sediment and accompanying nutrients, and as a result, it is considered to be one of the factors that determine the water quality of lakes and the composition of phytoplankton and zooplankton.

Although the inflow of sediment alone does not determine the lake ecosystem, the increase in sediment may contribute to the increase or decrease of relatively low-order small plankton such as cyanobacteria and diatoms. For example, in 2013, 2014, and 2015, the year after 2012 when there was a lot of deer feeding damage in Lake Biwa, in the year when there was about 400,000 m3 of total sediment inflow, the diatom predominance ratio was 40% or more[7] . This percentage was very higher than ordinary year diatom predominance. In view of these cases, it is considered that the production amount of low-order phytoplankton, which is the basis for characterizing the lake ecosystem, and the sediment inflow amount are strongly related.

Therefore, in order to maintain and adapt to the balance of lake ecosystems so far even in the situation of climate change downpour, managing the balancing of understory vegetation in the forest will bring the resilience to keep the freshwater ecosystem of Lake Biwa. And we considered that the resilience will also lead to the sustainability of local fisheries, because lake ecosystems include higher-order organisms such as fish.

5. Conclusion

- The decrease in understory coverage rate due to the increase of deer inhabiting in the Lake Biwa basin is related to the increase in sediment flux flowing into Lake Biwa.
- As a result of the simulation, the amount of yearly sediment flux flowing into Lake Biwa doubled on average annually after 1999 when the number of deer increased compared to before 1999 before the increase of deer.
- As a result of the simulation, after 1999, the amount of yearly sediment flux from the forest understory coverage rate increased about 8 times compared to before 1999.
- It was considered that managing the understory vegetation of forests in the basin may increase the resilience of lake ecosystems due to climate change and enable them to adapt.

Acknowledgements

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- This research was conducted as part of Eco-DRR research project of Research Institute for Humanity and Nature(Project No. 14200103).

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Lake Patzcuaro, Michoacan, Mexico: A threatened Mexican lake

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Abstract

An environmental diagnostic for Lake Patzcuaro is developed, from a simultaneous and systematic review of available literature from 1938 to 2021, and field work for bathymetry, water quality and P'urhepecha community development. The aim is to generate a proposal to solve the major problems of the region by describing the panorama of the ecological deterioration in the basin, the lake and its natural resources, such as the deforestation which [1], during the period from 2001 to 2021, 3.5% of primary humid forest was lost. The water balance indicates a progressive deficit in addition to the extraction of up to 15.0 Mm3/year from groundwater. A historical comparison was on morphometric parameters using bathymetric maps from 1989 [2] and 2019 [3] confirming a decrease in lake surface of 29.95 km^2, maximum length decreased 1.8 km^2, maximum width decreased 2.5 km and the shoreline decreased 23.1 km. These changes associated with water qual-

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ity deterioration, pollution and overfishing have contributed to the fishery collapse. In 1988, a fishing production of 2,523 tons was registered [4], however, this activity has decreased gradually, down to a total production of 54.18 tons in 2005 [5]. Human population growth, incompatible land use, pollution, habitat deterioration and overexploitation are increasing the advance of environmental deterioration of Lake Patzcuaro. Low fish production is now a secondary activity for self-consumption. To achieve sustainable benefits of regional natural resources, a strategic plan is necessary, where social participation is fundamental.

Keywords: *Patzcuaro, Mexican lake, water quality, fishing collapse, eutrophication*

1. Introduction

Lake Patzcuaro, located in the state of Michoacan, is one of the most important aquatic ecosystems in Mexico (Figure 1), because of its location in the Central Plateau, its ecological diversity including native and endemic fish fauna, and the presence of P'urhepecha Indian settlements around its shores [6] [7].

Figure 1. *Location of Lake Patzcuaro, Michoacan, Mexico.*

Table 1. *General features of the Lake Patzcuaro basin.*

General features	
Origin	**Tecto-volcanic**
Basin area	**929.0 km^2**
Climate type	**Sub humid**
Annual rainfall	**972.2 mm**
Annual evaporation	**1,447.40 mm**

The environmental richness of the basin (Table 1) and the diversity in natural resources favored the consolidation of the P'urhepecha civilization. The basin of Lake Patzcuaro includes mainly the lake shore municipalities of Patzcuaro, Quiroga, Erongarícuaro and Tzintzuntzan [8]. Other basin municipalities are Tingambato, Huiramba, Nahuatzen, Coeneo and Salvador Escalante, which together with all the communities register a total of 284,983 inhabitants [9].

Main regional economic activities are tourism, commerce, agriculture and fishing. However, fishing activity has been gradually losing its economic and social role due to the progressive deterioration of the lake, fishing over-exploitation and the negative effects of ecological competition by the introduction of exotic species. These processes have decreased the size of native and endemic populations [10] [11].

Other factors that have contributed to the fishing collapse are water pollution and the increase in tourism that has generated a greater demand for local gastronomy and aquatic transportation services. Therefore, Lake Patzcuaro is in an accelerated process of environmental deterioration due to the effects of the last six decades of environmentally incompatible and insufficient government policies.

Deforestation in the basin of Lake Patzcuaro is exacerbated by the rough topographic relief that has accelerated the progressive soil erosion, decrease in air humidity and water reduction due to the loss of forest cover, especially in those areas of infiltration and recharge of groundwater. This circumstance is even more pronounced due to the effects of climate variability and global warming, which has also been manifested in a reduction in the rainfall regime [12].

Since 1936, different initiatives have been carried out for lake and basin restoration, including decrees, programs, regional forums, government commissions, academic development and social organization oriented to reach agreements for sustainable natural resources management and restoration. However, an integrated strategic plan including social participation is still needed.

2. Materials and methodology

An extensive and systematic documental review from various sources was carried out, including scientific articles, magazines, physical and digital books, databases and institucional pages, which contain data from 1938 to 2021, with the aim of creating a detailed environmental, social and economic diagnostic of basin, lake and natural resources.

Simultaneously, field work was carried out including a bathymetry campaign for updating morphometric parameters. A water balance was estimated using conventional expressions.

Water quality sampling in four lake locations was developed including north basin, central lake, eastern south basin, and western south basin. Water quality index was estimated (WQI) according to [13]. Additionally, twelve P'urhepecha community visits were carried out to evaluate local perception.

3. Results and discussion

3.1 Causes of ecological deterioration

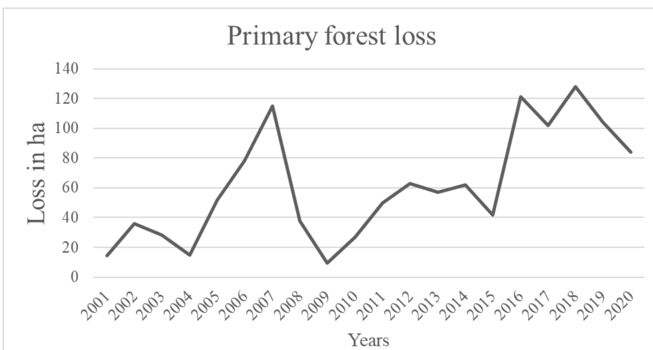
Since prehispanic times the basin of lake Patzcuaro has been under a progressive and severe anthropogenic effect [14]. During the last two centuries these circumstances have been magnified by urban settlements, intensive water quality deterioration, overfishing, and incompatible land use.

a) Deforestation

Most of the terrestrial original lakeshore vegetation has been removed and substituted by agriculture activities [15]. An extended surface of forest coverage has been lost between 1963 to 1990, with a deforestation estimate of 48.2% from the original forest coverage [16]. From 2000 to 2021 the municipalities registered a natural and plantation forest loss of Patzcuaro (3.5%), Quiroga (1.8%), Erongaricuaro (6.7%), and Tzintzuntzan (1.3%) (Figure 2).

According to [17] the forest coverage was estimated at 850 km^2 (91.80%). At present, it is estimated that a maximum forest coverage of 250 km^2 is remaining in the basin. A forest surface of 350 km^2 was transformed for agriculture, horticulture, avocado culture, grassland, urban development, and open sky trash dumps.

Figure 2. *Primary forest loss in the municipalities of Patzcuaro, Quiroga, Erongaricuaro, Tzintzuntzan, Tingambato, Salvador Escalante, Coeneo and Nahuatzen from 2001 to 2021.*



b) Soil downhill erosion

The intense erosion inside the drainage basin is closely associated to human activities that occured since the prehispanic and hispanic period [18]. However, it has been reported evidence of seismic events that occured 25,000-30,000 years ago, which could have also caused changes in the distribution of basin soil stability and lake sedimentation sequences on the island of Jaracuaro located in the South basin where high rates of erosion have been observed [18]. During the last century, change and inappropriate land use has had an increase of up to 85% of erosion [19] loads due to agricultural and livestock activities [20]; reported up to 50 ton/ha/year of soil erosion in the South basin [21].

c) Water balance

The water volume input from rainfall over the lake surface is estimated at 87.47 Mm^3 which is the equivalent to 58.25% of the total volume that enters into the lake. The water input from subsurface infiltration coming from the drainage basin is estimated at 62.45 Mm^3 equivalent to 41.65%.

The annual evaporation is estimated at 130.23 Mm^3 (84.46%), the rate of water extraction by direct pumping and water spring use is equivalent to 23.96 Mm^3 (15.54%). These calculations represent a deficit of 4.20 Mm^3 (2.77%) in the annual water balance. This figure suggests that the lake level decreases an average of 0.046 m per year.

d) Lake morphometry

A comparison of a 30 year period of lake morphometry indicates a substantial reduction in morphometric parameters. Lake surface has lost 29.95 km^2, whereas the shoreline length has reduced up to 23.1 km. Both maximum depth is 1.85 m and median depth is 0.70 m less. Consequently, the lake volume has been reduced in 182.0 Mm^3 equivalent to 28.98% from the total volume estimated in 1989 (Table 2).

Table 2. *Morphometry evolution of Lake Patzcuaro between 1989 and 2021.*

Parameter	1989	2021
Lake surface (A)(km^2)	130	100.05
Shoreline or perimeter (lo) (km)	114	90.90
Median depth (D_{50}) (m)	4.5	3.8
Maximum depth (Dmáx) (m)	12.2	10.35
Lake volume (V)(km^2)	628	446

c) Water quality

The northern part of the lake presents the deepest zone, and is characterized by the use of agricultural land on the shoreline. This zone receives the impact of urban centers, including Quiroga, Santa Fe de La Laguna, Tzintzuntzan and San Jeronimo Purenchencuaro. The water quality is average (63.73 ± 1.81 WQI) between the center (60.33 ± 1.70 WQI) and South zone (68.86 ± 1.16 WQI). The largest amount of discharge comes from Tzintzuntzan, which also has a deficient treatment [16].

The temperature in the lake has increased 3.32 °C in the last 25 years, having a temperature of 18.27°C [15] and [22] (Table 3).

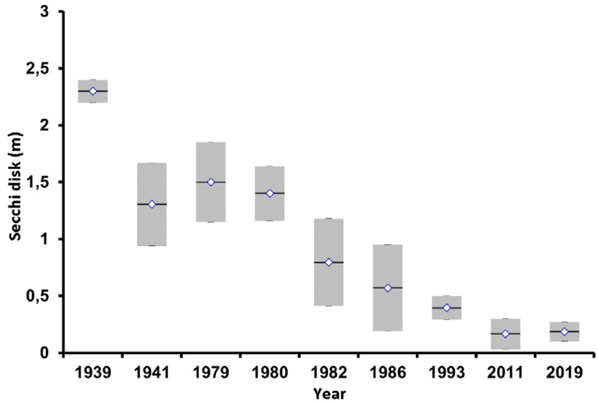
The lake also presents high levels of turbidity due to the presence of terrigenous deposits of volcanic origin, domestic, agricultural and municipal discharge; as well as the accelerated increase in sediments and high levels of inorganic materials of allochthonous origin (Figure 3).

Lake Patzcuaro is identified as an eutrophic aquatic ecosystem particularly in the North and South basin. Some small areas of mesotrophic and even oligotrophic environments are located in the Central basin where water currents occur and underwater springs are present.

Table 3. *Water quality parameters in Lake Patzcuaro.*

Parameter	1989	2019
Temperature (°C)	16.3	19.8
Electric conductivity (μS/cm)	820	928.8
pH	9.3	8.0
Total dissolved solids (mg/L)	572.4	648.3
Total Suspended Solids (mg/L)	21.1	45.3
Orthophosphates (μg/L)	39.2	104.0
Total phosphorus (μg/L)	64.4	171.2
Ammonium (NH_4)	0.022	1.21
Biochemical oxygen demand (mg/L)	10.77	57.3
Chemical oxygen demand (mg/L)	42.50	118.0
Chlorophyll (μg/L)	59.8	73.7

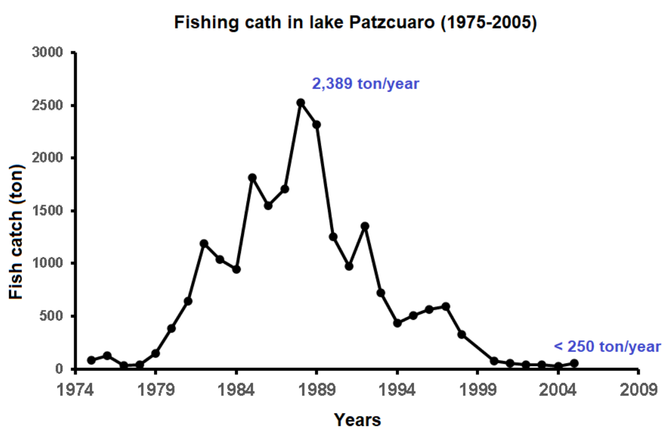
Figure 3. *Secchi disk transparency deterioration in Lake Patzcuaro, Michoacan, Mexico.*



d) Overfishing

Fishing has been traditionally a fundamental activity in Lake Patzcuaro. However, fish catches have been decreasing with time. In 1988 annual fish capture registered was 2,523 ton, whereas in 2015 the maximum capture was 54.2 ton. Therefore the fishery in Lake Patzcuaro is near to collapse. Considering the identity of this activity in the region, social and economic negative effects are expected particularly in P'urhepecha fishing communities (Figure 4).

Figure 4. *Multispecific fishing production (tons) from 1981 to 2005 [5].*



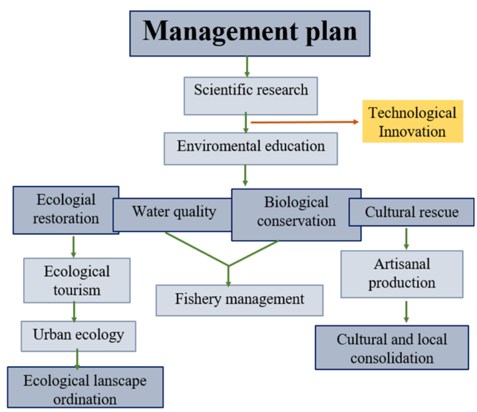
e) Introduction of exotic species

In 1929 the exotic species largemouth bass was introduced (*Micropterus salmoides*) [23]; in the 70's the authorities promoted the introduction of another exotic species as a result of the emergence of commercial aquaculture in the country, such as carp and tilapia. Due to this introduction, natural populations of endemic species of Lake Patzcuaro were reduced by ecological competition. This situation led to the establishment of the reserve of native species on Lake Patzcuaro [10].

4. Conclusion

To approach a successful ecological restoration of Lake Patzcuaro, a strategic plan is proposed in which social participation is fundamental for the rescue and consolidation of regional identity (Figure 5).

Figure 5. *Management plan in Lake Patzcuaro.*



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Lake Prespa (North Macedonia) and its vicinity studied by remote sensing methodology: a clue for its dramatic drop in water level

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Abstract

The Ohrid-Prespa lake system is the oldest and most diverse permanent lake system in Europe, dating from the Pliocene with more than 1Ma of existence. Its smaller component is Lake Macro Prespa (hereafter called Prespa), shared by North Macedonia, Albania, and Greece. Lake Prespa's depth was reported as 14m mean and 48m maximum not long ago. The lake is highly sensitive to external impacts including climate change and has been suffering major water loss over past decades. Lake-level decline of almost 10m was documented between 1950 and 2009 due to restricted precipitation and increased water abstraction for irrigation. This study describes the changes in the surface size of Prespa lake and the vegetation/land use in the surrounding area in the period 1984-2020 using satellite images (remote sensing, Landsat 5 & 8 images by ESA and USGS). The lake lost 18.87 km^2 of surface in this period (6.9% of its size; dropping from 273.38 km^2 to 254.51 km^2). Water loss was greater in the period 1987-1993 and 1998-2004.

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Analysis of Normalized Difference Vegetation Index (NDVI) in the area (app. 4.950 km^2) surrounding Lake Prespa revealed an increase in the mean NDVI values over the period studied (1984-2020) pointing to a general increase in vegetation. Areas with NDVI > 0.13 increased from 78% in 1984 to 86% in 2020, while those with the highest vegetation intensity (NDVI > 0.45) increased by 40%. These changes in vegetation may be related to the water loss of the lake.

Keywords: *Prespa Lake, Macedonia, surface, water level, satellite imaging*

1. Introduction

The Ohrid-Prespa lake system is the oldest and most diverse permanent lake system in Europe, dating from the Pliocene, with more than 1 Ma of existence [1]. Its relevance has been acknowledged, among other nominations, with the declaration of Ohrid-Prespa Transboundary Biosphere Reserve (North Macedonia/Albania, 446.244 ha) by UNESCO in 2014. The lake system is transboundary and composed of Lake Ohrid (shared by N. Macedonia and Albania) and Lake Prespa, which itself contains two lakes: Macro Prespa (Big Prespa, hereafter Prespa, with a surface of 253.6 km^2) shared by N. Macedonia, Greece and Albania; and Micro Prespa (Small Prespa, 47.4 km^2), which is entirely in Greece. These two lakes are linked by a small channel with a sluice that separates them. Between Lake Prespa and Lake Ohrid is Mount Galichica, a karstic massif through which Lake Prespa feeds Lake Ohrid with fresh water (Figure 1). State authorities of the three countries have enforced the protection status of Prespa through national and international legislative means. A large part of the lakes and their catchment basin has been characterized as a National Park (Albania and Greece), Monument of Nature (N. Macedonia) or/and a Wetland of International Importance under the Ramsar Convention (Greece, Albania and N. Macedonia).

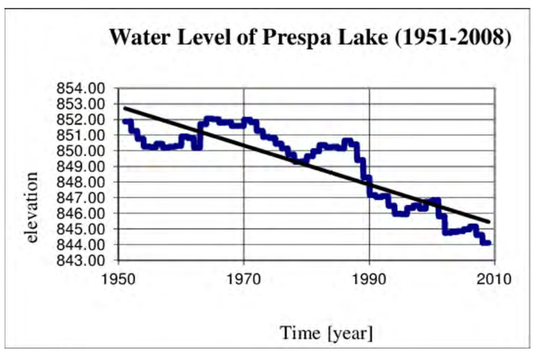
Lake Prespa is a tectonic lake situated at 849 m a.s.l whose exact age is still uncertain but may be even older than Lake Ohrid. It is a relatively shallow lake whose mean and maximum depths were reported as 14 m and

48 m respectively not long ago. The water input of the lake is 16.92 m^3/s, via rivers and catchment runoff (56%), direct precipitation (35%), inflow (9%) from the nearby Lake Micro Prespa and groundwater, whereas the water output is estimated to occur mainly through evaporation (52%), water abstraction for irrigation (2%) and subsurface outflow through the karstic aquifers of Galichica Mountain (46%).

The water level of lake Prespa has been dropping constantly for the last century. For illustration, as depicted in Figure 2, in the period 1951-2008, it declined from 852 m a.s.l to 844 m a.s.l, a dramatic ~8 m in less than 60 years [2]. The water in the lake during dry seasons decreases by 1 cm per day due to combined effects of evaporation and irrigation [3]. The current level is 847 m a.s.l as of September 2021. The causes of this major decline are complex and multiple and are likely a combination of climate change factors (which refers to restricted precipitation, specifically snowfall and higher air

Figure 1. *The Ohrid-Prespa lake system location in Southeast Europe.*

Figure 2: *Water level of Prespa Lake expressed as altitude or elevation above sea level (metres) in the period 1951-2008. Extracted from ref. [2].*



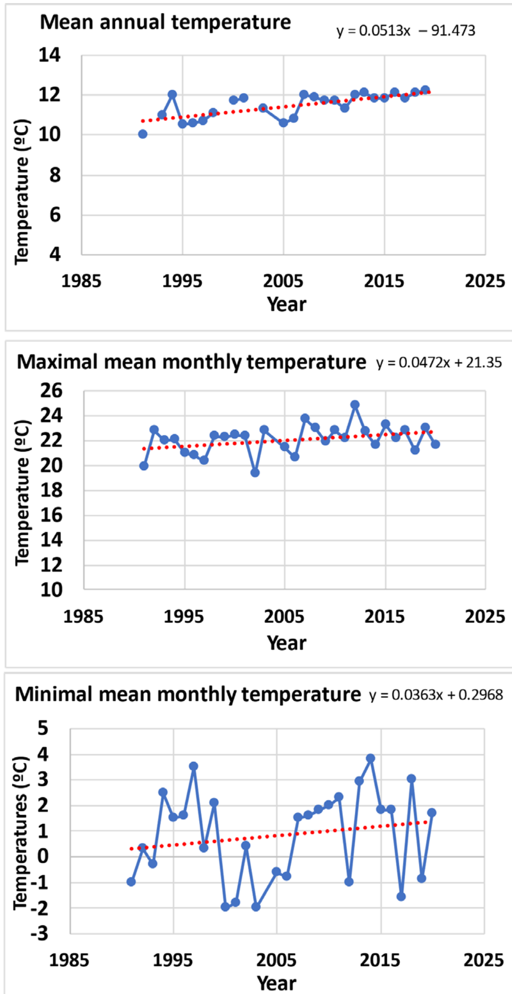
and water t°), diminished water input (rivers), increased water abstraction for irrigation as well as hydrogeological modifications (earthquakes), which enhance the water outflow through the underground karst drainage channels. In an effort to determine the causes of the decline, van der Schriek and Giannakopoulos determined that sustained low lake levels below 847m, following the dramatic water-level fall in 1987/88-1994/95, which was triggered by an extensive drought period, are caused by water abstraction (~72%) and amplified by climate-related inflow decreases (~28%) [4].

In order to evaluate the impact of climate on the lake's water level alterations, we have analyzed data (provided by the National Hydrometeorological Service in N. Macedonia) regarding temperatures and precipitation in the area (specifically in the village Pretor located on the shore, in the northeastern part of the lake). Analysis of the available data from the period 1991-2020 regarding the air temperature revealed fluctuations; however also the presence of an increasing trend in the mean annual temperature, maximal mean monthly temperature, and the minimal mean monthly temperature (Figure 3).

We also assessed the amount of precipitation in this same period and observed that the mean monthly precipitation and the annual precipitation did not decrease; rather there was a tendency to increase. Similarly, there were no major changes in trend of the maximal monthly precipitation; on the contrary, the percentage this value represents in comparison with the total annual precipitation showed a clear decreasing tendency (Figure 4). In other words, the month with the most precipitation each year represented cca 25% of the whole yearly precipitation in the early 1990s, while this figure dropped to 15% in the late 2000s. Exactly how these meteorological figures represent climate change in the area and how they are connected to the drop in the water level Lake Prespa has experienced is unknown and requires further study. Nevertheless, these data seem to support the idea that other causes may be the leading factor in the phenomenon of water loss.

The aim of this study was to describe the changes in i) the surface size of Prespa Lake and ii) the vegetation/land use in the surrounding area in the period 1984-2020.

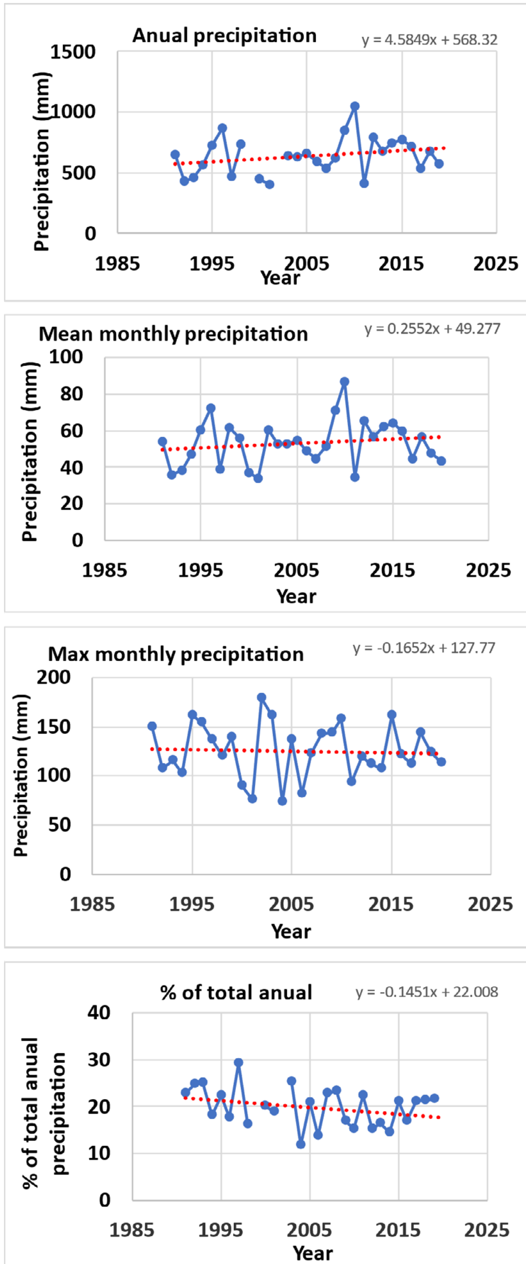
Figure 3. *Air temperature recorded in Pretor, a village on the shore in the northeast part of Lake Prespa in the period from 1991 to 2020. Source: National Hydrometeorological Service of N. Macedonia.*



2. Materials and methodology

We analysed satellite images (remote sensing, Landsat 5 & 8 images by ESA and USGS), obtained from the summer period (June-August). Satellite maps show the density of plant growth and can be used to quantify the amount

Figure 4. *Precipitations recorded in Pretor, a village on the shore in the northeast part of Lake Prespa, in the period from 1991 to 2020. Source: National Hydrometeorological Service of N. Macedonia.*



and type of the vegetation present. One of the most used indices is calculated from multispectral information as a normalized ratio between the reflectance in red and near infrared bands and is called Normalized Difference Vegetation Index (NDVI) [5], whose direct use is to characterize canopy growth or vigor as chlorophyll actively absorbs red and reflects near infrared light. NDVI values range from -1 to 1; negative values approaching -1 correspond to water; values close to zero (-0.1 to 0.1) correspond to barren areas of rock, sand, or snow; moderate values represent shrub and grassland (0.2 to 0.3); high values indicate temperate forests (0.6 to 0.8); while tropical rainforests are approaching 1.

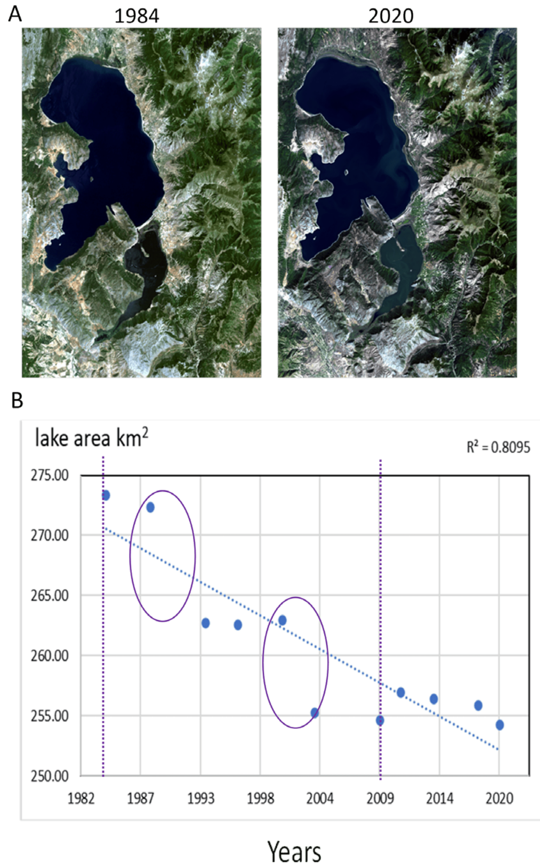
3. Results and discussion

Analysis of the data regarding the surface area of Lake Prespa was performed using satellite images in the period 1984-2020 (Figure 5A). The lake lost 18.87 km^2 of surface in this period, i.e. 6.9% of its size (Figure 5B), dropping from 273.38 km^2 (June 1984) to 254.51 km^2 (July, 2020). The rate of water loss was greater in the period 1987-1993 and 1998-2004 while the surface of the lake has not varied in the last decade. Of note, the two periods in which there was a major decrease in the surface area coincide with the two periods in which other authors reported a major decline in the water levels (Figure2).

NDVI is a measure of greenness calculated from the visible and near-infrared light reflected by vegetation as green vegetation absorbs most of the visible light that hits it and reflects a large portion of the near-infrared light. Analysis of NDVI in the area surrounding Lake Prespa revealed an increase in the mean NDVI values over the period studied 1984-2020 (Figure 6). In the studied area (app. 4.950 km^2, Figure 6B), the vegetated surface (NDVI > 0.13) increased from 78% in 1984 to 86% in 2020. In particular, the area with the highest vegetation intensity (NDVI > 0.45) has increased by 40%. This contributes on the one hand to the retention of runoff in the forest areas and, on the other, to water consumption in the irrigated areas.

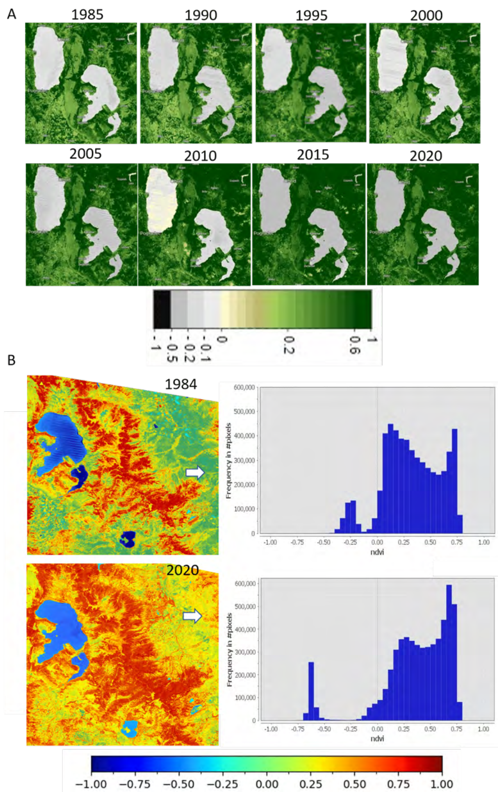
Further studies are needed to understand whether the changes in the amount and type of forests nearby, particularly Mount Baba (on the East

Figure 5. *Changes in the surface area of Lake Prespa. (A) Satellite images from 1984 and 2020. (B) Calculated surface area of the lake over the studied period (1984-2020). The circles show the periods of major loss of water surface.*



side of Lake Prespa) are related to the alterations of the water level of the lake. Similarly, the increase in the agricultural use of the land in the area and particularly in the water basin and catchment need to be studied in detail. The lake's water is used for agricultural purposes in all three neighboring countries. It is estimated that within the Prespa Lake region there are 6,500 ha of agricultural land [3]. Many of the agricultural fields are placed in Prespa's catchment; therefore, pesticides and fertilizers pollute the lake. Since the intensity of the source of pollution is more or less constant, when the amount of water decreases, the concentrations of polluting compounds increase.

Figure 6. *Assessment of the vegetation in the surrounding area. (A) Normalized Difference Vegetation Index (NDVI) in the period 1984-2020. Images were taken in the summer period (June-August) by Landsat-5 (1985-2010) and by Landsat-8 (2015 and 2020). (B) False color images for 1984 and 2020, and histograms showing color-NDVI values.*



4. Conclusion

Lake Prespa has suffered a dramatic water-level drop over the past decades. Remote sensing methodology seems a useful way to study changes regarding lake size and vegetation patterns in the surrounding area. The observed increase in the vegetation may be associated with enhanced irrigation for agricultural use, a factor contributing to the loss of water from the lake. The lake's survival requires urgent measures, strong legislation, and better co-operation among the three countries involved in its management.

Acknowledgements

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Microplastic characterization and concentration in surface waters of lakes Sampaloc and Yambo in San Pablo City, Laguna, Philippines

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Abstract

One of today's emerging environmental issues is the accumulation of plastics in the aquatic environment. Plastic comes in all shapes and sizes, which include microplastics that are less than 5 millimeters in any dimension. This type of plastic is controversial because of its ubiquitousness and persistence in aquatic environments. This comparative study on microplastics in Lake Sampaloc and Lake Yambo in San Pablo City, Laguna, Philippines, was conducted to fill research gaps regarding the occurrence of microplastics in freshwater systems. Lake Sampaloc is a lake with many fish farming structures in an urbanized catchment area while Lake Yambo is a rural lake and an ecotourism site. The microplastic analysis revealed that Lake Sampaloc had a significantly higher mean microplastic concentration (587 n/m^3) than Lake Yambo (449 n/m^3). Results also showed that fibrous, colored, and small-sized (<2 mm) particles were the main features of microplastics detected in surface waters of both lakes.

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In order to identify possible source that contribute to microplastic pollution in the lakes, a Knowledge, Attitudes, and Practices (KAP) survey was conducted on randomly selected residents from the lake catchment areas to describe their KAP on solid waste management (SWM) and the characteristics of their wastes generated. Results showed that respondents near Lake Sampaloc had significantly lower KAP levels on SWM than the respondents near Lake Yambo. Overall, this study is not only relevant in providing baseline data on microplastics but also in communicating salient information for decision-makers of San Pablo City to strengthen environmental policies and educational strategies related to plastic pollution.

Keywords: *Microplastics, Lake Sampaloc, Lake Yambo, solid waste, KAP Survey*

1. Introduction

Earth's ecosystems encompass a wide range of resources, which benefit human society and make survival of all living organisms on our planet possible. However, plastic, which is one of our ingenious discoveries, has become a reason to impair our ecosystems remarkably. The production and use of plastic has increased gradually over the past 75 years, with global production reaching over 300 million tons in 2014 (Plastics Europe, 2016). It indeed makes our modern life convenient but it also poses high health risks to various organisms both in the terrestrial and aquatic ecosystems. Since 1950 up to now, plastic is everywhere and only nine percent of the 6.3 billion tons of plastic waste has been recycled (Bouwman et al., 2018). One of today's emerging environmental issues that we need to be concerned of is the accumulation of plastics in the aquatic environment. Plastic comes in all shapes and sizes, which include microplastics that are less than five millimeters in any dimensions. This type of plastic is controversial because aquatic life and some birds can mistake it for food.

Microplastics can come from a variety of sources including larger plastic debris that degrades into smaller pieces called fragments; microbeads, which are added as exfoliants to health and beauty products; and synthetic fibers which can be produced from chemical and mechanical stresses that fabrics undergo during a washing process, for instance, in a laundry machine (National Ocean Service, 2018; De Falco, 2019). These tiny pieces of plastic in the form of fragments, microbeads, or fibers, once they made their way into marine and freshwater ecosystems, can pose a potential threat to all aquatic life forms, both wild caught and farmed (Royte, 2018). There is increasing evidence that microplastics may be transported through the food chain from prey to predator leading to possible bioaccumulation of toxins or exposure to other associated hazardous substances (Van der Meulen et al., 2014). Microplastics are hypothesized to affect the physiological functioning of aquatic organisms that consume them by decreasing their growth rates; prolonging their developmental periods at sizes most vulnerable to predation; depleting their energy reserves; and lowering their reproductive output and survivorship, either as a result of simply taking up space that could otherwise be occupied by food or through leaching of accumulated organic pollutants or plasticizers into their stomach lining (McCauley & Bjorndal, 1999; Bakir et al., 2014; Wright et al., 2013). Although there is currently limited evidence of transfer of chemicals from ingested plastics into tissues of organisms (Tanaka et al., 2013), still, its effect to aquatic food chain could pose potential ecological and human health risks which may then result in socio-economic costs.

As an emerging field of research, there is still much we do not know about microplastics. Research on microplastics has focused so far on marine ecosystems, and there are immense gaps of knowledge regarding freshwater microplastics (Wagner et al., 2014). According to previous studies, the Philippines is one of the highest contributors of plastics to the marine environment (Jambeck et al., 2015; Lebreton et al., 2017). Thus, the Philippines has started ventures in studying microplastics, although, still, there are no accurate figures on the extent of the problem of microplastics in the country, particularly in its freshwater environment (Tutton, 2018). Hence, a microplastic comparative study between Lake Sampaloc and Lake Yambo is of significant importance.

Lake Sampaloc is the largest of the seven crater lakes in San Pablo City Laguna, which serves as a source of livelihood for fishermen as well as a recreational site for locals and tourists. Meanwhile, Lake Yambo, also known as Pandin's twin lake, sits in between the city of San Pablo and the municipality of Nagcarlan. Same with Lake Pandin, they are the most pristine of the seven lakes in terms of its water quality (Laguna Lake Development Authority [LLDA], 2002-2005), which makes it an ecotourism site, suitable for recreational activities such as swimming, outings, and picnics (San Pablo City, 2015-2025).

Furthermore, this study is one of the pioneering researches to conduct baseline assessment of microplastics in the Philippines, and the first to describe the presence of microplastics in surface waters of Lake Sampaloc, an urbanized lake with many fish farming structures, and Lake Yambo, a rural lake and an ecotourism site, which could then add to the increasing body of knowledge regarding the occurrence and distribution of microplastics in freshwater ecosystems in the Philippines.

2. Materials and methodology

2.1 Water sampling

One-time water sampling using the volume-reduced method was conducted in the surface of Lake Sampaloc and Lake Yambo on November 2019 to provide a baseline information on the microplastic pollution level in the lakes. Volume-reduced samples refer to samples usually obtained by filtering large volumes of water with a net or sieve (Hidalgo-Ruz et al., 2012). Surface water samples were collected from the thirteen (13) sampling stations, purposively selected within each lake, of which ten (10) are located in the lake's littoral section and the rest are in its limnetic zone. The littoral sampling sites were grouped into two categories – near residence and near vegetation. Specifically, only those sites near natural vegetation on the lakeshore were considered and selected in this study. Three (3) replicates of 10 L surface water samples were collected from each station using a metal bucket and were filtered through a stainless sieve with a mesh size of 63 μm. The residues were rinsed into a glass jar using 250 mL distilled water and were preserved in the laboratory refrigerator prior to microplastic isolation. Thirty-nine (39) replicates of volume-reduced surface water samples were collected from each lake.

2.2 Microplastic analysis

2.2.1 Microplastic isolation

The method of isolating microplastics in the lakes' surface waters was adapted and modified from the protocol prescribed by Wang et al. (2018). In the laboratory, all the water samples were pre-treated with 20 mL of 30% hydrogen peroxide at room temperature for 12 to 48 hours in order to oxidize natural organic material in the sample. The addition of another 20 mL of 30% hydrogen peroxide was repeated until no natural organic material was visible. Afterwards, the solution was filtered through a 1.2 μm glass microfiber filter paper (GF/C, 47 mm ø, Whatman) on a filter funnel holder using a vacuum pump. In this study, other suspended inorganic particles such as minerals and decaying organic matter were not filtered during the microplastic isolation stage. Lastly, the filter paper was placed in a glass petri dish, using forceps, and then was oven dried at 40 °C for 24 hours to get ready for the microscopic examination.

2.2.2 Microplastic optical examination

After degrading the organic matter of each sample and separating the microplastics from it, quantification and identification of the possible isolated microplastics were employed. The filter papers were put in glass petridishes using steel forceps, and were subjected for visual inspection using an Olympus stereomicroscope with 10x magnification. Microplastic samples in filter paper were photographed, documented, counted, measured for maximum length, and physically classified based on a standard set by Hidalgo-Ruz et al. (2012). Particles detected to exceed 5 mm in any dimension were not counted as microplastics.

Microplastics were classified into six classes based on their sizes: class 1 (60-333 μm or 0.06-0.33 mm), class 2 (334-1000 μm or 0.34-1.00 mm), class 3 (1001-2000 μm or 1.01-2.00 mm), class 4 (2001-3000 μm or 2.01-3.00 mm), class 5 (3001-4000 μm or 3.01-4.00 mm), and class 6 (4001-5000 μm or 4.01-5.00 mm). According to their shapes, the detected microplastics were classified into six types: fragment, fiber, filament, film, foam, and microbead. In terms of color, all the observed colors of microplastics were documented.

2.3 Precautionary measures

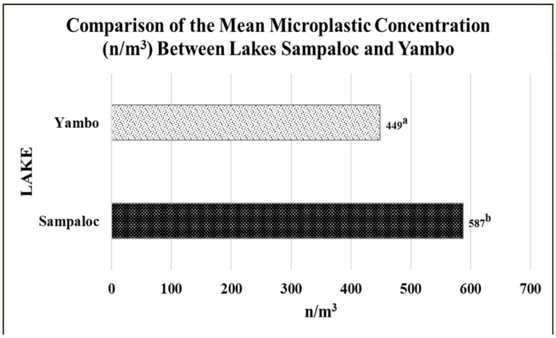
All precautions were taken into consideration such as the use of materials made of glass or metal instead of plastic; use of laboratory coats and nitrile gloves instead of synthetic clothes; and use of clean laboratory equipment and workplace at all times from the process of field sampling to laboratory analysis to prevent bias or contamination. Furthermore, all the glasswares used for data collection and sample preparation were pre-cleaned and rinsed with 2% citric acid solution to eliminate organic residue contaminations.

2.4 Household survey

A Knowledge, Attitudes, and Practices (KAP) survey is a kind of household survey used primarily to collect data on what is known, believed and done in relation to a particular topic (Zahedi et al., 2014). In this study, a KAP questionnaire was constructed, pre-tested, and employed to the residents living near or around the studied lakes in September 2019. Three hundred seventy-six (376) respondents are residents from the five barangays surrounding Lake Sampaloc, while ninety-four (94) are from Barangay Sulsuguin since it is the barangay closest to Lake Yambo. The total number of respondents was computed using Cochran's Formula and was equally divided per barangay through proportionate sampling.

The purpose of this survey is to determine the residents' knowledge, attitudes, and practices (KAP) on solid waste management. Subsequently, this study could lead to a better understanding of why small lakes like Lakes Sampaloc and Yambo are continuously being polluted, and what are the needed practical solutions to combat environmental problems like plastic pollution, in particular.

Figure 1. *Comparison of the mean microplastic concentration between Lake Sampaloc and Yambo.*



Note: Means with different letters are significantly different at $p<0.05$; and n/m^3 means number of plastic items or particles per cubic meter of water.

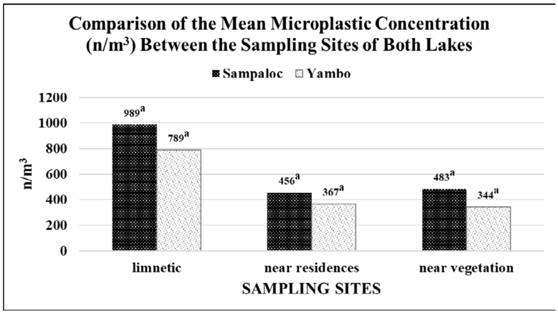
3. Results and discussion

3.1 Microplastic analysis

The microplastic analysis mainly consists of two steps: First, the isolation or extraction and second, the optical examination of microplastics under a stereomicroscope (NOAA, 2015-2017). In the microplastic isolation step, it was revealed that Lake Sampaloc had significantly higher mean concentration of microplastics (587 n/m^3) than Lake Yambo (449 n/m^3) (Figure 1).

Meanwhile, the results showed that there were no statistically significant differences between the microplastic concentrations of the sampling sites in both lakes as shown in the same letters above the bars (Figure 2). This implies that, although the sampling stations are different from each other in terms of geographic locations and conditions, the microplastic concentrations observed were still somehow the same. It also showed that among the sampling stations, both the limnetic regions of the studied lakes had the highest microplastic concentration investigated. Interestingly, microplastics were observed to be low in the sites near houses, which implies that abundance and distribution of microplastics are not just mainly determined by anthropogenic factors but by environmental factors as well (Veerasingam et al., 2016; Dris et al., 2018; Kim et al., 2015).

Figure 2. *Comparison of the mean microplastic concentration between the sampling sites of both lakes.*



Note: Means with different letters are significantly different at $p<0.05$; and n/m^3 means number of plastic items or particles per cubic meter of water.

These environmental factors include infiltration, runoff, river discharge, ocean currents, wind action, cyclones, turbulence, tides, wave current, hydrodynamics, plastic density, microplastic size and shape, and dispersion or movement of animals (Mehra et al., 2020). Despite the fast development of microplastic research and its growing number of results, our understanding of its pathways, fate, and distribution is still limited (Lusher, 2015; Kanhai et al., 2020).

In terms of size, results showed that most of the microplastics detected in both Lake Sampaloc and Lake Yambo are within 1-2 mm, followed by 2-3 mm (Figure 3 & 4). The presence of microplastics having smaller sizes of less than 2 mm suggests that in the lakes' surface waters, fragmentation of larger plastics may have been happening for a long time already. Microplastics having the size of <2000 μm or 2 mm share a similar size with the zooplankton, implying a high possibility of unintentional ingestion by lake organisms (NOAA, 2015-2017).

In terms of shapes, fibers were the majority of microplastics observed in both of the studied lakes (Figure 5 & 6). Consistent with many studies, fibers were the most common and abundant microplastic type observed in aquatic environment (Thompson et al., 2004; Mason et al., 2016; Sutton et al., 2016; Claessens et al., 2011; Stolte et al., 2015). Films and filaments were also present in surface waters of Lakes Sampaloc and Yambo (Figures 5 & 6).

Figure 3. *Comparison of the microplastic concentration (%) in terms of size among the sampling sites of Lake Sampaloc.*

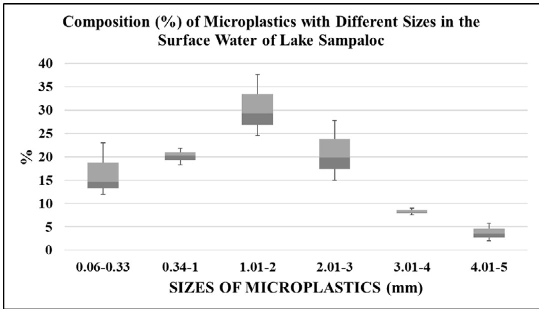


Figure 4. *Comparison of the microplastic concentration (%) in terms of size among the sampling sites of Lake Yambo.*

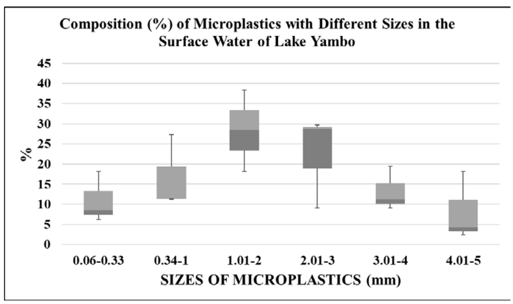


Figure 5. *Comparison of the microplastic concentration (%) in terms of shape among sampling sites of Lake Sampaloc.*

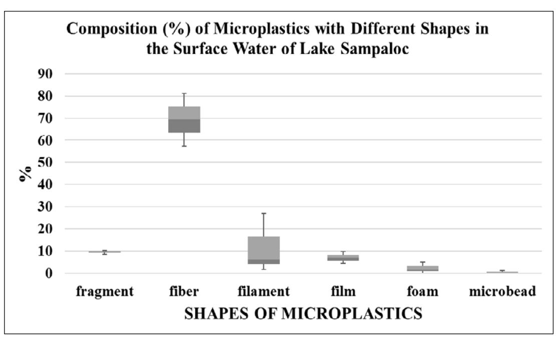
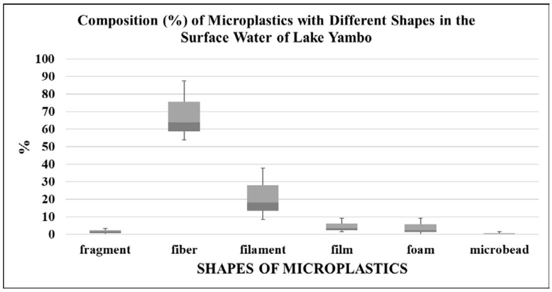


Figure 6. *Comparison of the microplastic concentration (%) in terms of shape among the sampling sites of Lake Yambo*



In terms of color, dominance of transparent, blue, blue and white, and black items can be associated with the prosperity of fishery and aquaculture sectors in both lakes, especially in Lake Sampaloc (Figures 7 & 8). Further, this conforms that fishery activities are potential sources of microplastic pollution in the lakes as fishing nets and ropes are usually transparent, black, or blue in color. The presence of colored microplastics indicates that they most likely came from fragmentation of colored larger plastic items. Aquatic organisms can accidentally ingest microplastics as these small-sized colored plastic particles mimic the color of their prey or food particles (NOAA, 2015-2017; Wright et al., 2013).

Figure 7. *Comparison of the microplastic concentration (%) in terms of color among the sampling sites of Lake Sampaloc.*

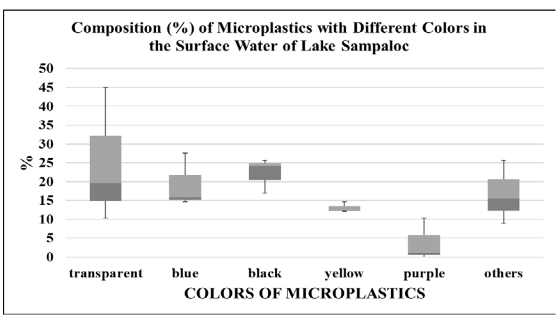


Figure 8. *Comparison of the microplastic concentration (%) in terms of color among the sampling sites of Lake Yambo.*

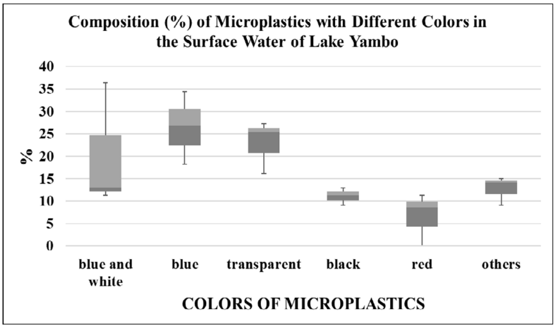
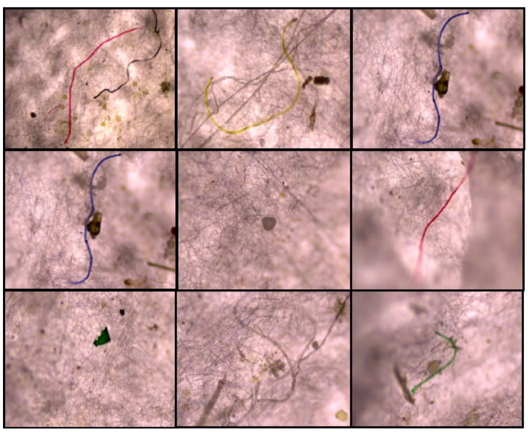


Figure 9 shows some of the typical images of microplastics with different colors, shapes, and sizes observed in surface waters of Lakes Sampaloc and Yambo under a stereomicroscope.

Figure 9. *Sample photographs of microplastics observed in lakes Sampaloc and Yambo.*



3.2 Household survey

A household survey was employed to determine the KAP (knowledge, attitudes, and practices) on solid waste management (SWM) of the residents surrounding the studied lakes. Results revealed that between the two lakes, the rank sum scores of Lake Yambo in all the KAP indicators were higher than the rank sum scores of Lake Sampaloc, indicating that respondents in Lake Yambo have higher knowledge, attitudes, practices and over-all KAP levels on SWM than the respondents in Lake Sampaloc (Table 1).

Results implied that despite the high economic status and educational attainment of the people living near cities like San Pablo, where Lake Sampaloc is directly located; the residents can still have lower environmental awareness, attitudes, and practices. Perhaps, the main reason why residents of Lake Yambo were observed to have higher KAP on SWM, on the other hand, is their dedicated involvement in promoting sustainable tourism since Lake Yambo is a source of livelihood for them and they benefit from taking care of it as well. More so, the residents are being incentivized when they collect their waste and bring them to the nearest material recovery facility (MRF).

4. Conclusion

The microplastic analysis revealed that Lake Sampaloc had a significantly higher mean microplastic concentration (587 n/m^3) than Lake Yambo (449 n/m^3), indicating that fishery activity and tourism could be important sources of microplastics. Results also showed that fibrous, colored, and small-sized (<2 mm) particles were the main features detected in surface waters of both lakes. Interestingly, respondents from Lake Yambo were found to have higher levels of knowledge, attitudes, and practices on solid waste management than those from Lake Sampaloc.

Overall, this study is not only relevant in providing baseline data on microplastics, but also in communicating salient information for decision makers of San Pablo to strengthen environmental policies and educational strategies related to plastic pollution.

Acknowledgements

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Molecular identification of fungal isolates for wastewater treatment

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Abstract

Currently, for the removal of polluting dyes from the textile industry, physicochemical treatments are being applied, which are highly efficient, but it has been observed that they have a negative impact on the environment, in addition to being very expensive. Therefore, in this work we focus on biological treatments using ligninolytic fungi, which have been reported to be efficient dye degraders. Initially 5 strains of fungi were collected from the Lacandon jungle, located in Chiapas, these strains were provisionally named as: CA, CH, GR, PS, PO, which were subjected to an isolation and purification process in YPG and PDA culture media. In order to molecularly identify these strains, their genomic DNA was extracted to amplify their 18S ribosomal genes.

Finally, when performing the analysis of the nucleotide sequences, the following genera were identified: Hypocrea, Trichoderma, Pycnoporus and Pleurotus. These isolated fungi have the particularity of being ligninolytic. It has been reported that this type of fungi produces enzymes that have the

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ability to eliminate, oxidize, absorb and/or modify industrial dyes, therefore, they have a high potential to be used in wastewater treatment, especially those generated by the textile industry.

Keywords: *Polluting dyes, ligninolytic, fungi*

1. Introduction

The textile industry is one of the ten main activities that produce toxic waste, where the aquifer is the final destination [1], causing fluctuations in parameters, such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), pH, color and salinity [2]. Additionally, these compounds are bioaccumulative [2], which causes an alteration in their chemical structures and give rise to the formation of mainly carcinogenic by-products [3].

Every year, around the world, several million tons of synthetic dyes are manufactured, such as azoic, cationic, anionic, vat, dispersive, reactive and indigoid dyes [4]. The main objective of these dyes is to obtain a longer duration of color on textiles.

However, being very varied and complex structures, they turn out to be highly resistant to the action of chemical agents and not very biodegradable [5][6].

Various physical and chemical wastewater treatment methods have been applied to treat textile effluents to meet regulatory discharge limits. However, it turns out to be unfeasible due to the constant energy demand, component complexity, high investment and maintenance costs [7].

Due to the above, research has chosen to focus on biological methods such as the use of microorganisms for the degradation and discoloration of waters that have these dyes. This technique is known as bioremediation. It is an attractive technique since it respects the environment as it is not generating toxic by-products, the operating costs are low, and they consume less water compared to several conventional methods [7][8].

The efficiency of discoloration by microorganisms is related to adaptability and enzymatic activity of the selected microorganisms. Among the microorganisms capable of discoloring a wide range of dyes we find bacteria, fungi, yeasts, actinomycetes and algae [9].

White rot fungi are used for the treatment of textile effluents because they produce different enzymes that are capable of oxidizing the aromatic rings of dyes, such enzymes are mainly: laccases, manganese-peroxidases, peroxidases and lignin-peroxidase. This type of discoloration has been studied in several fungi such as: *Trametes versicolor, Trametes modesta, Sclerotium roysii, Pleurotus ostreatus*, among others [10][11].

2. Materials and methodology

The main stages of this methodology are shown in Figure 1.

1. Collection of samples

The ligninolytic fungi used in this project were isolated from the stems of trees in the rotting stage, this sample collection was carried out in the Montes Azules Natural Park of the Lacandon jungle, located in Chiapas (Latitude: 16.8333; Longitude: -91.5).

2. Isolation of fungi and growth in solid culture medium

Initially, the fungi were isolated by means of successive inoculation in PDA culture medium pH 5, which were left incubating at 28 ºC until the mycelium completely covered the box (10-15 days).

3. Kinetics of growth in solid medium

The kinetics of the fungi was carried out by means of the radial measurement of the growth of the fungus mycelium.

4. DNA extraction

Genomic DNA was extracted by CTAB method [12] from pure cultures of fungal strains provisionally named: PO, CH, GR, PS and CA.

The fungi were isolated from the stems of trees. Later these fungal isolates were cultured on potato dextrose agar medium (Difco). The plates were incubated at 28 °C for 96 hrs. The mycelium from pure fungal colonies was used for DNA isolation.

a) **Sample grinding**. Lyophilized mycelium was ground in a mortar with a pestle previously frozen using liquid nitrogen up to obtain a fine powder. This process takes only a few minutes per sample.

b) **CTAB precipitation**. 0.5 ml of extraction buffer (1% w/v CTAB; 1M NaCl; 100 mM Tris; 20 mM EDTA; 1% w/v polyvinyl polypyrolidone, PVPP) were added to the ground material (100mg). The buffer was prewarmed before addition to avoid CTAB precipitation. The tubes were mixed by inverting them three times and then heated in a water bath for 20 min at 70 °C before adding one volume of chloroform: isoamyl alcohol (24:1 v/v). The resulting complex was mixed by inverting the tube and centrifuged for 6 min at 9000 rpm at room temperature. The upper aqueous phase was rescued in a new tube and the rest was eliminated. Two volumes of precipitation buffer (1% w/v CTAB; 50 mM Tris-HC1; 10 mM EDTA; 40 mM NaCl) were added to the supernatant and mixed well by inversion for 2 min. The mixture was centrifuged for 15 min at 13000 g at room temperature and the pellet was collected.

c) **Alcohol precipitation**. The pellet was resuspended in 350 μl of 1.2 M NaCl, to which one volume of chloroform: Isoamyl alcohol (24:1) was added. This was mixed vigorously and centrifuged for 5 min at 9000 rpm at room temperature. The upper phase was removed to a new tube and 0.5 volume of isopropanol was added. This was mixed by inversion and the tube was placed at -20 °C for 60 min. The final pellet was collected by centrifugation for 15 min at 10000 rpm at 4 °C. 2.5 μl of 10mg.m1^{-1} RNAase A, can be added to the sample and incubated at 37 °C for 45 min.

d) **Wash of pellet**. The final pellet was washed with 0.5 ml of 70% ethanol and recollected by centrifugation for 4 min at 10 000 at room temperature. The pellet was dried at 50 °C in thermomixer prior to resuspension in TE buffer (10 mM Tris pH 7.4, 1 mM EDTA). Extractions from 100 mg starting material were resuspended in 40-50 μl TE [12]. The purity and concentration of the DNA was evaluated by Spectrophotometer (Beckman). Finally, all DNA samples were kept at -20 °C and subsequently evaluated by polymerase chain reaction testing [13].

e) **Polymerase Chain Reaction (PCR).** For the molecular identification of the fungi of this project, the technique called PCR was applied, for which the NS1 and NS8 primers that amplify the 18S ribosomal genes were used [6]. The purification of the PCR products was carried out with GE Healthcare® kit: GFX PCR DNA and Gel Band Purification, based on the supplier's instructions.

f) **DNA sequencing.** All purified PCR products were sequenced at the National Laboratory of Agricultural, Medical, and Environmental Biotechnology (IPICYT-Mexico) using the applied biosystems brand sequencer, capillary model 3500, which applies the sanger method. Finally, the sequences were compared to those in the National Biotechnology Information Center (NCBI) database using the BLASTn algorithm (the basic local alignment search tool). This application is available on the NCBI website. The evaluation of the electropherograms and the alignments of the plus and minus chains was carried out. Multiple alignments of the sequences of the strain with other fungal species were carried out using the CLUSTAL X program [14].

Figure 1. *General scheme for the molecular identification of fungi.*

3. Results and discussion

The fungal strains were collected to determine their biotechnological potential in industrial wastewater treatment, specifically in colored water from the textile industry. To identify the strains used, the following codes were placed: CA, CH, GR, PS and PO (Figure 2).

Figure 3 shows the growth of the isolated fungi in PDA medium. After 4 days of growth, it can be seen that 2 of them have conidia (CH and CA).

Figure 2. *Fungy collected (from left to right) CA, CH, GR, PS and PO.*

Figure 3. *Isolated fungal strains (duplicate samples from left to right): PO, PS, CH, CA and GR.*

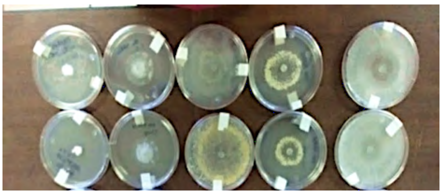


Figure 4. *Radius growth of strains: PO, PS, CA, CH, GR, PDA culture medium.*

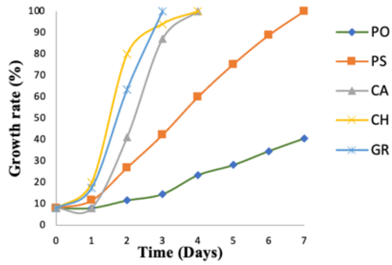
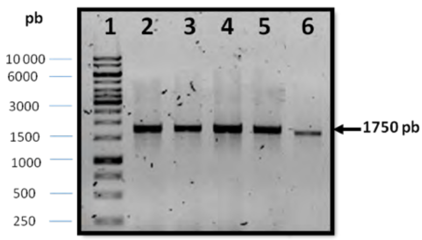


Figure 5. *Amplified 18S Ribosomal genes. Agarose Gel 1%, EtBr added. 1)Control ladder; 2)18S CH; 3)18S PO; 4)18S PS; 5)18S CA; 6)18S GR.*



According to Figure 4, the strains with the highest growth rate were GR and CH, which were able to reach 100% growth in a time of 3 days in the PDA medium.

Genomic DNA was extracted from pure cultures of the fungal strains: PO, CH, GR, PS and CA, to be used later in the PCR amplification of the 18S ribosomal genes with primers NS1 and NS8, which produced an amplicon of approximately 1750 bp (Fig 5)

The amplicons were subsequently purified as mentioned above in the methodology and finally sequenced. When performing the analysis and comparison of the sequences of the fungi of this project, with the sequences of those deposited in the Gene Bank, by means of the BLAST algorithm, the following genera were obtained: *Hypocrea* (CA, GR), *Trichoderma* (CH), *Pycnoporus* (PS) and *Pleurotus* (PO).

4. Conclusion

Based on the results of the sequencing in the molecular identification process, it is concluded that all the identified genera belong to the group of white rot fungi, which are ligninolytic fungi that have the ability to remove, oxidize, absorb and/or modify the dyes used in the textile industry, because they produce large amounts of laccase enzymes.

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Preliminary results of the Lake Catemaco, Mexico: information sheet

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Abstract

Based on documentary research, information is presented from Lake Catemaco and its basin in Mexico. The Lake Catemaco basin has ~251.82 km^2, a volcano (of San Martin) of ~1,764 m.a.s.l. and a lake of ~75 km^2 in the same name size, a volume of ~454 hm^3, and an average depth of ~7 m. Lake Catemaco is the most important body of water in the Los Tuxtlas region and the fifth largest in Mexico, and presents a considerable amount of endemism. The snail, *Pomacea catemacensis,* stands out due to its ecological and socioeconomic importance. In the basin, there are 117 localities with ~36,740 inhabitants, where agriculture is the predominant economic activity; logging is intense; livestock, poultry, and beekeeping are sectors with less presence; industrial activity is scarce and limited to bottled water and soft drinks; and tourism is an emerging activity that is concentrated in Lake Catemaco, for boat trips and excursions, although there are ecotourism projects in adjacent rural communities. The problem in the basin is due to deforestation and changes in land use; in the lake, it is due to overfishing, the introduction of exotic species, contamination by discharges of sewage and urban waste, eutrophication conditions due to erosion, nutrient supply,

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dragging of livestock excrement and agrochemicals from the basin. There are community and governmental proposals to reverse these impacts. However, there is still a lack of management of the basin and its lake to contain these pressures.

Keywords: *Watershed, volcanic lakes, Los Tuxtlas, environmental services, management, natural resources, ecological landscapes, environmental impact, Pomacea catemacensis*

1. Introduction

Lake Catemaco is located in the south center of the State of Veracruz, near the coast of the Gulf of Mexico. Its area is ~75 km², and its quadrangular shape, a volume of 454 hm^3 and about 10 by 8 km (Muñoz-Gamboa 2015; CONAGUA 2017). It is in a sub-basin of ~251.82 km^2 at the head of the Papaloapan river basin, with a volcano (San Martin) of ~1,764 m.a.s.l. (West 1964; Campos y Santiago 2010), and most of its surface is in the municipality of Catemaco, from wich ~21.34 km^2 belong to the municipality of San Pedro Soteapan. There are 117 localities in the subbasin with ~36,740 inhabitants (INEGI, 2020); ~28,655 in the municipal head, where the population density is 144.9 persons/km^2. The main economic activities of the municipality are agriculture and fishing, occupying 29.1% of the economically active population (EAP), secondary activities occupy 15.4% of the EAP, with little presence of industries, and tertiary activities occupy 53.8%, based mainly on local and municipality trade, as well as national tourism, especially from the State of Veracruz itself (Port of Veracruz and Coatzacoalcos) and nearby states like Estado de Mexico, Puebla, Tlaxcala, Tabasco, and also from Mexico City.

The high fish production provided by the lake has decreased due to the overexploitation caused by many registered and unregistered fishers and the bad practices and fishing gear used in a context of corruption and lack of authority. Other factors, such as habitat disturbance and modification, pollutants, and invasive predatory species (Loran-Nuñez et al., 2013; Jimenez-Garcia and Suarez-Morales, 2017), particularly may be playing a role in declining fish and mollusk populations, and possibly other species; however, it is necessary to research such topic.

The high biological and ecological wealth of the watershed and its Lake (Arriaga-Cabrera et al. 2000; Vazquez-Hurtado et al. 2002) suffer a gradual environmental degradation due to population growth, the expansion of urban areas and road infrastructure, especially close to the shores of the Lake, due to touristic and residential land speculation (Lozano-Garcia et al., 2007). Livestock and agricultural activities in the watershed must be ordered, incorporate best practices, be more sustainable, promote and support environmental restoration and conservation, especially in riparian areas and deep slopes.

The synthesis of the File Sheet of the Catemaco Lake Basin aims to provide information and make a wake-up call to know the importance of this lake and its basin. Therefore, this document could help public policies and decision-makers carry out a comprehensive management plan of the Catemaco basin. In this respect, it should incorporate municipal and regional development plans to stop and reverse the environmental degradation of the Basin's natural resources and the environmental services that lead to sustainable development.

2. Materials and methodology

This work is a synthesis of the Information Sheet of the Catemaco Lake Basin, carried out within the Lakes Basin Project of the Mexican Basin Network (REMEXCU, by its acronym in Spanish). A bibliographic review of articles, publications, and government information on Lake Catemaco and its basin was carried out, some at the municipal or regional level. This information was corroborated and contrasted with information in the field based on recent tours and information collected over years of work and studies in the area by the authors, both in socioeconomic, cultural, and biological aspects. We also used geographic information from the National Institute of Statistic and Geography (INEGI, by its acronym in Spanish) and satellite images with which the thematic cartography was elaborated in the basin: relief, geological, soil, climatic, hydrological, morphological, population, and demographic, infrastructure and urban, land use and vegetation. Image classification was performed for the analysis of land use and vegetation cover. There is abundant photographic material of fauna, flora, and landscapes from the ground and photo and video images of flights with uncrewed aerial vehicles (UAV or drones).

3. Description of the Lake Catemaco and its watershed

Lake Catemaco is located in the southern center of the State of Veracruz, near the coast of the Gulf of Mexico. Lake Catemaco is the fifth-largest natural lake in Mexico; its surface area is about ~75 km^2, its shape is quadrangular, about 10 by 8 km (Muñoz-Gamboa 2015; CONAGUA 2017).

Lake Catemaco is a shallow, warm, polymictic tropical lake, exposed to prevailing winds from the north and occasionally from the south. From a mesotrophic state, it is passing to a eutrophic state in recent decades (Torres-Orozco and Zanatta, 1998; Tavera and Castillo, 2000). Its average depth is ~7 m, reaching up to ~22 m (Pérez-Rojas and Torres-Orozco 1992). Its volume is about ~454 hm^3 (Muñoz-Gamboa 2015; CONAGUA 2017), and its perimeter is about ~50 km. The shape of its bucket resembles an elliptical parabola. It has an irregular coastline with some remains of volcanic cones (West 1964; Wilson and León-Estrada 2020). There are six little islands in the lake (Lorán-Nuñez et al., 2013). The monthly average temperature in the region ranges from 18 to 26 °C, and the water temperature of the Lake varies accordingly (Soto 1979).

The Catemaco Lake Sub-basin has an extent of ~251.82 km^2 (Campos y Santiago 2010) and is considered part of the river San Juan Basin, one of the twelve included in the Administrative Hydrological Region number 28, the Papaloapan River Basin (46,517.4 km^2), the second in Mexico for its flow. The height of the watershed ranges from 330 m.a.s.l. at Lake Catemaco to 1,299 m.a.s.l., with a mean height of 495 m ± 139 m of SD m.a.s.l. The mean slope is 7.24% in the Cuetzalapan River, the mainstream, East of the lake. The climate in the watershed is tropical warm humid, with an increase in aridity towards the southwest and more temperate on the higher mountains in the Southeast. The annual rain ranges between 2,000 to 4,500 mm across the basin, with a volume of about ~940 cubic hectometers. The total river length sums ~358.24 km, and the drainage density is categorized as excellent with ~1.89 km/km^2.

Table 1. *Vegetation and soil use in Lake Catemaco watershed. Source: elaborated from SIATL-INEGI.*

Vegetation and soil use	**Area** (km^2) (%)
Secondary vegetation of the high evergreen forest	14.19(6%)
Evergreen high forest	4.11(2%)
Built urban	4.16 (2%)
Induced grassland	129.39 (52%)
Annual seasonal agriculture	15.52 (6%)
Permanent seasonal agriculture	8.33 (3%)
Water bodies	73.93 (29%)

Figure 1. *Lake Catemaco Basin: rivers and Sentinel 2 image from May 2nd, 2020.*

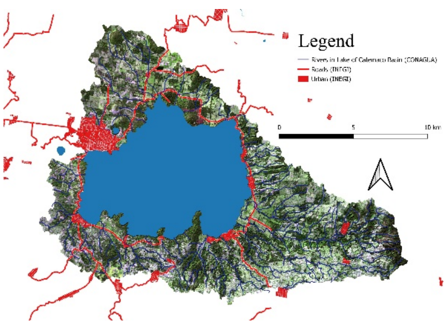
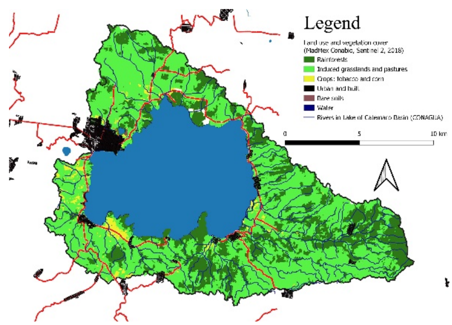


Figure 2. *Classified vegetation and soil use in Lake Catemaco Basin. Source: image Sentinel 2 (CONABIO 2018).*



4. Management of the lake catemaco and its watershed

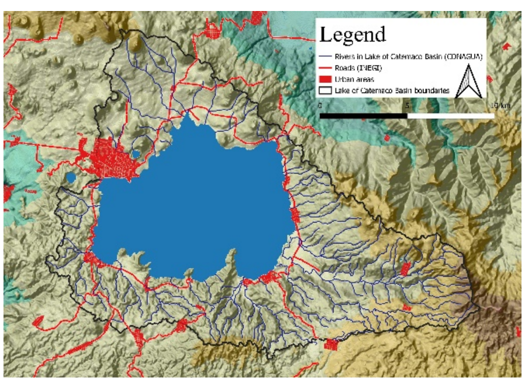
In past decades, Lake Catemaco was characterized by its high productivity. It's a lake rich in biodiversity and endemic species. There are 15 species of fish registered, nine of them endemic (Miller and van Conner, 1997). Commercial fishing in the lake is multispecific and based on 19 species. Three are endemic, two species of tilapia are introduced, and two cichlid species have been transplanted in the lake (Lorán-Núñez et al., 2013). The rest of the species are native. The pepesca (*Bramocharax caballeroi*), the topote (*Dorosoma petenense*), the mojarra (*Oreochromis aureus*), the tegogolo snail (*Pomacea catemacensis*) stand out, and practically for self-consumption or as baits, shrimp called acociles are captured on the shores: *Macrobrachium acantophorus, M. vazquezae* and *M. catemacoensis*. A native clam (*Plagiola* (*aratonaias opacata*) has been also used. Some of these species are endemic to the lake or its basin. The high fishing production of about 1,800 t per year in Lake Catemaco in the 90's (Loran Núñez et al., 2013) fell to about 1,200 t per year in the last years of the second decade of the 21st century.

Among the causes of the decline in fish production, the main ones are probably overexploitation by more than 2,700 registered fishers and an un-

Table 2. *Some stream indexes from the Lake Catemaco watershed.*

Mainstream indexes	Value
Maximum height	1 299 m
Mean height	819 m
Minimum height	339 m
Length	29 020 m
Mean slope	3.306%
Time of concentration	197.55 min
Drainage area	250.5 km^2
Return period	50 years
Runoff coefficient	0.35 (35%)
Probabilistic rain	479.21 mm
Rain intensity	145.66 mm/h
Peak flow	3 547.43 m^3/s

Figure 3. *Relief map of Lake Catemaco Basin.*



determined number of unregistered illegal fishers. That means a density of more than 0.26 fishers/ha in the lake. There is a widespread use of harmful fishing gear and practices that include the lack of respect for specie's life cycles, schedules, bans, use of prohibited nets and mesh sizes, and poisons. In addition, the basin presents erosion problems due to livestock and agricultural activities, many of them causing high soil erosion in high slope lands and pollution due to the use of agrochemicals.

Communities' wastewaters in Catemaco city are discharged to the water bodies with little or no treatment, and the lake has gone from a mesotrophic to a eutrophic state (Torres-Orozco and Zanatta 1998; Tavera and Castillo 2000).

Corruption, insecurity, lack of institutionalism, and governance have worsened in the last decade, and pressures on the lake and the watershed are increasing.

The urban development and road infrastructure, and the tourist-residential speculation of land, especially on the shores of the lake, threaten the vegetation and riparian ecosystems around the lake, and they trigger the appearance of new sources of pollution.

5. Main "impact stories" about the lake

5.1 Conservation and protection official mechanisms

In 1937, the Official Gazette of the Federation (DOF, by its acronym in Spanish) published the decree establishing the Prohibited Forest Protective Zone of the Catemaco Lake Hydrographic Basin (DOF, 1937) to halt the deforestation process in the region and the change in land use, covering a surface of 285 km^2. The decree is still in force but "forgotten," obsolete, and without practical application.

On April 28th, 1980, the Sierra de Santa Marta was decreed a forest protection zone and wildlife refuge covering 200 km^2 that included part of the upper part of the basin of the rivers east of the Lake Catemaco basin.

Despite these protection measures, from the 50-60s to the 90s, due to agrarian distribution and colonization, both by settlers in the modality of private property and agricultural colonies and in the form of ejido endowments, in the basin some ejidos initiated crops of coffee and agroforestry systems. However, since the coffee crisis of the 90s, deforestation and conversion of agroforestry systems to pastures for cattle ranching were imposed more rapidly (de la Vega-Leinert et al., 2017).

In 1998 the DOF published the Decree establishing Los Tuxtlas Biosphere Reserve covering 1,551.22 km^2 (DOF 1998). This natural protected area has been partially effective. However, it's presenting preservation problems due to invasions and lack of governance, few personnel, and few resources for effective management and conservation, especially in the last decade. The North, East, and Southeast of the Catemaco Lake watershed were included in the Biosphere Reserve. The Lake was excluded because of the existence of the former conservation decree of 1937. However, another reason was to prevent socioeconomic conflicts with fishers, communities, and landowners next to the Lake if the area was included in the Biosphere Reserve polygon.

5.2 Introduction of exotic species

The major impacts of Lake Catemaco have to do with the introduction of the two exotic species of tilapia (*Oreochromis aureus* and *O. niloticus*) and with the translocation of two species of mojarras (*Thorichthys* sp.) (Lorán-Núñez et al., 2013), and *Mayaheros urophthalmus* (before "*Cichlasoma*" *urophthalmus*) (Jiménez-García and Suárez-Morales, 2017). These introductions were aimed at increasing or sustaining the high fishing productivity of the lake. However, they generated serious imbalances and impacts on native species, and in the medium or long term, this introduction and restocking with their fingerling have been insufficient or ineffective due to the high increasing pressure on the resources. Fishers attribute the loss of production to the lake regulation dam for hydroelectric production. This may prevent the sector from becoming aware of other impacts and pressures from the fishing sector itself on its resources. In the last decade, the problems of governability and security in Mexico (Benítez-Manaut 2009) have resulted in less effective surveillance and sanctioning. In many fisher's organizations, there is no respect for the directors or their own monitoring committees. Fishers complain of lack of support, so they say they are forced to continue fishing and overexploiting fishery resources. In the last decade, the state administration promoted the change of jurisdiction or control of many of the cooperatives from the federal agency (National Aquaculture and Fisheries Commission) to the state agencies (Secretariat of Agricultural, Rural, and Fisheries Development), reducing in the practice their access to many federal supports and possibly generated greater lack of control and disorganization in the fishing sector of the Lake.

5.3 The apple snail or "tegogolo": a victim of its own success

The "tegogolo" snail, *Pomacea catemacensis*, an endemic species of Catemaco, has sociocultural importance, and is a reference in gastronomy, not only for the inhabitants of the region but also for tourism. However, official statistics show periods of a dramatic decline in the extraction of this fishery resource. From 1992 to 1997, the "tegogolo" catch decreased from 150 to 75 t, with a rebound to 180 t in 1998, decreasing progressively to 50 t in 1999 (unpublished data, Federal Fisheries Sub delegation, SAGARPA, Veracruz). From 2007 to 2013, catches diminished progressively from about 270 t to less than 50 t (Unpublished data, Fisheries Information System and Aquaculture, SADER, CONAPESCA, Veracruz). *Pomacea catemacensis* recently was placed as an imperiled (N2) endangered species within the conservation category of N1 (critically imperiled) to N5 (Secure) (Czaja et al., 2020). Unfortunately, there are no formal studies about the role that several factors could be related to, like overfishing, non-compliance with regulations (NOM-041-CFSP-2004), pollution, habitat modification or disturbance, and presence of invasive species.

5.4 Land speculation on the shores of the lake: the threat of the road for land speculation and real estate developments on the lakeshore

In 2007, a group of environmentalists denounced the administration and government of the Municipality of Catemaco as the promoter of the construction project of the road that would close the circuit around the lake for the irregularities and shortcomings of the project and its manifestation of environmental impact. These actions, and perhaps others of a political and financial conflict, helped to prevent the construction of that road section, which would have impacted one of the largest and best-preserved areas of the surroundings of Lake Catemaco. Environmentalists proposed alternatives that communicated more communities and populations at a greater distance from the lakeshore. What was really intended was lotification and land speculation. After 13 years, the threat of a similar project being promoted again, with few environmental considerations, is still present.

5.5 Private and communal ecological reserves in the Catemaco Lake surroundings and its watershed

There are several private reserves that have served to protect some of the last areas of vegetation around Lake Catemaco. Although the Nanciyaga Ecological Reserve has been famous and recognized at the regional and state level, it has also served indirectly as one of the attractor foci of tourism and the flow of boats somewhat crowded and often not so respectful of the environment for decades. It also seems to have served as an attractor for other supposed touristic projects in its vicinity but resulting of dubious ecological or sustainable character, despite the propaganda and image they want to sell.

Since approximately 2003, the ejidos Las Margaritas and Benito Juárez, on the Southeast of the lakeshore, dedicated their ejido common use areas to conservation and established some measures at the community level advised and guided by the Los Tuxtlas Biosphere Reserve Office. In the case of the Benito Juarez ejido, it accessed the Program of the National Forestry Commission of Payment for Environmental Services of Biodiversity with its Common Use Area of 35 ha, which would later be expanded to 41 ha in 2008. In these communities, ecotourism projects are developed linked to the conservation and management of their community reserves. Some of the best-preserved jungle areas in the surroundings of the lakeshore are present, with canyons and streams of great ecological and landscape value.

In the community of El Porvenir, in the south center of the lake, biologists, and environmentalists acquired several plots with patches of forest that make up the Selvas del Toztlan Ecological Reserve, which total about 20 ha dedicated to conservation and restoration. Unfortunately, in these reserves, it has not been possible to eradicate poaching, hunters, extraction, and trafficking of flora and fauna. In communities south of Lake of Catemaco the main traffickers of flora and fauna of the region have settled. For decades, they have monopolized many of the specimens of organisms captured or extracted in the region.

6. Main issues and challenges of governance of the lake basin

The Lake Catemaco basin has suffered, like many parts of Mexico, a loss of governance (Paz, 2008; Beaucage, 2010; Martínez and Espejel, 2015). Fear and insecurity dominated during the administration of some municipal governments and administrations, culminating in the violent seizure and burning of the Municipal Palace in 2016. In the last government and the current one, a certain level of peace and security has been recovered. The COVID-19 epidemic has paralyzed or slowed down some socioeconomic processes and activities, both government actions and citizen initiatives (Chiatchoua et al., 2020; Dávila-Flores and Valdés-Ibarra 2020). From the environmental point of view, the federal and state governments have some programs in favor of soil conservation, productive conversion to more sustainable crops, focused on diversification, and food self-sufficiency. However, many programs and resources allocated to the environmental sector directly have been canceled or reduced: at the federal level, the resources and financial support from the Ministry of the Environment and Natural Resources (SEMARNAT, by its acronym in Spanish), and the National Commission for Natural Protected Areas (CONANP, by its acronym in Spanish) and its regional office in the Biosphere Reserve have reduced significantly.

The programs and budgets of the National Forestry Commission (CONAFOR, by its acronym in Spanish) have been strongly reduced, as well as the budget of the Federal Attorney for Environmental Protection

(PROFEPA, by its acronym in Spanish), among other things, due to its lack of transparency, results, and corruption.

At the state level, the trust of the Veracruz Environmental Fund (FAV, by its acronym in Spanish) of the Secretariat of the Environment of Veracruz has been eliminated. This fund supported various associations and civil organizations with environmental programs in the region and in the lake watershed: protection of the forest and riparian areas around the water springs and creeks, and other supporting protection and breeding of native bees and the vegetation and their habitats.

The activity of civil associations (or some of them) is increasingly limited and hindered by the fiscal control of the Ministry of Finance and the limitation of resources they received from federal or state government programs, such as the FAV.

At the municipal level, the following incoming governments should incorporate the basin approach into their municipal development plans, with an impact on urban and territorial planning plans. It is necessary to support and encourage the most open, plural, and effective social participation in various figures of social participation: municipal development councils, ecology committees, an advisory council of Los Tuxtlas Biosphere Reserve, Advisory Council of the Forest Management Unit (UMAFOR, by its acronym in Spanish) of Los Tuxtlas, where the representatives of the different social and productive sectors involved are representatives of those sectors and do not participate only in a personal capacity cut are really open and inclusive.

Governability and security issues in the country and the state of Veracruz have affected legality, the rule of law, and legal certainty. Insecurity and loss of governability and institutionalism have favored land occupation, deforestation, and land-use change, especially in Core Zone 2 of the Biosphere Reserve. They are adding a federal and state policy that puts the supposed rights of indigenous people and indigenous or rural communities over conservationist, protectionist, or environmental policies. However, the government's permissiveness with these occupations and land-use changes does not cease to have a component of political clientelism and is indeed hiding a lack of political courage. These invasions and land occupations are not exempt from opportunism, corruption, chiefdoms, and violent groups of power, with an environmental cost far greater than the social benefit they could provide.

To these problems was added the COVID-19 pandemic in 2020, which further reduced the institutional presence, surveillance, and inspection in the Biosphere Reserve and in the upper part of the Lake Catemaco basin.

7. Conclusions

The ecological and socio-economic importance of the Catemaco basin requires implementing and continuously evaluating a plan for its integral management. All of the above will also require will and work to rescue the governance.

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Reconstruction of past metal(loid)s pollution and sources from the sediments of Bukit Merah Reservoir (BMR), Perak, Malaysia

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Abstract

Human pressure, especially due to agricultural activities, tourism and other land use forms, have significantly intensified in the catchment area of Bukit Merah reservoir, the oldest man-made reservoir in Malaysia since the 1980s. This intensification has resulted to high sedimentation and pollution of the reservoir. However, there is little or no records whatsoever regarding past environment change of the reservoir. Thus, this research was conducted to reconstruct past metal pollution records of the reservoir. A 25 cm sediment core was retrieved from the reservoir using Uwitech corer. Sediment chronologies were determined using ^{210}Pb sediment dating methods, while metal(loid)s (As, Cu, Pb, Zn and Fe) were analysed using ICP-OES. The ^{210}Pb age depth profile showed that the sediment core extended back to 34 years and three time periods were identified based on dated sedimentary profile. From the 1980s to 1990s, As, Cd, Cu, Pb Zn and Fe have shown low

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concentration, indicating a relatively stable reservoir condition. Rapid population growth, intensifying agricultural practices, and expanding tourism was reflected by the increasing trend in metals between 1990s to 2000s. Severe soil erosion from continuous logging and sand mining remained a major source of metals to the reservoir from 2000s onward. The I_{geo} index showed uncontaminated to strongly contamination for As, Cd, and uncontaminated to moderate contamination for Pb, Zn and Cu. The EF metal enrichment indicated anthropogenic input of metals from the catchment area. Therefore, regular monitoring, public awareness and imposing necessary environmental laws is recommended.

Keywords: *Toxic metals, lake sediment, pollution, environment change*

1. Introduction

Sediments, cores are natural archives and one of the most accessed resources utilized in the reconstruction and evaluation of past contamination trends in aquatic ecosystems [1]. The cores provide valuable information used to describe sediments geochemistry, physical properties, and grain size composition [2]. Vertical profiles of given pollutants can reflect sedimentation rate and the impact of anthropogenic activities in the watershed of aquatic environment [3].

Compounds, especially metal(loid)s, have become a major concern due to their toxicity and environmental persistence[4].Trace metals which originate from different sources including industrial, agricultural, or weathering of rocks, are easily bioaccumulated or accumulated in the tissues of plants and animals, making them an important health concern [5]. Metals released to the aquatic environment undergo different processes, including photolysis, chemical oxidation, adsorption, and microbial breakdown [6], eventually adsorbed on particulate matter and accumulated on bottom sediments [6].

Sediments are important sinks to different anthropogenic contaminants and can be used to trace local pollution history where long term monitoring information is lacking [7]. More so, the knowledge from ecological risk assessment of anthropogenic contaminants from dated sediments will help improve lake management strategies [8].

Over the last few decades, the water quality of Bukit Merah Reservoir (BMR) has deteriorated significantly due to tourism, agricultural activities, population growth and other land use activities among others [9]. Consequently, the pollutants from these activities are transported and deposited in the reservoir, making the bottom sediment an archive and potential source of different substances, including trace metals [10]. Past studies have focused on the surface sediment pollutions of the reservoir [11]. However, there are no records of historical changes in trace metal pollution of the reservoir. Thus, this study is aimed at reconstructing metal(loid)s arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn) and iron (Fe) pollution history and sources in Bukit Merah Reservoir using ^{210}Pb sediments dating methods. This research also offers important information on the present heavy metal pollution status of the reservoir.

2. Materials and methodology

2.1 Sample collection

A bathymetric survey was conducted in November 2019, after which a 25 cm sediment core was retrieved from the reservoir (Figure 1) in a depth of 2.65 m, using a UWITEC gravity corer with internal diameter of 9 cm. The core was transported to the laboratory, sub-sampled at 1 cm intervals and stored in a whirl-pak® at a temperature of 4 °C. Samples were then freeze-dried at -50 °C using Labconco 6 liters benchtop freeze-dryer system, then grounded with a mortar and pestle, homogenized, and filtered through a sieve of 100 μm mesh size prior to analysis.

2.2 Radiometric dating of sediment

Activities of radioisotopes of ^{210}Pb, ^{137}Cs, ^{214}Am and ^{214}Pb were analysed using intrinsic germanium detector for ^{210}Pb gamma dating following the methods of [7]. Approximately 0.5 g of freeze-dried sediment samples were

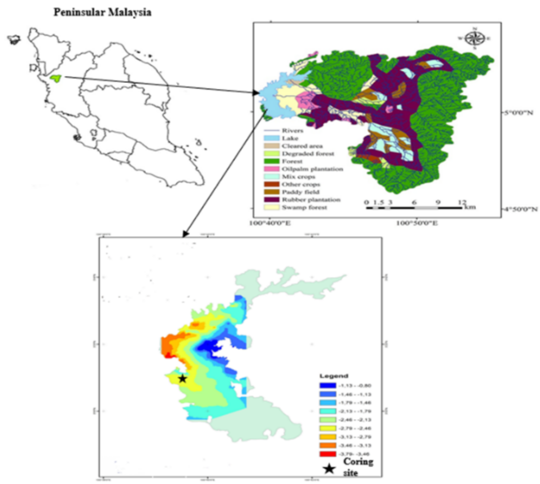


Figure 1. *Map of study area showing sampling site.*

placed into a plastic test tube and sealed with 2-Ton Epoxy®, kept for three weeks to ensure radioactive equilibrium before placed in a gamma counter. Unsupported ^{210}Pb was computed by deducting ^{226}Ra activity (as unsupported ^{210}Pb) from total ^{210}Pb activity. Sediment's rate of accumulation and sediment age were computed using he Constant Rate of Supply (CRS) dating model [7], by linear regression between excess ^{210}Pb and core depth.

2.3 Trace metal analysis

About 0.5 g of freeze-dried sediment samples were measured into Teflon tubes, and aqua regia solution (HNO_3 and HCL in 7:3 ratio) was poured into the sediment sample and placed in a microwave digester at a temperature of 200 °C to 300 °C for samples to digest. Digested samples were left to cool, then filtered through a 0.45 µm filter paper and made up to 50cm^3 volume with distilled water. The filtrates were analysed for metal(loid)s (As, Pb, Cd, Cu, Fe and Zn) using ICP-OES (Agilent Technologies 700 series). Standard sediment reference material (SUD-1, Environment Canada, National Research Institute, Canada) with 92% to 104% recoveries was used to access the accuracy of analysed metals. Three replicate sample of each metal were analysed per run to ensure analytical precision. More so, blanks and standards were frequently run with each sequence of analyses to corroborate data obtained.

2.4 Determination of metal enrichment in the sediment

The geochemical index (I_{geo}) and enrichment factor (EF) were applied to study the change in pollution level of metals with respect to sedimentary process and depth of sediment core. Trace metal concentrations at the base of the BMR 2 sediment core corresponds in time of about three decades before the present, therefore, are not suitable as pre-industrial backgrounds. As such Continental Shale value, [12] were used as backgrounds values for the computation of I_{geo} and EF. The used background values were (Cu = 45, Cd = 0.3, Pb = 20, Fe = 47, 200, Zn = 95 and Ni = 68).

Thus, Igeo was computed using equation 1:

$$I_{geo} = \log_2 [C_n/1.5B_n] \quad (1)$$

where C_n represents determined concentration in the sediment for metal n. B_n is baseline value for the metal n [12], while the factor 1.5 was applied to stabilize possible variation in baseline values due to lithological process.

The geochemical index was categorised into six classes according to [13], namely, $l_{geo} \leq 0$ = unpolluted; $0 < l_{geo} \leq 1$ = unpolluted to moderately polluted; $1 < l_{geo} \leq 2$ = moderately polluted; $2 < l_{geo} \leq 3$ = moderately to highly polluted; $4 < l_{geo} \leq 5$ highly to very highly polluted; $l_{geo} > 5$ = very highly polluted.

The EF value was computed from equation 2:

$$EF = \left(\frac{M}{Fe}\right)_{sample} \times \left(\frac{Fe}{M}\right)_{baseline} \quad (2)$$

Where (*M/Fe*) *sample* is the ratio of the measured metal to Fe in the study sample, while (*Fe/M*) *baseline* is the natural baseline value of total metal to Fe ratio [14]. EF assessments were grouped into five enrichment standard values, namely, EF <2: deficiency to minimal enrichment; EF = 2 – 5: moderate enrichment; EF = 5 - 20: significant enrichment; EF = 20 – 40: very high enrichment; EF > 40: extremely high enrichment.

2.5 Statistical analysis

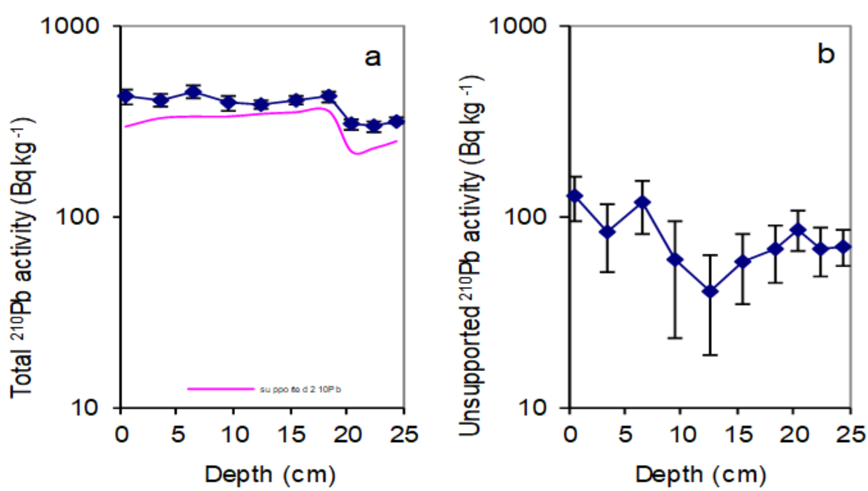
Pearson correlation analysis was utilised to understand the association, sources, and pathways of trace metals in this study.

3. Results and discussion

3.1 Radiometric dating of sediment

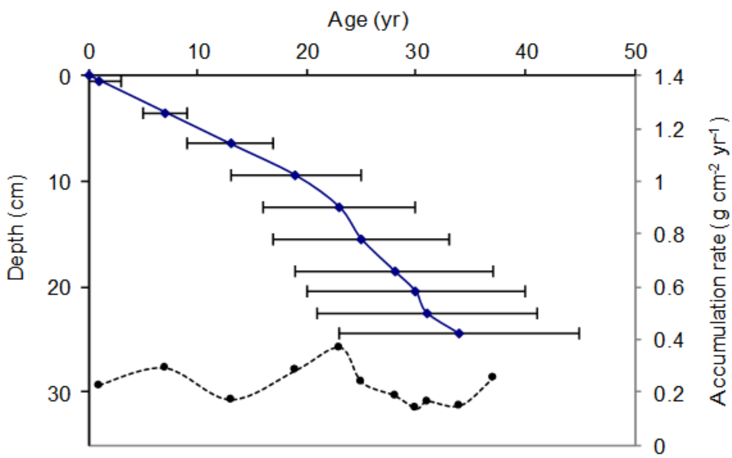
Results indicated that activities of radioisotopes of ^{210}Pb, was non-monotonic (Figures 2a and b), which was probably due to sediment mixing and resuspension associated with the ageing of the reservoir [10]. Similarly,

Figure 2. *Fallout radionuclide concentrations in sediment core BMR from Bukit Merah Reservoir, Malaysia, showing (a) total ^{210}Pb and (b) unsupported ^{210}Pb concentrations versus depth.*



^{241}Am activities were found in two disconnected samples but too low to be suitable for dating, while ^{137}Cs was not detected in BMR sediment core, which may be attributed to high sedimentation rate of the reservoir causing indiscriminate deposits of newer sediments on older ones. Nevertheless, no substantial change of sediment texture was observed along the layers. Hence, sediment ages of BMR were derived by the CRS (constant rate of ^{210}Pb supply) dating model, which dated the oldest sediments (22.5-24.5) to AD 1985 ± 34 years (Figure 3).

Figure 3. *Radiometric chronology of sediment core BMR from Bukit Merah Reservoir, Malaysia, showing the CRS model ^{210}Pb dates and sedimentation rates. The solid line indicates chronologies, while the dashed line shows sedimentation rates.*



3.3 Stratigraphic trace metal content and enrichment

The Bukit Merah reservoir can be characterized as a conventional artificial reservoir in an agriculturally dominated watershed in Northern Malaysia, comprising a heterogeneous landscape. Such attributes were deemed to cause variations in the sedimentation process. Therefore, the trace metal variations in the core were interpreted by environmental change and the characteristics of human activities in the water shed. This finding is divided in to three time periods (Figure 4)

By the 1980s, the vertical variations of trace metals (As, Cu, Cd, Pb, Zn and Fe) were minimal and had an unclear pattern, suggesting that the sedimentary environment was static, and the metal input loading into the reservoir was greatly influenced by natural process. Thus, arsenal As, Cd, Cu, Pb, Zn and Fe had their minimum concentrations of 8.45 mg/kg (24 cm) in 1985, 0.39 mg/kg (22-24 cm) in 1987, 0.98 mg/kg (23 cm) in 1986, 11.50 mg/kg (18-20 cm) in 1989, 20.45 mg/kg (20-22 cm) in 1988 and 35.40 mg/kg (23-24 cm) in 1986, respectively.

Since the 1990s, the trace metals concentrations increased, which may be attributed to rapid population growth and intensifying agricultural practices leading to the expansion of rice paddies, oil palm and rubber plantations [10]. As Cu and Zn and Fe recorded a high concentration of 10.38 mg/kg, 1.78 mg/kg, 22.5 mg/kg and 37.8 mg/kg, in 1995 (14-17 cm), 1991 (13-15), 1993 (14-35 cm) and 1998 (24-34 cm), respectively, the increase may be attributed to the use of agrochemicals, especially Mancozeb, broadly utilized for the control of plants diseases [15]. Oil spills from increasing number of machinery used for farming activities may contribute to the high concentration of Pb and Cd in the reservoir [3]. Additionally, increasing use of motorized boats for tourist activities at the reservoir has led to additional inputs of metals, especially Cd and Pb into the reservoir [11].

From 2000 onward, trace metals steadily increased to the top of the core with As, Cu and Pb attaining their peak concentrations of 12.5 mg/kg, 2.62 mg/kg and 35.6 mg/kg in 2018, 2010 and 2017, respectively, Whereas Cd, Zn and Fe recorded high concentrations of 0.82 mg/kg, 33.5 mg/kg and 53.5 mg/kg in 2008, 2005 and 2009. The rise in concentrations of these metals may be due to severe soil erosion eroding metal bearing sediments into the reservoir caused by continuous logging and loss of vegetation in the upstream of the catchment area.

Sediment enrichment factor of I_{geo} showed that As ranged from uncontaminated between ca. 1986 and 1987 to strongly contaminated in ca. 2010 (Figure 5). Cd, Cu and Zn ranged from uncontaminated between ca. 1985 to 2000, to moderately contaminated throughout the core until 2018. Pb ranged from moderately contaminated between 1985 to 1987 to strongly contaminated from ca. 1990 to 2017. The variation in the I_{geo} of BMR core reflects the level of agricultural activities and landscape transformation due to population growth and tourist activity.

Also, the EF values for Cd, As, Cu, Pb and Zn (Figure 4) ranged between 0.92 to 1.51, 0.98 to 1.49, 1 to 1.51, 0.89 to 1.50 and 0.95 to 1.51, respectively. Generally, the EF value was greater than 1 (EF > 1.5), indicating anthropogenic sources of trace metals, however, not limited to the agricultural activities but also from nearby hill where mining activities are taking place in the catchment area.

Figure 4. *Vertical variation of trace metals in Bukit Merah reservoir.*

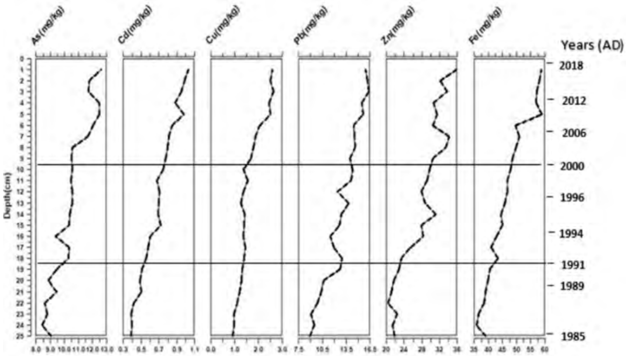
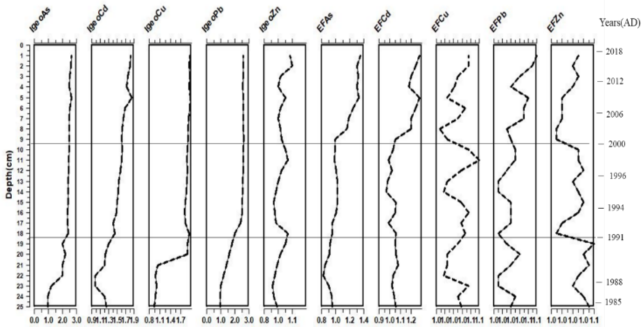


Figure 5. *Variation of geo-chemical (I_{geo} and enrichment factors (EF) of Bukit Merah reservoir.*



3.4 Correlation analysis

Inter-elemental association matrix provides vital information about the pathway and sources of metalloids (Table 1). Thus, a significant positive association ($p < 0.05$) was observed between Cu and Zn ($r = 0.87$, $p = 0.001$), indicating common sources of these metals. A positive relationship was observed between Fe and Cu (r = 0.65) and Fe and Zn (r = 0.60), with sources linked to runoffs and sediment inputs from the watershed. In contrast, results revealed that there was no significant relationship between Cu and Cd (r = 0.31, p = 0.42), As and Cd (r = 0.34, p = 0.49), As and Pb (r = 0.25, p = 0.31), Cd and Zn (r = 0.09, p =0.64), indicating that these metals might have originated from different anthropogenic sources in the catchment area and were later transported to the reservoir. Additionally, non-significant negative association was observed for As and Zn (r = -0.35, p = 0.41); Cd and Pb (r =-0.05, p = 0.72); Cu and Pb (r = - 0.19, p = 0.61). This relationship is unclear; nevertheless, sources of metals to the study area were from anthropogenic activities in the catchment area.

Table 1. *Pearson's correlation analysis between metals concentration in BMR.*

	As	Cd	Cu	Pb	Zn	Fe
As	1.00					
Cd	0.34	1.00				
Cu	-0.37	0.31	1.00			
Pb	0.25	-0.05	-0.19	1.00		
Zn	-0.35	0.09	0.89*	-0.08	1.00	
Fe	0.29	0.36	0.65*	0.32	0.60*	1.00

* Correlation is significant at the 0.05 level (2-tailed)

4. Conclusion

The ^{210}Pb dating model revealed that the sediment at the bottom of the studied core dated back to 34 years. Three time periods were identified based on dated sedimentary profile. Relatively stable reservoir conditions between 1980s to 1990s displayed low As, Cd, Cu, Pb, Zn and Fe concentrations. 1990s to 2000s witnessed rapid population growth, intensifying agricultural practices, and expanding tourism reflected by the increasing trend in metals. From the 2000s onward, severe soil erosion from continuous logging and sand mining remained a major source of metals to the reservoir. The I_{geo} index showed uncontaminated to strongly contaminated for As, Cd and uncontaminated to moderate contaminated for Pb, Zn and Cu. The EF metal enrichment indicated that the reservoir was polluted mainly by metals from anthropogenic sources.

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Research and development of Integrated Lake Basin Management Plan (ILBMP) for Timah Tasoh Lake and Melati Lake, Perlis, Malaysia

MOHD FADHIL KASIM, ZATI SHARIP, ZUBAIDI JOHAR[1]

Abstract

This study discusses on the development of ILBMP for Timah Tasoh and Melati Lake, Perlis, Malaysia. Timah Tasoh and Melati Lake are located at Perlis river basin covering 191 km^2 for Timah Tasoh Lake catchment and 16.24 km^2 for Melati Lake catchment. The Timah Tasoh Lake can hold 40 million cubic meters of water, mainly used as a water storage reservoir or irrigation in Perlis and functions as a catchment area to prevent floods while Melati Lake mainly uses water for recreational activities. This study was sought to understand and find solutions for the current state of the quality and environmental performance related to the lake management plan. Besides, this study also reviewed the existing governance structure and system and its policy direction affecting the lake basin of Timah Tasoh Lake and Melati Lake. The study also discusses the need for Perlis river basin management as approach to the management of the entire Perlis river basin, to ensure the management of Timah Tasoh and Tasik Melati for sustainable use in lake ecosystems and catchment areas.

Keywords: *Timah Tasoh Lake, Melati Lake, Integrated Lake Basin Management, lake environment*

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1. Introduction

Timah Tasoh Lake Basin is one of sub-catchment from Perlis River Basin. The catchment area of the Timah Tasoh Lake Basin is located at the upper reaches of River Basin. The catchment area covering 191.00 km^2 rises from Pelarit River to Timah River and Jarum River to Tasoh River (NAHRIM, 2020). Timah Tasoh Lake is a man-made reservoir in Perlis, Malaysia. It got its name from two rivers, Timah River and Tasoh River, which provide the main catchment to it. Its construction began in 1987 and was completed in 1992. The lake has a total surface area of about 13.00 km^2 and it can hold 35.3 million liters of water (DID, 2017). It was designed to irrigate 30.75 km^2 of paddy land for double cropping and to supply 7.80 Mgd (0.41 cumecs) for domestic and industrial uses (DID, 2017). As of 1992, the Development and Innovation (D&I) demand has increased to 8.00 Mgd while the irrigation demand was curtailed to 23.72 km^2. A bird sanctuary also is set up at Timah Tasoh to protect the habitat of migratory birds that flock the lake during winter in the northern hemisphere (Ismail & Rahaman, 2004).

Melati Lake is located between north and east of Kangar, Perlis, Malaysia. It is a small but beautiful lake. The name of Tasik Melati is inspired on the lotus flowers floating around the wetland. According to Ali et al. (2007) back in 1977, water from Melati Lake was used for agriculture purposes by local farmers as the water never dries. Melati Lake is a small lake with shallow water. There are more than 150 sand shelters found scattered around the lake. A bridge has been built along the lake to allow visitors a great view. Along this bridge, there is also a place to rest. Melati Lake is famous within families and visitors for its recreational facilities. Bridges, jogging tracks, playground, toilets and gazebo are built along the lake to enable visitors to enjoy the great view in Melati Lake (Ali et al., 2007). This man-made lake is known as picnic area and a great place for entertainment. As the centre of tourism, Melati Lake has been exposed to poor water quality (NAHRIM, 2020).

This study was part of development process of an Integrated Lake Basin Management Plan (ILBMP) for this two lake, in order to monitor the lake from the possible sources of pollution. At the same time, a governing body will be identified and developed to manage all parties with interest on these lakes where the data collected from this research shall be utilized to govern the lake from pollution as well as the sources of pollution.

2. Lake profile

Table 1 and Figure 1 show the distribution of land use in Timah Tasoh Lake Basin areas in 2014. The agriculture activities are the dominant land use component covering 45.23% of the total area (191 km^2). Forest Areas are the second dominant land use covering 32.99% - of the whole Timah Tasoh Lake basin. Other types of land use in Timah Tasoh Lake basin are open space and recreation areas with 8.03%, water body areas with 6.98% and development areas within 6.78% from of the whole Timah Tasoh Lake basin (JPBD, 2014) (NAHRIM, 2020).

Table 1. *Land use distribution in Timah Tasoh Lake basin by catchment (NAHRIM, 2020).*

Type of Land Use	Area (km^2)	Percentage (%)
Forest Area	63.02	32.99
Agriculture Area	86.39	45.23
Development Area	12.95	6.78
Open Space and Recreation	15.33	8.03
Water Body (Timah Tasoh Lake)	13.33	6.98
Total	191.02	100.00

Figure 1. *The distribution map of land use in Timah Tasoh Lake basin in 2014 (NAHRIM, 2020)*

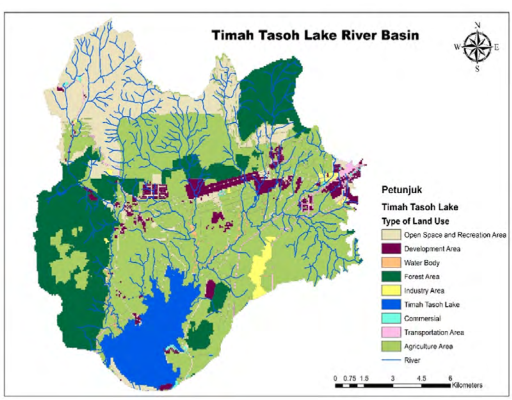
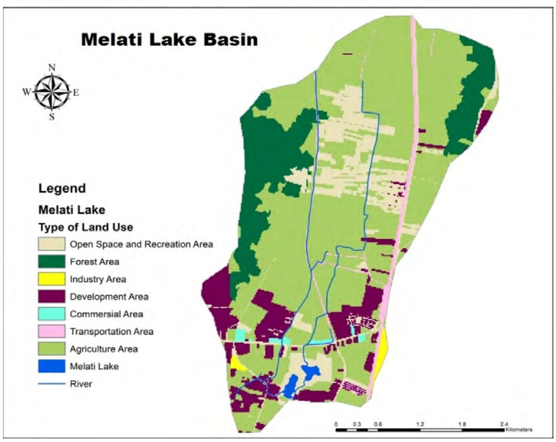


Table 2. *Land use distribution in Melati Lake basin by catchment (NAHRIM, 2020).*

Land Use	Area(km^2)	Percentage (%)
Agriculture Area	9.96	61.33
Development Area	1.92	11.82
Forest Area	2.02	12.44
Open Space and Recreation Area	2.28	14.04
Melati Lake	0.06	0.37
Total	16.24	100.00

Table 2 and Figure 2 show the distribution of land use in Melati Lake Basin areas in 2014. The agriculture areas are the dominant land use component covering 61.33% of the total area (16.24 km^2). Open space and recreation area are the second dominant land use covering 14.04% of the whole Melati Lake basin. Other types of land use in Melati Lake basin are forest area with 12.44%, development area with 11.82% and Melati Lake areas with 0.37% (JPBD, 2014) (NAHRIM, 2020)

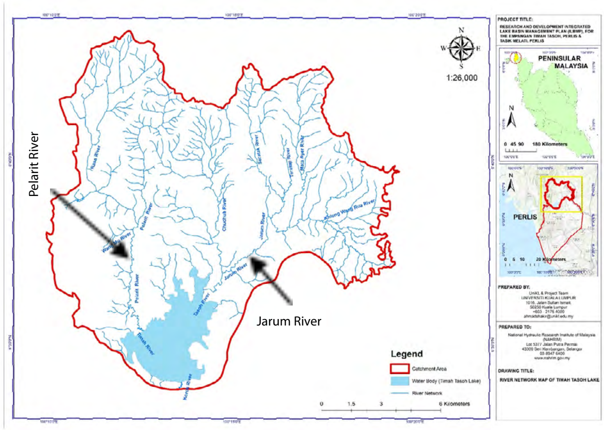
Figure 2. *The distribution map of land use in Melati Lake basin by catchment in 2014.*



3. Hydrological information

Timah Tasoh Lake Basin is one of sub-catchment from Perlis River Basin. The catchment area of the Timah Tasoh Lake Basin is located at the upper reaches of Perlis River Basin. The catchment area covering 191 km^2 rises

Figure 3. *River Network system in Timah Tasoh Areas.*



Source: Topography map from Department of Survey and Mapping Malaysia (JUPEM) (JUPEM, 2014).

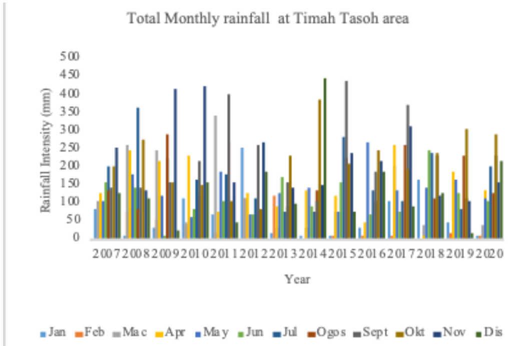
from Pelarit River to Timah River and Jarum River to Tasoh River. This region is categorized by the hydrological Procedure No. 12 as Region 9 with average precipitation between 37.79 mm to 226 mm. Figure 3 shows the River Network system in Timah Tasoh Areas.

According to the topography map from Department of Survey and Mapping Malaysia (JUPEM), there are two main rivers that drain into the Timah Tasoh Lake named Timah River (flow from Pelarit River) and Tasoh River (flow from Jarum River) and flow out to Korok River.

3.1 Rainfall

Timah Tasoh Lake recorded the highest intensity of rainfall during September to November every year with monthly average of 225 mm to 222 mm, while the lowest rainfall was recorded during January to April with average range of 62 mm to 114 mm. During 2007 to 2020, the maximum daily rainfall intensity recorded was 162 mm in November 2010. The higher intensity of rainfall during September to November every year was caused by the northeast monsoon season (NAHRIM, 2020).

Figure 4. *The Distribution of Total Monthly Rainfall at DID Rainfall Station Tasoh from 2007 to 2020 (NAHRIM, 2020).*



3.2 Water Level

Table 3 shows the water level records from a few water levels stations around Perlis State. Pelarit River Station and Jarum River Station situated at upstream of Timah Tasoh Lake Basin. Based on the data from the Detailed Environmental Impact Assessment in Proposed Timah Tasoh Dam Raise Project, Perlis, December 2011, the level value records in upstream station is higher than downstream areas (DOE, 2011). Measured water levels at upstream and downstream water level stations around Perlis state show that the low-flow water level at the same discharge decreased, and the lowest water level increased due to dry-season reservoir discharge. The decline of the low-flow water level below the dam was less than the undercutting value of the flow channel of the river, the food level at the same discharge below the dam was slightly elevated, although peak water levels decreased, flood characteristics changed from a high discharge–high flood level to a medium discharge–high flood level and an expected decline in the flood level downstream was not observed.

Table 3. *The water level records from water level stations in Perlis (DID, 2020).*

	Water Level Stations in Perlis			
River	Station	Normal	Alert	Danger
Pelarit River, Kaki Bukit	6602402	35.00	38.30	39.00
Korok River, Upstream Timah Tasoh Dam	6502436	29.00	29.40	29.60
Kolam Air, Timah Tasoh Dam	6502403	19.40	21.00	22.00
Arau River, Kampung Sungai Bakau	6402401	1.50	3.00	3.50
Arau River, Kampung Kuala Tunggang	6402433	12.45	12.85	13.30
Buluh River, Kampung Batu Bertangkup	6502404	24.00	28.00	30.00
Jarum River, Kampung Masjid	6602403	30.00	33.00	33.60

3.3 River Discharge

Figure 5 and Figure 6 show monthly average water discharge of the Pelarit River and Jarum River from 2000 until 2019 (based on historical data from DID hydrological station) (DID, 2020). The average monthly discharge recorded at the Pelarit river ranged between 8.46 m^3/s to 79.78 m^3/s, with the monthly maximum discharge of 79.78 m^3/s, recorded in October. For the Jarum River, the monthly discharge average ranged between 83.85 m^3/s to 23.19 m^3/s, where the maximum monthly discharge was recorded in December. The lowest monthly discharge at both stations was recorded in February with both stations having the same dry condition with no storm events recorded since January (NAHRIM, 2020)

Figure 5. *Monthly Average of Water Discharge of the Pelarit River, Perlis from 2000 to 2019 (DID, 2020) (NAHRIM, 2020).*

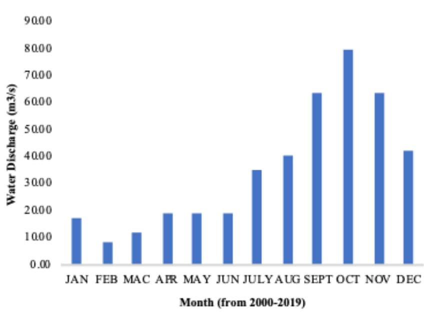
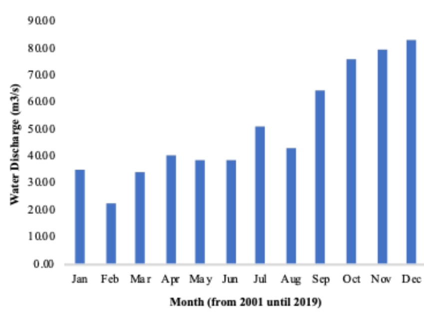


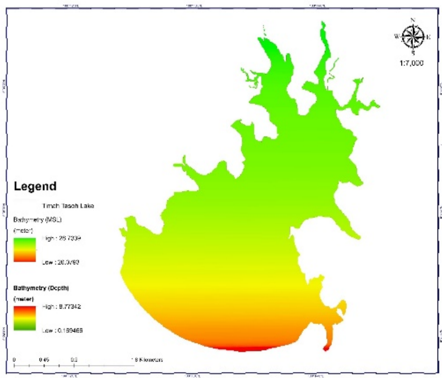
Figure 6. *Monthly Average of Water Discharge of the Jarum River, Perlis from 2000 to 2019 (DID, 2020) (NAHRIM, 2020).*



3.4 Bathymetric analysis

Figure 7 shows the profiling of bathymetry map that is located in Timah Tasoh Lake. The range of bathymetry of the lake is between 0.17 m to 8.77 m, where the green color indicates the shallow area, yellow color indicates the middle area in depth and red color shows the deepest area of the lake. The maximum depth of the lake recorded downstream is 8.77 m, while the minimum depth of the lake is 0.17 m at the upstream. From Figure 48, we can see that the pattern of the bathymetry increasing in depth starting from the upstream to the downstream area (NAHRIM, 2020)

Figure 7. *Bathymetry Map of Timah Tasoh Lake (NAHRIM, 2020).*



4. Water quality characteristics

4.1 Timah Tasoh Lake

The average BOD level at Sg. Pelarit was 2.81 mg/l, which was within the NWQS of Class II (1 mg/l - 3 mg/l), while Timah Tasoh Dam was 5.07 mg/l and Sg. Perlis was 4.97 mg/l, which both were within Class III (3 mg/l – 6 mg/l). Meanwhile, COD level for Sg. Pelarit and Timah Tasoh Dam were classified under Class II NWQS (10 mg/l – 25 mg/l) with the average values of 16.27 mg/l and 18.33 mg/l, respectively. Sg. Perlis was within the Class III NWQS (25 mg/l – 20 mg/l) with the average of 28.75 mg/l. Sg Pelarit had the highest dissolved oxygen (DO) level with the average value of 7.08 mg/l, followed by Timah Tasoh Dam at 6.38 mg/l and the lowest average value was Sg. Perlis 3.74 mg/l. Therefore, Sg. Pelarit and Timah Tasoh Dam were within Class I (>7 mg/l) and Class II (5 mg/l – 7 mg/l) of NWQS level for DO, and Sg. Perlis was within Class III NWQS (3 mg/l – 5 mg/l).

The pH of all the streams was in a range from 7.16 to 7.58, which was within the Class I of NWQS (6.5 – 8.5). The average TSS level for Sg. Pelarit was below than 25 mg/l (Class I of NWQS), which meant the suspended solid in the stream was low. However, Timah Tasoh Dam was in Class II (25 mg/l – 50 mg/l) with average value of 26.00 mg/l and Sg. Perlis was in Class III (50 mg/l – 150 mg/l) with average value of 90.59 mg/l. The NH3-N level for Sg. Pelarit and Timah Tasoh Dam were lower than the Class I of NWQS (0.1 mg/l), with the values of 0.03 mg/l and 0.08 mg/l, respectively. However, at downstream, Sg. Perlis recorded a high average value of NH3-N, 0.84 mg/l, which was within the Class III of NWQS (0.3 mg/l - 0.9 mg/l).

Table 4. *General descriptive statistics of the main water quality parameters for Perlis River Basin (NAHRIM, 2020).*

Statistics	Parameters					
	BOD (mg/l)	COD (mg/l)	DO (mg/l)	pH (unit)	TSS (mg/l)	NH_3-N (mg/l)
Upstream (Sg. Pelarit)						
Min	1.00	5.00	0.93	6.16	1.00	0.01
Max	14.00	47.00	9.89	8.69	134.00	0.19
Mean	2.81	16.27	7.08	7.58	18.75	0.03
Sd	2.54	7.74	1.50	0.41	27.04	0.03
Midstream (Timah Tasoh Dam)						
Min	3.00	12.00	4.14	6.87	16.00	0.01
Max	10.00	40.00	7.90	8.11	49.00	0.31
Mean	5.07	18.33	6.38	7.53	26.00	0.08
Sd	1.65	6.76	1.30	0.38	9.14	0.08
Downstream (Sg. Perlis)						
Min	1.00	5.00	0.89	5.85	1.00	0.01
Max	16.00	102.00	9.03	8.06	618.00	10.42
Mean	4.97	28.75	3.74	7.16	90.59	0.84
Sd	3.15	15.72	1.71	0.38	113.46	1.12
* Min = Minimum, Max = Maximum, Sd = Standard deviation						

4.2 Melati Lake

The average water temperature values for both stations were found to be higher, ranging between 31.65 °C and 32.07 °C compared with the normal water body temperature for dams and lakes. Meanwhile, DO values for both stations show the normal amount of DO in the lake waterbody.

The lowest values of DO concentration for both stations are all within the Category A criteria of the National Lake Water Quality Standard (NLWQS) classification (6.3 mg/L), which indicated high concentrations of DO. In the study, the pH level for both stations ranged between 7.6 and 7.8, which are neutral and considered to be within the national WQI standard of Class I and IIA, classified under Category A criteria of the NLWQS classification (6.3 – 7.8). Table 5 shows the general descriptive statistics of the selected parameter measured at Melati Lake by (NAHRIM, 2020).

Table 5. *General descriptive statistics of the selected water parameters for Melati Lake (NAHRIM, 2020).*

Parameter	Statistics			
	Min	Max	Mean	SD
DO (%)	105.240	115.886	109.698	3.464
DO (mg/L)	7.689	8.410	7.993	0.264
pH	7.674	7.872	7.727	0.060
Temperature (°C)	31.225	32.305	32.073	0.253
Specific Conductivity (μS/cm)	343.233	421.187	353.193	19.930
Salinity (PSU)	0.165	0.203	0.170	0.010
Total Dissolved Solids (ppt)	0.223	0.274	0.230	0.013

5. State of the ecosystem

The existing flora and fauna within the areas was evaluated based on the secondary information gathered from the previous studies on Detailed Environmental Impact Assessment in proposed Tasoh Dam Raise Project, Perlis (December 2011) (DOE, 2011). During the construction of the Timah Tasoh Dam in the early 1990s, significant impacts to the flora and fauna species within the reservoir had occurred. In the past years, secondary forest vegetation has established around the fringing areas of the dam and, these areas would provide a habitat for some faunal species. Additionally, some of these areas have also been converted to small agriculture plots. The additional 1,160 km^2 area to be inundated does not include any gazette forest reserves areas (DOE, 2011)

5.1 Terrestrial flora (DOE, 2011)

An assessment of the existing rich flora biodiversity at the surrounding forest reserves near the Timah Tasoh reservoir was based on the compilation by Jabatan Perhutanan Perlis in 2001 as report by NAHRIM (2020). Data was extracted from their landmark expedition from 28 September to 4 October 1999 in the Wang Kelian area. Pertinent aspects of the forest vegetation are summarized as below:

i. *Flowering plant species* - 164 flowering plant species belonging to 129 genera and 65 families are typical at White Meranti Gerutu Seasonal Forest found in Perlis. The recreational park of Tasik Meranti lists 131 plant species belonging to 82 genera and 37 families.
ii. *Mosses* - 71 species of mosses from 36 genera and 19 families, representing 15% of the 48q taxa of mosses recorded for Peninsular Malaysia.
iii. *Ferns and fern allies* - 57 species of ferns and 9 species of fern allies, representing 10.2% of the 647 taxa of pteridophytes in Peninsular Malaysia.
iv. *Reed bed* -16 reed bed species at the fringes of Tasik Meranti.

5.2 Terrestrial fauna

The fauna recorded in the vicinity of Timah Tasoh reservoir are the small varieties of mammals, reptiles, amphibians and birds, including migratory birds. There are about 68 species of mammals which could only be found in the dam area, signifying the rich biodiversity in Perlis. A list of 124 species is reported in Perlis, of which, Malaysian Nature Society in 2005 has listed 82 species of birds in the Nakawan Range Timah Tasoh region while there are 18 species and free sighters reported additional species (NAHRIM, 2020). The northwest parts of Peninsular Malaysia are common for the homes of vipers. Ground survey indicates the widespread sightings of snakes such as vipers, cobras, kraits, leaf snakes, water snakes, sea snakes and the monitor lizards. There are also frequent sightings of turtles.

6. Governance

Currently, the agency responsible and accountable for the management of Timah Tasoh Dam is the Department of Irrigation and Drainage (DID). However, there are several key issues identified in the current management of Timah Tasoh which include performance measurement effectiveness for the vision and strategic plan that has been implemented for the conservation and tourism development of Timah Tasoh, which need additional maintenance budget allocation for watergate, drainage system and waste disposal. There is no specific management guidelines for Timah Tasoh, limited funding for Timah Tasoh's improvement, and accurate information dissemination to the local community related to flash flood routing system. Furthermore, this dam is also affected by garbage disposal by visitors (NAHRIM, 2020).

For this study, the ESSVA concept has been applied. The Political, Environmental, Social, Technological, Economical, and Legal (or better known as PESTLE analysis) was used to analyze the key player's involvement. The PESTLE is then mapped against the six governance pillars: policy, institutional, participation, information, technology, and financial.

Based on the PESTLE analysis, DID contributes to the policy pillar by assisting lake management and ensuring that public users' policy is in place. There is a well-defined SOP for lake operation for the institutional pillar, and all key players perform excellently. However, there is still room for improvement in terms of communication and monitoring. Although there is existing technology to assist them with water quality checking, key players have expressed a strong desire for additional and new technology to improve current conditions. In terms of the finance pillar, these lakes are funded by the state and federal governments. According to current conditions, the dam, watergate, drainage system, and waste disposal system require additional maintenance budgets.

7. Conclusion

This study indicated that the environmental and water level at Timah Tasoh dam has slightly continued to be affected by the climate factors, agricultural, quarrying, and municipal work. According to current conditions, the dam, watergate, drainage system, and waste disposal system require additional maintenance budgets. Fortunately, in 2021 the State Government of Perlis allocated some budget for conservation surrounding the Timah Tasoh, safety gate surrounding the protection area of Timah Tasoh and upgrading Timah Tasoh Dam Phase 3.

Acknowledgements

Thanks to the Perlis state government as well as state government agencies for their assistance and cooperation in conducting this study. Thanks also to UniKL as a research partner.

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GIS Representation for flood vulnerability index in Morelia City, Michoacan, Mexico

C.X. Roblero[1], S.T. Sánchez[1], J.J. Madrigal[1]

Abstract

As urban areas that are close to tributaries and with little city planning expand both geographically and demographically, the risk of flooding increases. Although it would be thought that floods depend solely on excess rainfall, there are several factors that are part of this problem, such as geographical location, topography, land use, etc. Therefore, the determination of a flood vulnerability index requires a thorough spatial representation process that goes hand in hand with numerical analysis; for this, geographic information systems are used, which are now essential in any branch of science and technology, This is especially necessary in the analysis of this work, since by spatially obtaining information on areas vulnerable to flooding it will be possible to provide solutions for resource management, urban planning, logistics, since it is possible to capture, store, manipulate, analyze and display the information available, thus it will be possible to identify the most vulnerable areas, the reasons that make these areas vulnerable and therefore find targeted solutions for each situation.

Keywords: *Flooding, geographic information systems*

[1] UMSNH, Michoacan, Mexico.

1. Introduction

Geographic information systems are a formidable tool for solving theoretical and practical problems, in addition to their potential for achieving significant progress in each of the aforementioned areas.

It is important to have both spatial and temporal information, both from the existing bases as well as those to be designed in the short and medium term in relation to this concept. Both in Mexico and internationally, GIS geographic information systems applied to watersheds have been used as tools for the determination of the physiographic characteristics of the watershed (surface, slope, drainage network, shape), determination of land use change, hydrological balances, hydraulic planning and management, sediment and pollutant transport, hydraulic modeling for the determination of flood areas, droughts, climate change, agricultural boundaries, land use changes, deforestation, etcetera.

GIS is understood as a spatial analysis procedure, since it is a systemic tool that allows the management of information to facilitate the analysis of various dimensions of the same problem, hence the need to build a GIS, which will allow us to interpret the results in cartographic form and which will be practically useful for public policy decision-making.

The definition of vulnerability has been enriched over the years as a result of all the studies in which the term is used. The United Nations (1979) has defined vulnerability to floods as the degree of loss for a studied element.

The parameters and indicators should be designed to produce information for specific target areas and should mitigate the different hazards that societies face, such as floods (Davidson and Frickel 2004).

This paper is based on the following definition of vulnerability, which relates directly to flooding and cites the degree to which a natural or manmade system is susceptible to flooding due to exposure, a disturbance occurring with its ability (or inability) to cope, recover or adapt. (Balica and Wright 2009). This paper focuses on assessing flood vulnerability at the urban scale by applying the FVI methodology developed by Karmaoui-Balica (2019).

The indicators used show the variables that have a bearing on flooding and provide an important tool for decision making, monitoring and evaluation of changes over time. They help to determine which are the priority components in the affected sectors in order to take the necessary measures.

2. Materials and methodology

The processed information and the preparation of thematic maps are related to elements of the basin's hydraulic infrastructure, location and registration of hydrometric and climatological stations, sub-basins and drainage network, state and municipal divisions, communication routes, dams, irrigation districts and socioeconomic activities.

The objective of this process is to locate the areas that present vulnerability to flooding due to various indicators which are also represented in the Geographic Information System.

In the non-geographic phase of the planning process, the surface area goals to be achieved in the study region for each of these land uses must be established. In other words, to determine the amount of area in the region that should be allocated to cover the intended objectives,

The reception capacity at each point depends, as we have already mentioned, on two issues, and the concept of "point" of the territory varies depending on the type of representation that is being used in the process in this case an analysis by block is performed, since this is how they will be analyzed to know the potential impact that can be produced in each of them.

Among the variables that this methodology will analyze are mentioned:

CLIMATIC COMPONENT

$IVI_c = [Hr]$ [1] Hr = Pouring Rain

PHYSIOGRAPHIC COMPONENT

$$IVI_f = \frac{[T, Pr]}{[Dsc, Rd]} \qquad [2]$$

T = Topography
Pr = Proximity to River
Dsc = Dams
Rd = River Discharge

LAND USE COMPONENT

$$IVI_{lu} = \frac{[Cr, In, Ug, Ds]}{[Ga]} \qquad [3]$$

Cr = River Contact
In = Inequity
Ug = Urban Growth
Ds = Drainage System
Ga = Green Areas

ANTHROPOGENIC COMPONENT

$$IVI_{an} = \frac{[Pr, Pfa, C, H, Cp, Dp]}{[Ed, Es]} \qquad [4]$$

Pr = Proximity To River
Pfa = Population In Flood Area
C = Cultural Heritage
H = Human Development Index
Dp = Disabled Persons
Cp = Communication Penetration
Ed = Evacuation Routes
Es = Emergency Service

ECONOMIC COMPONENT

$$IVI_{ec} = \frac{[Pr, Un, In]}{[Dsc]} \quad [5]$$

Pr = Proximity To River
Un = Unemployment
In = Inequity
Dsc = Dams

ACCESS TO SERVICES COMPONENT

$$IVI_{as} = \frac{[Dp, Cp]}{[Ed, Hs]} \quad [6]$$

Dp = Disabled Persons
Cm = Infant Mortality
Cp = Communication Penetration
Ed = Evacuation Routes
Hs = Hospitals And Shelters
Es = Emergency Services

According to Balica (2009) a society is vulnerable to floods due to three main factors: Exposure, Susceptibility and Resilience. In this work, various indicators are normalized for each selected spatial scale and this numerical index reflects the flood vulnerability status for each region.

The general equation of IVI (Equation 7) links the values of all the indicators and factors mentioned above to obtain the general index.

$$FVI = \frac{Exposure * Susceptibility}{Resilience} \quad [7]$$

The indicators belonging to Exposure and Susceptibility increase the Flood Vulnerability Index, therefore, the Resilience indicators decrease the value of this index and that is why they are placed in the denominator.

The flood vulnerability analysis is performed through a detailed evaluation of all the components, which are gathered and calculated to obtain the global vulnerability after being standardized from 0 to 100 using the following formula: (Equation 8)

$$FVI_{Standardized} = \frac{[FVI_{Scale}]}{[FVI_{Max}]} \quad [8]$$

The general equation links the values of all indicators to the flood vulnerability components and factors.

$$FVI_{Standardized} = \frac{[FVI_C + FVI_{ph} + FVI_{lu} + FVI_{an} + FVI_{ec} + FVI_{as}]}{[No.components]} \quad [9]$$

3. Results and discussion

Figure 1. *Climate component.*

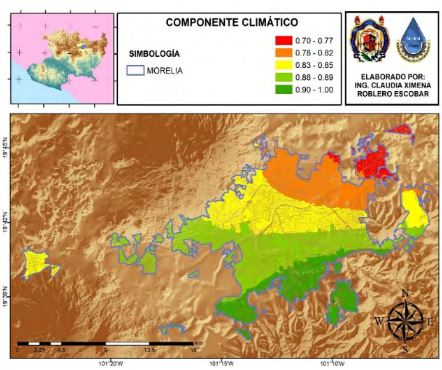


Figure 2. *Physiographic component.*

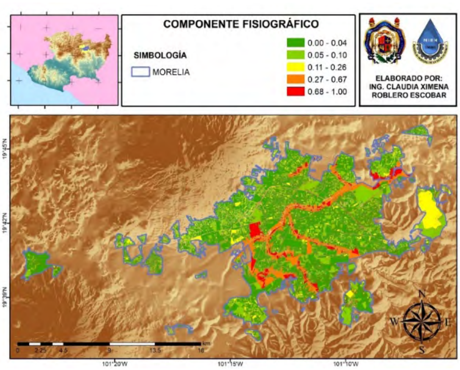


Figure 3. *Land use component.*

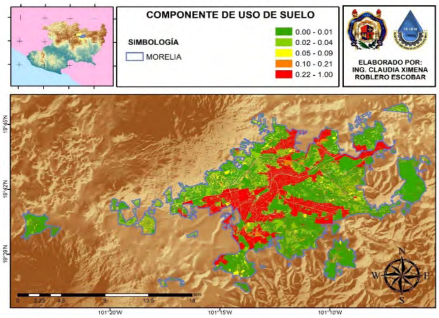


Figure 4. *Physiographic component.*

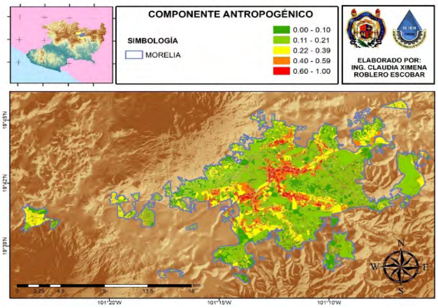


Figure 5. *Economic component.*

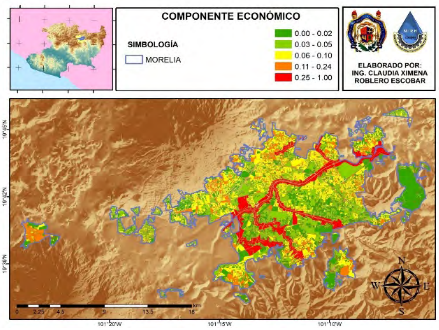


Figure 6. *Service access component.*

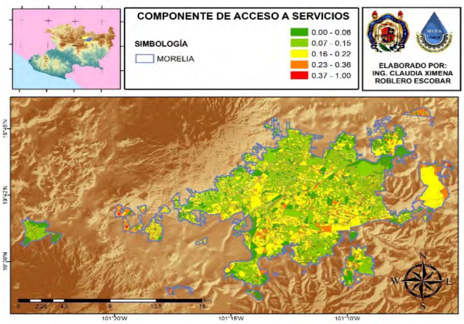
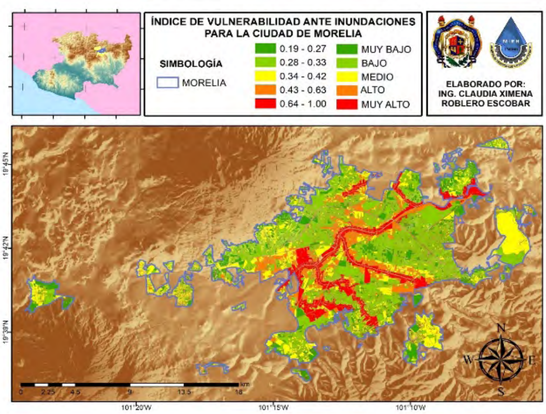


Figure 7. *Flood Vulnerability Index for Morelia City (Block Scale).*



The methodology used is based on several indicators for different factors and different spatial scales focusing on urban flooding and can be reflected in the values of exposure, susceptibility and resilience. This index can be adapted to different uses, depending on the information available.

The proposed methodology makes it possible to identify risks and assess vulnerability to floods. It makes it possible to know the priority components and sectors of vulnerability to floods in order to take urgent adaptation measures.

It has been possible to construct and propose a first static index based on the processing of information which, according to discussions held with professionals with expertise in the area, is acceptable since it does represent a latent problem in the city.

The index is a complete and easily updatable database due to the way in which the analysis was carried out, i.e. taking as a minimum cell each of the blocks that the city now has.

The index is constructible and according to the information with which it is worked, that is to say, depending on how reliable or well treated it is, it will give values that are increasingly closer to reality.

The indicator maps, by themselves, also represent other problems in a visual way, which are considered as important collateral results during the development of this project.

The analysis of the data gives us a better understanding of the current situation in Morelia, which is of utmost importance due to the amount of floods that have been experienced and problems caused to the population. With this system implementation we have a considerable advantage by having the ability to provide valuable time for the timely development of evacuation measures and / or attention to any possible disaster caused by flooding.

4. Conclusion

Flood vulnerability has spatial, socioeconomic, demographic, environmental and physical contexts, in which the spatially represented risk assessment index provides an overview of the degree of risk of a flood disaster in an area.

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Statistical analysis of the growth of *Rhodococcus gordoniae* and *Exiguobacterium indicum in the presence* of As(III)

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Abstract

The present work shows the behavior of growth in the presence of As(III) of two bacteria: R. gordoniae (R:g) and E. indicum (E.i). Where, by the application of an ANOVA (analysis of variance) and Tukey analysis, it was possible to define the optimal time of growth, that for R. g was 48 hrs and for E.i was 24 hrs. According to ANOVA, there are differences in growth between the bacteria after 24 hrs of growing, where R.g was the strain with major capacity of interaction with As(III) defined by Tukey analysis. The statistical methods show the capacity of bacteria to interact with As(III), and make them a plausive candidate to bioremediation processes.

Keywords: *Bacteria, arsenite resistance, water treatment*

1. Introduction

Conventional technologies (physicochemical processes) for arsenic (As) removal from water have high efficiencies, unfortunately, they are not af-

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fordable for decentralized water treatment systems, and to remove low As concentrations, they also generate a considerable amount of by-products that increase operating costs [1]. Biotechnology offers an affordable alternative to the above. Due to the fact that there are a diverse number of organisms capable of biotransforming As [2], among these reactions, the arsenite (As(III)) bacterial oxidation is one of the mechanisms that has attracted most attention as a substitute of the use of chemical reagents, so that after this reaction is carried out, once in As(V) form it is precipitated and removed it. This summary shows the results of the statistical analysis of the kinetic growth of 2 bacterial strains in presence of As(III), isolated from the mining district of Xichú, Gto. [3]. Through the ANOVA analysis (P>0.05), its growth capacity in the presence of As(III) (100 μg L^{-1}) (optical density (O.D)) was corroborated. Optimal growth times were identified by Tukey's multiple comparison method, 48 hrs for *R.g* and 24 hrs for *E.i*, as well as differences in their growth, where *R.g* showed similarities to a chemilitoautotrophic metabolism, while *E.i* resembles one heterotroph metabolism. Biotechnology is an option for decentralized water treatment systems (rural areas) and for removal of low concentrations of As, especially in developing countries.

2. Materials and methodology

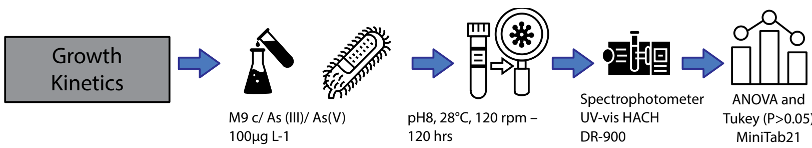
2.1 Growth kinetics

In order to observe the growth time of the isolates, growth curves were planned with the bacterial strains *Rhodoccocus gordoniae* and *Exiguobacterium indicum*, in M9 medium with 100 μgL^{-1} of As(III) each one. Incubation conditions: temperature 30 °C at 120 rpm for 8 days (Figure 1). Each assay was measured every 24 hours. Absorbance was measured at 600 nm in a Uv-vis Spectrophotometer. The bacterial strains were isolated by previously works from the Xichu river.

2.2 Statistical analysis

Initially, the determination of Normality (Shapiro-wilk test), Homogeneity (Bartlett test) and independence (Durbin Watson test) of the data obtained was carried out. The experiments in this study were performed in triplicate (n = 3). The growth kinetics were performed using a factorial designs "A*B" of two-factor 8 × 2 (time and strain), where the "A" factor has eight levels (0-168 hours) and the "B" factor has four levels (*R.g*, and *E.i*), respectively. Data obtained from the factorial design were analyzed by two-way ANOVA analysis, and the Tukey multiple comparisons method ($P < 0.05$ and level of significance of $\alpha = 0.05$), the above by using the MiniTab 2019 software. This to corroborate the growth of the strains and identify the differences in their growth in contact with As (III).

Figure 1. *Methodology diagram of growth kinetics.*



3. Results and discussion

3.1 Growth kinetics

R. g was the strain with major growth in presences of As(III) $P > 0.05$ (figure 2) in this study. Showing a significative difference in growth since 24 hrs ($P > 0.05$) in comparation with other strain in study. Its optimal growth time (exponential phase) was defined at 48 hrs, this strain does not show difference in growth from this moment ($P < 0.05$) (Table 1). On the other hand, *E. i* shows a similar growth, presenting an exponential phase in 24 hrs and entering in its stationary phase from this moment ($P < 0.05$) (Table 1)

Figure 2. *Growth kinetics of the bacteria strains in presences of As(III) 100µg L-1.*

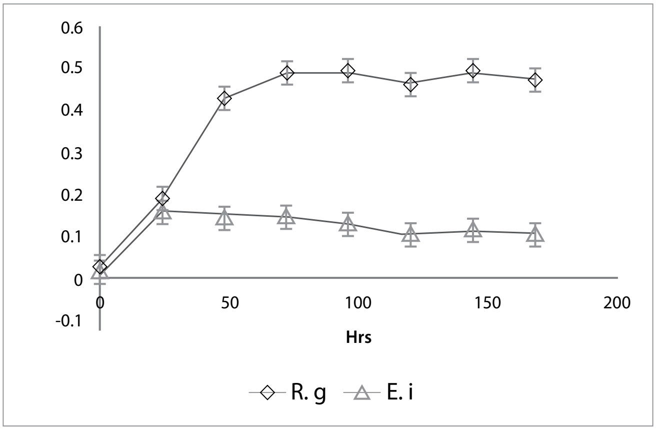


Table 1. *Tukey analysis of the strains.*

Strains*Time	Media	Grup					
R. g 96	0.495675	A					
R. g 144	0.494275	A					
R. g 72	0.489558	A					
R. g 168	0.471892	A					
R. g 120	0.463575	A					
R. g 48	0.431825	A					
R. g 24	0.190292		B				
E.i 24	0.1612		B	C			
E.i 48	0.150892		B	C			
E.i 72	0.149608		B	C			
E.i 96	0.131383		B	C			
E.i 144	0.115058		B	C			
E.i 120	0.106775			C	D		
E.i 168	0.093988			C	D	E	
R. g 0	0.031037				D	E	F
E.i 0	0.01675					E	F

Both bacteria showed a biofilm formation in their growth in the first 48 hrs, being most abundant in *R.g* (Figure 3); this fact is relevant because this form of grow is excellent to adhere to several materials and act as a biofilter. The biotechnology offers an immense range of opportunities, the intrinsic ability of the bacteria to interact with As(III), the formation of value added by-products from this reaction and the possible low cost, make this technology a great opportunity for developing countries to mitigate the As contamination in water [4].

Figure 3. *Biofilm formation by R.g after 48 hrs of incubation in presences of As(III).*

4. Conclusion

R. g was identified by statistical analysis as the major bacterium interactring with As(III), it could be a chemolithotrophic metabolism, defining its optimal growth time at 48 hrs, the log phase represents the most important growth phase to study because it is during this period that occurs the oxidation reaction of As(III), which is one of the bioprocesses most studied to remove As from contaminated water .

E. i showed to be heterotrophic and reached its optimal growth time at 24 hrs. This work contributes to the development of affordable technologies for the bioremediation of As from water by means of bacteria.

Both bacteria were able to grow in form of biofilm in the first 48 hrs.

Acknowledgements

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Status of biodiversity and hydrological studies in Candaba, Pampanga, Philippines

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Abstract

Candaba is home to a variety of fauna, from important native migratory birds to invasive fish species. It is a promising research area with massive potential for further scientific studies in upcoming years. To establish concrete research targets in the area, we herein present the historical trends of current scientific literature from Candaba swamp in terms of the number of publications, list of available data on biodiversity and hydrology, and potential threats to its biodiversity taken from both primary peer-reviewed studies and grey literature. We compiled a preliminary list of flora and fauna from public records of morphological studies. To our surprise, only a total of 21 papers were published, ranging from 1985 to 2020. So far, these encompass studies on birds, fish species, flood assessment, and water quality analysis. The highest number of publication of research papers was attained in the year 2015, that focused on the biodiversity of birds, condition of the land use, and seasonal reproduction of climbing perch. Further studies on fishes have been published from 2010 to 2020 that include biodiversity, cytogenetic analysis, and bioaccumulation of heavy metals. In this way, we offer recommendations on wetland restoration and protection to save

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critical wildlife habitats. Future consideration in providing basic information on the abundance, diversity, identification, and ecology of all species found in Candaba is considered critical.

Keywords: *Candaba, biodiversity, hydrology, swamp, wetland, Pampanga*

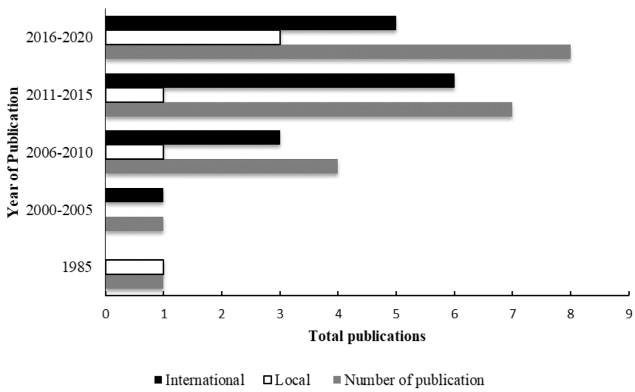
1. Introduction

The Philippines has several wetlands including Las Piñas-Parañaque Critical Habitat and Ecotourism Area, Olango Island Wildlife Sanctuary, Naujan Lake National Park, Agusan Marsh Wildlife Sanctuary, and Candaba wetlands (DENR-PAWB, 2013). Candaba is the second-largest municipality in Pampanga with a landmass of 176 km^2. It is situated between 15°05'36" N and 120°49'42" E. It also represents the lowest point in Central Luzon. The closest municipalities are Arayat, Santa Ana, San Luis, and San Simon. A renowned feature within the basin is the 32,000-hectare Candaba swamp. It is a focal inland wetland where seasonal floodwaters support a distinct faunal and floristic diversity that plays a significant role in the ecological community and ecosystem stability. Currently, the swamp is being utilized to its full potential to contribute to food, economic growth and to improve livelihood opportunities. Seasonal changes essentially affects the inhabitants of the swamp. In fact, during the rainy season, the swamp serves as a sanctuary for migratory birds that are continuously passing through the town from China, Siberia, and the Northern Hemisphere. Thus, the site is considered a tourist attraction for bird watching. Many fish species also enter swamps to breed and spawn as a fishing ground. The dry season provides cultivated rice and other crops production (Melendres, 2014). In addition, swamps act as a natural flood control device and water treatment plant of nature (Gupta et al., 2008). However, human activity modifies these conditions. Agriculture, aquaculture, poultry, human settlements, household, and industrial wastes are areas of concern that could be deleterious to the swamp (Chandran & Mesta, 2001); Navarrete et al., 2018) stated that improper use of pesticides leads to water pollution and infiltration. Therefore, further monitoring of the ecological status and raising environmental awareness are essential to address this domain of interest (Arbotante et al., 2015).

In this concern, we intend to present the status of biological and hydrological studies in Candaba taken from primary peer-reviewed studies and grey literature. We also compiled a preliminary list of flora and fauna from public records of morphological analysis. We aim to discuss potential threats to biodiversity that could provide an outline of publications that may be used by other researchers when finding gaps in research planning.

2. Results and discussion

Figure 1. *The number of local and international publications from 1985 to 2020.*



2.1 Timeline of published scientific research

A total of 21 papers were selected and analyzed, ranging from 1985 to 2020. The earliest research paper published by Sirikantayakul in 1985 explained the life cycle and egg-shell of *Orientocreadium batrachoides* Tubangi, 1931, in *Clarias macrocephalus* Gunther, 1864. In the last decades, another publication about the first authentic record of Latham's Snipe *Gallinago hardwickii* was published in 2002 by Shigeta et al. In addition, the two short notes ranging from 2009 to 2010, record migratory birds such as the black-browed reed warbler and streaked reed warbler. Due to frequent flooding in the area, researchers drew attention to the assessment, management, mitigation, and landscape utilization of Candaba in 2014. Consequently, research papers in 2015 account for the highest number of publications focusing on bird species (Jensen, 2015), fish reproduction (Bernal et al., 2015), and hydrological analysis (Rivera & Navarra, 2015, Arbotante et al., 2015). However, in the years 2016 and 2018, two papers have also been published, respectively. Only 1 paper about fish inventory and fishing practices in the Candaba swamp was published from 2016-to 2020. Overall, an increase in publications provides future researchers to investigate and examine the effects of water on organisms residing in the area.

2.2 Biodiversity and hydrological studies

The only parasitic study in Candaba has been relatively well described by (Sirikantayakul, 1985). The researcher investigated the life cycle, histochemical nature of the egg-shell, systematic status, and the possible control measures for *Orientocreadium batrachoides* infection. Furthermore, the researcher determines the host-parasite relationship between *Lymnaea viridis* and larval stages of *O. batrachoides*. The observation of developmental stages such as egg, miracidium, sporocyst, and cercariae of *O. batrachoides* recovered from *L. viridis* showed the ecology and physiology of the parasite. In addition, various specimens were infected with metacercaria of *O. batrachoides*. The present findings showed that *Clarias macrocephalus* have been pronouncedly infected. The mortality rate of *L. viridis* was recorded as high due to the increased number of eggs per exposure. Similarly, a considerable number of metacercaria died due to extensive exposure to Ultraviolet rays. In contrast, the mortality of the cercariae is variable.

Numerous publications on hydrological studies measuring physical and chemical parameters have been evaluated in the area (Arbotante et al., 2015) performed water analysis in the Pampanga River to detect the pH, temperature, dissolved oxygen, ammonia, nitrate, and phosphate.

Results revealed that the average pH is weakly basic, low dissolved oxygen indicates the occurrence of additional organic pollutants, and the high concentrations of ammonia and phosphates mean poor water quality, which may be attributed probably to anthropogenic activities of the barangays.

Table 1. *List of available data on biodiversity and hydrobiological studies in Candaba, Pampanga.*

Year/s	Parameters	Value/Observation	Reference	Notes
1985	Number of cercariae produced per sporocysts	10-15 cercariae 7-14% (+) infection	Sirikantayakul	Lack of the proper understanding of the parasite ecology and physiology.
2002	*Gallinago hardwickii*	1 species	Shigeta et al.	
2009	*Acrocephalus bistrigiceps*	1 species	Round and Fisher	
2010	Length-weight relationship (LWR) Body shape Gill raker counts *Acrocephalus sorghopilus*	57% introduced species, 43% native species 90% fish weight Varies 1 species	Garcia Santos et al. Round and Allen	Lack of baseline data on fish fauna in the study area Determine the physicochemical as well as genetic factors that could have contributed to such variation
2014	Flood damage assessment α, β, γ Archeology History Ethnography	Physical-based numerical model Satellite-based information Socio-economic factors 1.0, 110% Earthenware pottery Ceramics Porcelain jars	Shrestha et al. Okazumi et al. Melendres et al.	Satellite information should be used as supplementary measures
2015	SL TBW GI GSI pH temperature DO Ammonia Nitrates phosphates Migratory birds Floodable area Run-off	Female-104.15±1.11mm Male 97.63±1.29mm Female40.58±1.23g Male 30.46±1.13g Female 6.3% - 1.8% 3.0%-9.0%, 9.2% Male 3.8%- 4.3% Female 0.3-2.1%, 8.3-5.5% Male 1%, 5.1% 8.29 30.7° C 4.37ppm 0.321 ppm 5.38ppm 0.737ppm 8 species	Bernal et al. Arbotante et al. Jensen et al. Rivera and Navarra	 Intend to continue sampling to monitor the environmental status of the river and raise awareness in the community Lack of ornithological studies Provide a safe and livable human settlement
2016	Flood risk management Chromosomal aberration- breaks, gaps, dicentric and polycentric deserialized, complex sticky and rings	Rainfall run-off model Remotely sensed data Livelihoods Mean T1= 2.333 T2= 2.0 T3=3.33 T0=0	Juarez-Lucas et al. Bostre and Gracilla	Bioaccumulation studies are conducted and actions and programs are designated to remove or reduce the pollutants of the Pampanga River.
2017	Temperature pH DO Electrical conductivity Lead Cadmium Mercury Cadmium	29 ±16.74 to 35.23±1.01°C 8.70± 5.02 to 9.57±1.11 5.20±3 to 7.57±0.77 mg/L 220±0.01 to 489±0.57µS/cm 0.01mg/kg 0.02mg/kg 0.01mg/kg 0.29ppm- 0.4ppm	Sandoval et al. Lace et al. Octura et al	Farmers should be educated on better management practices for feeding and pond management
2018	Calanoid copepods Body size pH DO Conductivity Turbidity Salinity Phosphate Nitrate	1.01-1.10mm 1.07-1.22mm 7.0-8.3 2.5-5.9 SW-0.3-2.47 63-91 4(1)-9(4) 0.0-0.12 2-3x > 0.5mg L^{-1} < 0.7 mg L^{-1}	Guinto et al. Navarette et al.	 Propose biological monitoring using a battery of biomarker tests
2020	Fish	14 species, 14 families	Mallari et al.	Survey and inventory the population of fish species

Similar parameters were detected by (Sandoval et al., 2017), the overall mean value of pH, and DO and temperature were significantly different in the pond area. Subsequently, a high electrical conductivity value indicates a good level of nutrients in the water. Navarette et al. (2018) described the Physico-chemical characteristics of the surface water and groundwater to detect the concentration of organochlorine pesticide in the Pampanga River. Seven organochlorine pesticides were identified on the surface and groundwater along the Pampanga River. They include dieldrin, endrin-aldehyde, β-BHC, δ-BHC, £-BHC, γ-chlordane, and endosulfan II, continuous exposure may have detrimental effects on both humans and organisms. Lace et al. (2017) presented the effects of heavy metal accumulation in the gill tissue of *Oreochromis niloticus*. Such observation reveals profound damage in the tissues of *O. niloticus* like desquamation, necrosis, shortening, and proliferation. Bostre and Gracilla (2016) observed that zebrafish (*Danio rerio*) exposed to heavy metals such as lead and copper showed five different chromosomal abnormalities such as chromatid break, chromatid gap, endoreduplication, fragmentation, and a ring chromosome. Indeed, cadmium can interfere with the development and reproduction of mallard ducks. This study confirmed that Cd accumulates primarily in the liver and ovary at the late laying stage (Octura et al., 2017). Therefore, this observation further highlights the continuous contamination of water in Candaba and its effect on all organisms inhabiting the area.

Comprehensive research on the utilization of the Candaba swamp from prehistoric times up to the present provides us with a wealth of information on the early origins of the area. The researcher explains the archival records, ethnographic data, geographical location, seasonal variation, and diversification of flora and fauna in the area. A change in season affects the richness and abundance of birds, fishes, invertebrates, rats, and snakes. The locals cultivated the land to propagate rice which is one of the products in Pampanga. Furthermore, the people learned to plant other crops such as corn, peanuts, sugarcane, vegetables, and fruit-bearing trees that supply the entire region and nearby areas (Melendres, 2014). Jensen (2015); Round and Allen (2014); Round and Fisher (2002); Shigeta et al. (2002) remarkably recorded different species of migratory birds such as *Acrocephalus bistrigiceps*, *Arcocephalus sorghopilus*, *Gallinago hardwickii*, *Anser serrirostris, Anser albifrons,* *Platalea leurocodia, Vanellus vanellus, Limnodromus scolopaceus, Dicrurus macrocercus, and Motacilla citreola.* With this data, the Candaba wetland is recognized as a bird sanctuary and biodiversity area by the Department of Environment and Natural Resources (DENR). Interestingly, calanoid copepods known as *Praedictus sulawensis* were first identified by the locals. Guinto et al. (2018) hypothesized that migratory birds brought it to our country. Moreover, updated taxonomic classification and morphological characteristics of copepods were carefully examined and recorded.

2.3 Flora and fauna in Candaba, Pampanga

Much scientific interest accounts for the diversity of birds. A total of 85 species of migratory birds visited the Candaba swamp. Wild Bird Club of the Philippines (WBCP) with the Department of Environment and Natural Resources-Biodiversity Management Bureau (BMB) provides us awareness and preservation of Philippine avian biodiversity. Fortunately, these agencies were able to record the number of species and species names by bird watching. The Philippine database indeed established the avifaunal records from published sources. Based on the data, we obtained a large flock of Anatidae. The migration of these birds may be due to several factors, including food procurement, reproduction, nesting, and weather conditions (Barcante et al., 2017). They also serve as an indicator of whether or not an ecosystem is still in a good and healthy condition (Gregory et al., 2010). Even their excrement can be an effective fertilizer as it increases the nutrient levels of the soil. They can be an aesthetic source of pride that attracts tourists. Meanwhile, studies on fish highlight cytogenetic analysis, histopathology, morphology, and physiology. Garcia (2010) has shown the length-weight relationship of 18 fish species, of which Cyprinids are the most dominant. This study is a valuable instrument in fisheries to provide details on the condition of fish species and growth patterns (Radhi et al., 2018). Bernal (2015) describes the seasonal reproductive cycles of *Anabas testudineus.* He noted that *c*ertain factors such as food intake affect the gonadal activity of both sexes that coincides with the season change through the gonadosomatic index (GSI). In addition, these studies would yield baseline data for the conservation and management of ichthyofauna. Melendres (2014) listed some mammals in his paper that account for seven mammalian species, giving their lowest number. Our results revealed that the Candaba Swamp is poor in mammalian wildlife. Even though a significant number of invertebrates thrive in the area, further studies are needed to broaden our understanding of their biological and ecological importance. Furthermore, recent studies on flora focused mainly on the production of watermelon and melon (Urrutia et al., 2014). The authors developed a programming model that enable farmers to gain a higher profit. We also collected records from the Department of Science and Technology (DOST) of the products from sorghum which is now being utilized in Candaba to produce other products such as biofuel, food bagasse, and fodder.

Table 2. *List of fauna and flora in Candaba Swamp.*

Fish*[1] *(n=24)	***Birds*[2] *(n=85)***		
Anabas testudineus	*Arcocephalus sorghopilus*	*Aythya baeri*	*Motacilla flava*
Arius dispar	*Acrocephalus bistrigiceps*	*Aythya fuligula*	*Nycticorax nycticorax*
Barbonymus gonionotus	*Acrocephalus orientalis*	*Bubulcus ibis*	*Passer montanus*
Carassius auratus	*Acrocephalus stentoreus*	*Calidris acuminata*	*Phoebastria albatrus*
Channa striata	*Actitis hypoleucos*	*Calidris melanotos*	*Platalea leurocodia*
Chanos chanos	*Alauda gulgula*	*Calidris subminuta*	*Platalea minor*
Clarias batrachus	*Alcedo atthis*	*Centropus bengalensis*	*Pluvialis fulva*
Clarias macrocephalus	*Amaurornis cinerea*	*Charadrius alexandrinus*	*Porphyrio martinicus*
Cteopharyngodon idella	*Amaurornis phoenicurus*	*Charadrius dubius*	*Porphyrio pulverulentus*
Cyprinus carpio	*Anas acuta*	*Chlidonias hybrida*	*Pycnonotus goiavier*
Glossogobius biocellatus	*Anas clypeata*	*Chlidonias leucopterus*	*Rostratula benghalensis*
Glossogobius giuris	*Anas falcate*	*Cinnyris jugularis*	*Saxicola caprata*
Hypopthalmichthys nobilis	*Anas formosa*	*Circus spilonotus*	*Spilopelia chinensis*
Labeo rohita	*Anas luzonica*	*Cisticola exilis*	*Streptopelia bitorquata*
Leiopotherapon plumbeus	*Anas platyrhynchos*	*Cisticola juncidis*	*Tachybaptus ruficollis*
Leiopotherapon plumbeus	*Anas querquedula*	*Dicrurus macrocercus*	*Todiramphus chloris*
Liza subviridis	*Anser albifrons*	*Falco peregrinus*	*Tringa totanus*
Megalops cyprinoides	*Anser serrirostris*	*Gallicrex cinerea*	*Tringa glareola*
Monopterus albus	*Anthus richardi*	*Gallinago gallinago*	*Tringa nebularia*
Oreochromis niloticus	*Ardea alba*	*Gallinago hardwickii*	*Tringa stagnatilis*
niloticus	*Ardea cinerea*	*Gallinula chloropus*	*Tyto longimembris*
Pterygloplichthys disjunctivus	*Ardea intermedia*	*Gallirallus*	*Vanellus vanellus*
Rhynchorhamphus georgii	*Ardea purpurea*	*Limnodromus scolopaceus*	
Trichogaster pectoralis	*Ardeola bacchus*	*Locustella ochotensis*	
Trichogaster trichopterus	*philippensis*	*Lonchura castaneothorax*	
	Glareola maldivarum	*Lonchura punctulata*	
	Grus sp.	*Megalurus palustris*	
	Himantopus himantopus	*Megalurus timoriensis*	
	Hirundo tahitica	*Merops philippinus*	
	Hydrophasianus chirurgus	*Motacilla citreola*	
	Ixobrychus cinnamomeus		
	Ixobrychus flavicollis		
	Ixobrychus sinensis		
	Lanius cristatus		

Mammals3 (n=7)	***Invertebrates 4 (n=18)***	***Flora 5 (n= 22)***
Bos Taurus	*Belostoma sp.*	*Abelmoschus esculentus*
Bubalus bubalis	*Bracchionus diversicornis*	*Arachis hypogaea*
Capra aegagrus hircus	*Brachyura sp.*	*Artocarpus heterophyllus*
Rattus argentiventer	*Chironomus sp.*	*Carica papaya*
Bubalus bubalis carabanensis	*Cladocera sp.*	*Citrullus lanatus*
Ovis aries	*Corixa sp.*	*Cocos nucifera*
Sus scrofa domesticus	*Gerris sp.*	*Cucumis melo*
	Gyrinus sp.	*Cucumis sativus*
	Libellula sp.	*Cucurbita maxima*
	Lymnaea sp.	*Eichhornia crassipes*
	Macrobrachium sp.	*Luffa aegyptiaca*
	Mercenaria mercenaria	*Mangifera indica*
	Mytilus edulis	*Momordica charantia*
	Notonecta sp.	*Musa sp.*
	Pila luzonica	*Nelumbo nucifera*
	Planorbarius sp.	*Nymphaea nouchali*
	Praedictus sulawensis	*Oryza sativa*
	Zygoptera sp.	*Phaseolus vulgaris*
		Saccharum officinarum
		Solanum lycopersicum
		Solanum melongena
		Zea mays

More so, Fantastic F1 (tomato) and a lotus-like flower called "tukal" were introduced in barangay Mangumbati, Candaba, and Pampanga (see agriculture.com.ph).

2.4 Potential threats to fauna and flora

Over the years, the Candaba swamp has provided countless benefits to the ecosystem and humans. Its plays a vital role in protecting the ecosystem diversity, maintaining the hydrological cycle, and providing direct and indirect services to human beings (Xu et al., 2019). However, the Candaba swamp has been radically altered and increasingly degraded due to several factors like agriculture, aquaculture, human interference, invasive species, pollution, and climate change. Navarette et al. (2018) explained that organochlorine pesticides residues coming from the farms nearby could directly contaminate the surface water and groundwater, thereby affecting the residents and other organisms residing in the area. Similarly, studies on the population of Philippine duck and the morphology of Nile tilapia (*Oreo-*

chromis niloticus) show how profoundly affected they are by agricultural runoff with pesticides, fertilizers, and animal manure that flows into the swamp and river. Findings indicate a decline in duck production (Octura et al., 2017) and abnormal tissues of Nile tilapia (Lace et al., 2017) due to exposure to heavy metals like cadmium, lead, and mercury that cause damage to the reproductive organs and tissues, respectively. Another challenge covered in one study was the accumulation of heavy metals that revealed different chromosomal abnormalities in zebrafish (*Danio rerio*) (Bostre and Gracilla, 2016). In addition, Arbotante et al. (2015) identified the sources of pollution and water quality by determining dissolved oxygen (DO), ammonia, and phosphorus concentrations. Thus, contamination of water poses risks to organisms and human health.

Recently, a survey of migratory birds conducted by the Department of Environment Natural Resources together with the Asian Waterbird Census (AWC) obtained the following data: 17,000 in 2008, 13,160 in 2010, 8,725 in 2011, 10,456 in 2012, 5475 in 2013, 5,149 in 2014, 3,596 in 2015, 5145 in 2016 and 6,467 in 2017. The results show a rapid decline in the population of migratory birds. Most evidence points to habitat destruction and alteration, anthropogenic activities, and climate change (Gonzalez-Oreja, & Zuberogoitia, 2020). The declining number of migratory birds at Candaba was copiously blamed on bird hunting, trapping, poaching, and killing. Moreover, climate change has posed a problem in the country that alters the patterns of altitudinal migration, behavior, and distribution of birds (Barcante et al., 2017). Prolonged dry seasons and extreme flooding may drive the birds away from the site that subsequently depends on available food supply and shelter.

3. Conclusion

Candaba swamp encompasses basic information on the abundance, identification, and assessment of water quality. Seasonal inundation provides Candaba swamp with a fishing ground and bird sanctuary (Juarez-Lucas et al., 2016). Presently, the land area has been reduced to 32 hectares to protect the diverse wildlife and rehabilitate the swamp. The local government units

(LGUs) undertake a campaign against hunting, electric fishing, pollution, and the use of pesticides and insecticides. In this paper, we present our perspectives on the status of the Candaba swamp by presenting the past and current studies to look for future possibilities in academic and research topics to achieve sustainable development. The opportunity to explore the Candaba swamp gives us new knowledge and insights about wildlife and ecosystem services. The impact of hydrological change dramatically affects the organisms thriving in the area. However, further analysis of the ecological stability and the hydrological conditions should be elucidated to establish better plans for the long-term management and monitoring of the Candaba swamp. We suggest that stakeholders and local governments venture into Geospatial technology and GPS tracking devices necessary to acquire more data for monitoring and reporting species diversity and landscapes. In this way, we might be able to disseminate awareness about wetland restoration and protection. Furthermore, this benchmark data could be a source of information in doing future research, most especially on the biodiversity, taxonomy, molecular analysis of existing flora and fauna, and the resilient management planning of Candaba wetlands. We also encourage people to be more responsible and vigilant to address ongoing and emerging threats in the Candaba swamp.

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The UNESCO World Heritage Committee and the Ohrid Region: a saga of deception

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Abstract

Since 1972, the Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention) has aimed at identifying, protecting, conserving, presenting and transmitting Earth's most precious natural and cultural heritage for present and future generations of humankind. To 2021, it covers numerous lacustrine features of global importance. Nonetheless, the Convention risks failing in its mission to conserve and protect due to anthropogenic pressures. Here, weaknesses in its implementation are presented with the specific example of the Natural and Cultural Heritage of the Ohrid Region, where ancient Lake Ohrid, a hotspot of endemic aquatic fauna, has experienced decades of increasing threats and declining ecological conditions despite its concurrent UNESCO World Heritage Site status.

Keywords: *UNESCO, World Heritage, World Heritage Committee, ancient lake, Lake Ohrid*

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1. Introduction

Covering 190 United Nations (UN) member and 4 non-member states (hereafter States Parties) as of 2021, the Convention Concerning the Protection of the World Cultural and Natural Heritage, commonly known as the World Heritage Convention, was adopted at the November 1972 General Conference of the United Nations Educational, Scientific and Cultural Organization (UNESCO) with the expressed mission to identify, protect, conserve, present and transmit to future generations those aspects of our planet's nature and human culture perceived to have Outstanding Universal Value (OUV) to all humankind. The adoption was undertaken in consideration of the increasing threat of heritage destruction due to social and economic change as well as the duty of the international community to participate in the alleviation of such pressure (World Heritage Committee, 1972).

To achieve this task, under Article 11 of the Convention, a World Heritage List was established upon which locations (hereafter referred to as World Heritage Sites or WHS) would be designated, provided that they passed certain criteria to demonstrate OUV. These were to become the focus of heritage preservation under the auspices of the governments of their respective states, yet also with assistance and cooperation from an international body composed of 15 (later rising to 21) elected UN States Parties known as the World Heritage Committee (WHC). The WHC was to receive support in the implementation of its Decisions by a Secretariat (the World Heritage Centre since 1992) and advice from three specialist advisory bodies for culture and nature respectively: ICOMOS, ICCROM and the IUCN.

The World Heritage List was unveiled in 1978. Just one year later, the first specific designations for lacustrine phenomena were enshrined: Plitvice Lakes and Lake Ohrid both in then-Yugoslavia. With extant inland waters now mentioned in official descriptions for about 72 natural or mixed natural/cultural WHS[1] under 46 States Parties across the globe, the World Heritage Convention has since become a major tool in efforts to protect

[1] Approximated by searching for the keyword "lake" in the description for every natural and mixed WHS on the official website for the UNESCO World Heritage List (www.whc.unesco.org/eng/list/) as of January 2022, discounting lakes which have desiccated or lie outside WHS boundaries, and saltwater lagoons.

Earth's most scientifically and biologically precious freshwaters. However, there are fears that implementation weaknesses, including monitoring deficiencies and decisions motivated more by politics than conservation (Meskell, 2015; Dalberg Advisors, 2019), combined with an unprecedented scale of anthropogenic stress are facilitating heritage deterioration. The following paper examines this perspective via the example of the aforementioned Lake Ohrid, an ancient inland water on the border of the present-day Republics of Albania and Macedonia in South East Europe.

1.1 Lake Ohrid: overview

Located in a tectonically active graben at 693 m above sea level, Lake Ohrid formed to its current deep-water conditions 1.3 to 1.9 million years ago (Wagner et al., 2017). As such, it is the oldest lake in Europe, but also the deepest by average depth (155 m). Its inflow is characterized by the high proportion of water (roughly 50%) supplied by terrestrial and sublacustrine springs, which arrives via filtering underground channels in a karstic massif and national park, Mount Galichica, to the lake's east. These are fed almost equally by precipitation seeping into the karst and a sister lake, Macro Prespa, which lies further to the east on the other side of the same mountain. Direct precipitation and surface tributaries make up the remaining inflow, contributing to a 289 m deep (maximum), 30.4 km long and 14.7 km wide waterbody with a residence time of 70 years, a full mixing regime once about every 7 years, and a single outflow to the north via the River Black Drim.

Lake Ohrid's exceptional longevity, oligotrophic conditions and habitat heterogeneity furnished by features such as its remarkably stable springs have enabled relict species to endure the processes that drove them to extinction elsewhere and entirely new taxa to evolve in-lake too. In total, over 200 endemics are represented among at least 1,200 native species. Consequently, Lake Ohrid's 358.18 km^2 extent is believed to be the most biodiverse inland water on the planet when measured by endemicity to surface area (Albrecht and Wilke, 2008). In addition, the humid and comparatively mild climate guaranteed by its waters has established a refugium for surrounding terrestrial habitats, contributing to elevated species richness and regionally rare wetland flora (Sadori et al., 2016; Spirovska et al., 2020).

Much of this information is stored in sediment archives that are comparatively unique in the world in terms of their length, quality and continuity. These are revealing the climatic, evolutionary and environmental history of the lake and surrounding region over hundreds of thousands of years (Wagner et al., 2017; Wilke et al., 2020).

2. World heritage recognition

Reflecting the complex interplay between geography and politics that often afflicts conservation, Lake Ohrid's 1979 nomination to the World Heritage List was opposed by the IUCN as the Albanian third of the lake and a large portion of its watershed were not contained in the application boundaries (WHC, 1979). That notwithstanding, the WHC accepted the nomination, and, in 1980, the scope of the designation was extended to include cultural values: The Ohrid Region became the second WHS to received mixed recognition, i.e. for both nature and culture. To date, only 39 locations hold this honor.

The terrestrial boundary was amended marginally in 2009, before, in 2019, the site was finally enlarged to incorporate the Albanian portion of Lake Ohrid as well. Thus, under the title Natural and Cultural Heritage of the Ohrid Region, the entire of Lake Ohrid is now enshrined on the World Heritage List within a 94,728.6 ha WHS, although parts of the watershed, including a significant share of National Park Galichica, are still excluded even from the buffer zone (UNESCO, 2020). For nature, it is designated under Criterion (vii) as containing "superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance."

3. 40 years of UNESCO

The OUV statement that justifies Lake Ohrid's fulfilment of Criterion vii specifically mentions oligotrophic waters, freshwater refuge, endemic species, and birdlife. Yet indications for all of these factors suggest serious decline, including during the WHS era: Phosphorus concentrations in 2007 were already 3.5-fold higher than 100 years beforehand and inputs believed to require a 50% reduction to secure sufficient oxygen for benthic organisms in future decades (Matzinger et al., 2007). Although pelagic total phosphorus and Secchi depths are generally held to reflect stable oligotrophic conditions, dissolved oxygen has been decreasing and total phosphorus increasing in deep waters (150 m+) over the last 20 years (Giamberini et al., 2020). Measures based on the macrophyte index reveal immense to massive pollution at 14 of 29 locations around the lake perimeter at depths of 0-2m (Trajanovska et al., 2014). Carlson's Trophic State Index has further recorded mesotrophic and eutrophic conditions for the littoral close to river inflows and tourism facilities, particularly during summer (GiZ, 2017a).

For endemic flora and fauna, the situation is alarming Among *Gastropoda*, from 56 species considered unique to Lake Ohrid or its springs, no less than 44 are threatened according to the IUCN Global Red List. One, *Ohridohauffenia minuta,* is very possibly extinct (Hauffe et al., 2010). Most other species categories containing endemics are only partially assessed if at all: For example, of 5 trout taxa endemic to the lake, only one, *Salmo ohridanus*, has a Global Red List Entry: Vulnerable. All the others are Data Deficient, although two, *Salmo letnica* and *Salmo lumi*, do have entries on the Albanian National Red List, where they are Vulnerable and Endangered respectively. The little public data that exists for ichthyofauna, largely compiled for the Macedonian fishery, implies a crisis too: Total catch of commercially desirable fish, constituted predominantly of *S. letnica* and *S. ohridanus*, had dropped to under a third of its 1988 peak in Macedonia by 2003, when data collection was discontinued (Ministry of Environment and Physical Planning, 2020). More recent attempts to assess piscine populations have barely discovered any salmonids at all, suggesting that the composition of the lacustrine ecosystem may be switching towards cyprinids and non-natives (Spirovski, 2017). Macroinvertebrates and diatoms, two groups which display high levels of endemic species, are signaling a shift to cosmopolitan and pollution tolerant taxa (Lorenschat et al., 2013; Cvetkoska et al., 2018). Birdlife is no less concerning: International Waterbird Census results for the Macedonian side of Lake Ohrid show a crash from 79,000 in 1989 to a post-2010 average of 21,319 (Ministry of Environment and Physical Planning, 2021), albeit with a 20-year data vacuum in between.

Habitat trends imply that the lake's freshwater refuge is imperiled too: The Shorezone Functionality Index reveals that 75% of Lake Ohrid's coast is no longer able to perform basic ecological functions, including 72.2% of the Macedonian territory that had held UNESCO status up to the time of assessment (GiZ, 2017b). Wetlands have continued to degrade: 19% of core habitat at Studenchishte Marsh, the last fully functional habitat of its kind along the shore, was lost from 1984 to 2015 (Apostolova et al., 2017). Government figures suggest a 16.13% shrinkage since 2014 too (Ministry of Environment and Physical Planning, 2020). Of 11 nationally rare plant taxa once found at the marsh, 7 are thought to be locally extinct (Spirovska et al., 2020).

4. Threats

The watershed has experienced widescale urbanization over the past 40 years, an explosion of planned and unplanned growth that has resulted in a minimum of 20,000 illegal constructions in the WHS (State Audit Office, 2020a, 2020b), some even concreting the shore or erected over water. Driven in part by a tourism industry that sees an influx of at least 1,000,000 visitors per year to the Macedonian side of the lake alone, a slew of hotels, apartments and holiday homes couples with an overcapacity wastewater system covering only 72% of the basin population; unsealed landfills in karst terrain; wetland conversion; unregulated dumpsites; uncontrolled boat traffic; overfishing; illegal fishing; mine pollution; effluent and run-off from industry; noise and light pollution; spring capture; climate change; overuse of agricultural chemicals; fires; manipulation of riverbeds; and hydroelectric dams that block the migration route for critically endangered *Anguilla anguilla* and drain the water level, sometimes below legal parameters (Kostoski et al., 2010; Monetti et al., 2020; IUCN, 2020).

In recent years, plans for various infrastructure projects have been added to these existing threats in the watershed, including an express road, highway, railway, marina, gas pipeline, watersports complex with luxury housing, ski-resort, additional hydropower, three industrial development zones, and several tourism development zones. Around half of these are still moving forward, alongside other, smaller projects.

5. UNESCO reaction

The WHC has made 15 Decisions for the Ohrid Region WHS in 42 years, although not all concern threats. In addition, the World Heritage Centre and/or its advisory bodies have made reactive or advisory missions to the site on 5 occasions: 1998, 2013, 2017, 2019 and 2020. Each resulted in advice and recommendations. However, cross-referencing mission reports and WHC Decisions with the situation on the ground reveals serious delays, deficiencies and questionable qualitative conclusions.

For example, as early as 1998 (UNESCO), the World Heritage Centre, ICOMOS and the IUCN conducted a mission to the Ohrid Region and concluded that an "enormous increase in constructions and settlement activities has seriously altered the original balance in the region". They advised changes to the legal framework and extension of boundaries to include all of National Park Galichica. However, it was not until 2014 that a WHC Decision explicitly addressed the development issue; multiple constructions are still proceeding; large parts of the national park remain outside the WHS in 2021; and the legal framework is still deficient in regard to scope, exceptions and enforcement (Ohrid SOS, 2020, 2021; UNESCO, 2017, 2020).

The wastewater system has been a weakness too. Despite investment on both sides of the lake in the early 2000s, overflows of sewage were estimated to occur 100 days per year into just the Macedonian portion by 2012 (JICA, 2012). Only in 2017 did the WHC request action with Decision 41COM 7B.34. Yet by 2019, it was noting progress with satisfaction even though remedial work had not begun at the time (WHC, 2019). To 2021, some maintenance and replacement of pumps has now been undertaken, but overflows still occur; the network has not expanded; and the main treatment plant still cannot operate beyond 50% capacity (Ohrid SOS, 2021).

The same WHC Decision from 2019 praised action with the River Sateska, which was artificially routed to enter Lake Ohrid in 1961, subsequently becoming a source of 39% of the total phosphorus inflow from tributaries and 47,678m^3 of sediment annually. Technical documents to redivert the river to its original path were first produced in 1998. Although the project to return the river has been recently revived, it is still at a similar stage of completion now. In the meantime, the Sateska's sediment trail has stretched 4-5 km into the lake from the river's mouth (Mihajlov, 2021).

6. State party intransigence

Focusing on Macedonia as the long-term holder of WHS status at Lake Ohrid, in response to UNESCO pressure, authorities at the local and national level have demonstrated adeptness at delaying meaningful action; selectively reporting; and avoiding interventions recommended by World Heritage Centre, ICOMOS and IUCN missions, even when they have been underlined by WHC Decisions. Indeed, of 19 such recommendations from 2017, the majority are partially or entirely incomplete (UNESCO, 2020).

Illegal construction is a case in point: Macedonia was called upon to inventory, assess and remove harmful structures built contrary to law via Paragraph 7 of WHC Decision 41COM 7B.34. In the 4 years since, no full inventory is known to exist; and no impact assessments have been conducted. Instead, deadlines for legalization of outlaw structures have been extended and new illegal construction completed. Despite this, around 30 objects have been deconstructed and Macedonia has used these examples to report progress to the World Heritage Centre and WHC, omitting the detail that some have been only partially removed and others have returned to operation post-demolition (Ohrid SOS, 2021).

The same Decision required a moratorium on any coastal or urban transformation in the WHS until effective control and juridical mechanisms were established. Despite the Macedonian Ministry of Culture (2018) implying in a progress report to UNESCO that a moratorium was achieved in 2018, none was actually announced until 2020. Then, it only lasted a few months; contained exceptions for almost any kind of construction; and allowed approved building permits to proceed (UNESCO, 2020). Juridical upgrades are not in evidence and the Commission on Management of the

Natural and Cultural Heritage of the Ohrid Region, established as a control mechanism, lacks independence and true power under law.

Obfuscation takes other forms: In 2019, Macedonian representatives presented a new Law on Management of the Natural and Cultural Heritage of the Ohrid Region to the WHC's 43rd Session to demonstrate commitment to conservation, but the law was withdrawn from parliament almost as soon as the session finished. It is yet to reappear. Similarly, the State Party seems to be moving forward with establishing a protected area for Studenchishte Marsh at the national level. However, the draft law for the proclamation only gives genuine protection to 8.85% of the wetland, providing little legal shield from construction in 66.11%. Key features like springs and the lakeshore are omitted from boundaries too.

As stated in WHC Decision 43COM 7B.36 (2019), Macedonia is also not informing the World Heritage Centre of all projects in the WHS, while the reports that it does produce contain verifiable errors such as the claim that Lake Ohrid water levels are kept within legal parameters (Ministry of Culture, 2021). Data from both the relevant hydropower company (ESM, 2020) and the National Hydrometeorological Institute (2020/21) show that levels were 1-3 cm below the minimum of 693.10 m above sea level from 25th November until at least 10th December 2020.

7. Committee vs. secretariat

ICOMOS and the IUCN have recommended for the Ohrid Region WHS to be placed on the List of World Heritage in Danger, a warning that its OUV and World Heritage status are at risk. The World Heritage Centre (2019 and 2021a) has twice drafted decisions to this effect. However, each time the WHC rewrote the drafts to avoid such action.

8. Flaws in the UNESCO system

There are 1,154 WHS across the globe, each embedded within its own legal structure, facing its own particular challenges. The number is growing every year and the cumulative spatial extent is already larger than India. However, international monitoring for WHS and coordination of WHC Decisions largely rests with the World Heritage Centre, its staff—established and temporary—of 67 (based on the 2020/21 biennium) and its present annual budget of approximately US$15,000,000, including for the advisory bodies. Given the resource shortfall, important heritage issues can fly under the radar (as with the aforementioned Studenchishte Marsh at Lake Ohrid), not least since national governments are simultaneously the main source of reporting for the WHS in their borders and a key agent of threats.

Moreover, the World Heritage Centre attempts its task without formalized, objective, continuous indicators to resolve issues such as whether a site is in danger or not and its authority often rests with the WHC, which has ultimate power to make heritage decisions, despite being increasingly dominated by ambassadors and politicians, not experts in relevant fields (Meskell, 2015). Advisory bodies are similarly undermined by the WHC, which not infrequently ignores their input regarding nominations and recommended danger listings (Meskell, 2015; IUCN, 2019), even though the former exacerbate resource issues and the latter are a major tool to catalyze change.

As seen in the Ohrid Region with cancellation of plans for an express road in 2017, WHC Decisions can bring action, especially when tied to financing via the policy of investors. However, too few such tie-ins exist and mechanisms to deal with incremental degradation are insufficient.

9. Conclusion

Lake Ohrid demonstrates that the World Heritage Convention is inadequately robust to ensure protection of globally important inland waters.

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Water quality assessment of Laguna de Bay, Philippines, through geostatistical analysis of physicochemical parameters

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Abstract

The waters of Laguna Lake, located in the southwest of Luzon Island, Philippines, support the local aquaculture industry, serve as a waste sink for household and industrial wastes, and more. The pollution caused by the incorrect disposal of human and chemical waste and eutrophication due to the numerous aquaculture sites has deprived parts of the lake of its dissolved oxygen, leading to reported fish death. A previous study from 2018 assessed the water quality of Laguna Lake through geostatistical modeling, a method that uses pre-existing data to generate prediction maps, with the results showing that its water quality and ecosystem are in danger. The present study is an updated geostatistical model of the state of Laguna Lake to check whether the efforts for its sustainable development have been practical. Variogram models and kriging were generated to model data for October 2020 for biological oxygen demand, dissolved oxygen, pH, ammonia, nitrate, and inorganic phosphate. Cross-validation tests were performed to ensure the validity of the models. Overall, the models displayed trends attributed to the lake's aquaculture activities, with the West Bay showing high levels of ammonia, biological oxygen demand, and inorganic phosphate. Further

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monitoring and sustainable development efforts must be made to maintain its health. The study showed the utility of using geostatistical models to improve understanding and monitoring of lake systems even with limited data. Additional information on water movement and other parameters are recommended to improve the models further.

Keywords: *Laguna Lake, water quality, geostatistics*

1. Introduction

Laguna de Bay is a 911-949 km² lake with two peninsulas extruding from its northern shore and the Laguna Caldera. It is considered the largest Philippine lake and, along with its tributaries, is a natural resource that supports fisheries and aquaculture, provides irrigation water for agriculture, supplies domestic water, and serves as a waste sink for household and industrial wastes, and more[1].

Water quality monitoring is defined as the sampling and analysis of water quality at a given location over time. The procedure is usually done by measuring collected water samples for laboratory analysis or using probes that can record data at a single point in time or logged at regular intervals over an extended period[2]. Data analysis will then focus on finding any introduced pollutants, such as pesticides, metals, and oil constituents, and investigating the values of physical, chemical, and biological parameters such as dissolved oxygen (DO), pH, and nutrients at a given time[3].

Geostatistics is one of the methods for measuring water quality. It is a class of statistics used to analyze and predict the values associated with spatial or spatiotemporal phenomena and serves a powerful instrument for assessing water quality and estimating pollutant levels[4]. Many studies, such as those by Bhuiyan et al. (2016)[5] and Karami et al. (2018)[6] had mapped the physicochemical parameters of bodies of water through the use of geostatistical modeling. They examined the groundwater quality of the Lakshmipur Sadar in Bangladesh and the Varamin plain in Iran, respectively, through kriging. Their results had led them to discover the groundwater quality of the area of study, the source of the pollutants, and the spatial distribution of each parameter which led them to claim that geostatistical mapping is a valid method for assessing water quality.

A previous study[7] assessed the water quality of Laguna de Bay and its tributary rivers through geostatistical mapping using data from October to December of 2018. They used ordinary kriging (OK) and universal kriging (UK) to map out the spatial interpolation of the physicochemical parameters. They found that half of the parameters, mainly ammonia, biological oxygen demand (BOD), and DO, failed the Department of Environment and Natural Resources Water Quality Guidelines (DENR WQGs), and concluded that danger looms over Laguna de Bay.

This study modeled the Laguna Lake Development Authority (LLDA) water quality data for October 2020 and assessed the health of Laguna de Bay in terms of the DENR WQGs. This was achieved through geostatistical analysis in terms of variogram modeling (spherical, exponential, Gaussian) and kriging (ordinary, universal) of the physicochemical parameters ammonia, BOD, DO, inorganic phosphate (IP), nitrate, and pH.

2. Materials and methodology

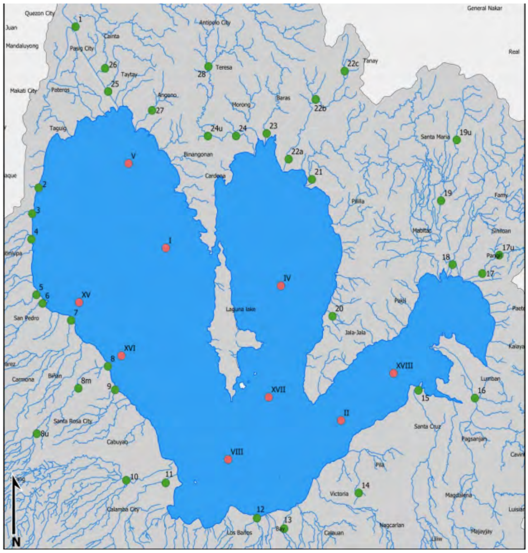
2.1 Data Sources

A raster of Laguna Lake from PhilGIS was imported into GIS software. The longitude and latitude coordinates in degrees, minutes, and seconds of all LLDA sampling stations, as shown in Figure 1, were inputted into a spreadsheet along with the water quality data, and saved as a comma-separated values (.csv) file. Said data were imported into the ArcGIS project, with the X Field and Y Field set to longitude and latitude, respectively.

2.2 Variogram Modeling and Kriging

The kriging function was used to generate a prediction map for each parameter and for each kind of variogram model. Since prediction maps created using OK and UK require the data to be approximately normally dis-

Figure 1. *Map of Laguna de Bay and LLDA Sampling Stations.*



Note: Retrieved from *Quarterly Water Quality Monitoring Report: October to December, 2020* by LLDA, 2020, https://llda.gov.ph/ldb-and-its-tributaries/.

tributed to make the most accurate results, the histogram of frequency distribution, skewness, and kurtosis for each parameter was generated and examined[8]. For a data set to have a normal distribution, its skewness must be close or equal to 0, and its kurtosis must be close or equal to 3. Logarithmic transformation was applied to ammonia, BOD, IP and nitrate to minimize clustering and outliers, while no transformation was applied to pH and DO. Then, the kind of kriging and variogram model was chosen, and the Optimize Model function of the GIS software was also applied.

Equations of the spherical, exponential, and Gaussian variogram models, respectively, are as follows[9]:

$$\gamma(h) = \sigma^2\left(\frac{3h}{2r} - \frac{3h^3}{2^3}\right) \text{for } h \le r \; or \; \sigma^2$$

$$\gamma(h) = \sigma^2\left(1 - e^{\frac{-3h}{r}}\right) for \; h \le r \; or \; \sigma^2$$

$$\gamma(h) = \sigma^2\left(1 - e^{\frac{-3h^2}{r^2}}\right) for \; h \le r \; or \; \sigma^2$$

where σ^2 is the sill, h is the distance between two points, and r is the range.

Additionally, the equation of OK and UK are as follows:

$$\hat{Y}(s) = \sum_{i=1}^{n} \varpi_i(s) Y(s_i)$$

where n is the sample size, s_i is the observed point, s is the unobserved point, $\tilde{\omega}_i(s)$ is the weight of s, $Y(s_i)$ is the observed value at point s_i, and $\hat{y}(s)$ is the predicted value at point s. However, OK assumes an unknown constant trend, while UK assumes a general linear trend model.

2.4 Statistical Treatment

The models underwent the statistical analysis of cross-validation, specifically Mean Standardized Error (MSE), Root Mean Square Error (RMSE), and Root Mean Square Standardized Error (RMSSE). These helped test how well the models can predict values at unknown locations or points by removing data locations and predicting their associated data using the given data in other locations. The predicted and observed data will be compared, thus determining the quality of the kriging model[10]. The equations of the tests are as follows[4]:

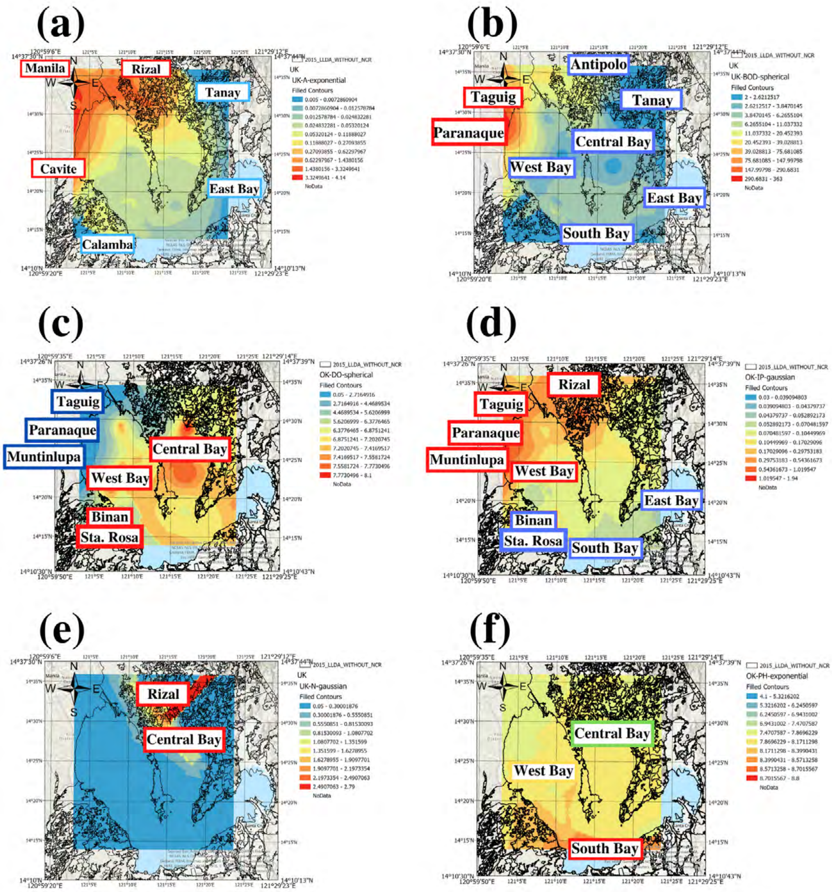
$$\text{MSE} = \frac{\sum_{i=1}^{n} \left(\hat{Z}(s_i) - z(s_i)\right) \div \hat{\sigma}(s_i)}{n}$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} \left(\hat{Z}(s_i) - z(s_i)\right)^2}{n}}$$

$$\text{RMSSE} = \sqrt{\frac{\sum_{i=1}^{n} \left[\left(\hat{Z}(s_i) - z(s_i)\right) \div \hat{\sigma}(s_i)\right]^2}{n}}$$

where n is the sample size, s_i is the observed point, $z(s_i)$ is the observed value at point s_i, $\hat{Z}(s_i)$ is the predicted value at point s_i, and $\hat{\sigma}$ is the estimated standard deviation at point s_i.

Figure 2a-2f. *The prediction maps for ammonia (a), BOD (b), DO (c), IP (d), nitrate (e), and pH (f).*



3. Results and discussion

Kriging and Cross-validation Testing

A. Ammonia

The most unbiased and accurate model for ammonia (Figure 2a) was made using exponential variogram modeling and UK, while the least unbiased and accurate model was made from exponential variogram modeling and OK. Ammonia were found in high levels in the north of the West Bay of

Laguna de Bay using exponential variogram modeling and UK, with the log-ammonia values ranging from 0.62 to 4.14, which is roughly equal to 1.83 mg/L to 4.14 mg/L. Low levels of ammonia were found in the middle of the East Bay and in rivers in Calamba with log-ammonia values ranging from around 0.01 to 0.02, which is roughly equal to 0.019 mg/L. Overall, ammonia values in the north of the West Bay failed the WQGs for Classes A to D for water supply, recreation, fishery, agriculture, and navigable waters, whereas the middle of the East Bay and rivers in Calamba, Tanay, and Antipolo passed.

B. Biological Oxygen Demand (BOD)

The most unbiased and accurate model for BOD, as shown in Figure 2b, was made using spherical variogram modeling and UK, while the least unbiased and accurate model was made from exponential variogram modeling and OK. Using spherical variogram modeling and UK, high levels of BOD were found in the northwest bay of Laguna de Bay with log-BOD values ranging from 39.03 to 363.00, which is roughly equal to 21 mg/L to 363 mg/L. Meanwhile, low levels of BOD, with log-BOD values ranging from 2.00 to 6.27, roughly equal to 2 mg/L to 12 mg/L, were found in the east of the West Bay, west of the South Bay, the Central Bay, and in rivers in Tanay and Antipolo, north of the Central Bay. Overall, BOD values in the areas around Taguig and Paranaque failed the WQGs for Classes A to D for water supply, recreation, fishery, agriculture, and navigable waters, whereas the east of the West Bay, west of the South Bay, the Central Bay, and rivers in Tanay and Antipolo passed.

C. Dissolved Oxygen (DO)

The most unbiased and accurate model for DO, as shown in Figure 2c, was made using spherical variogram modeling and OK, while the least unbiased and accurate model was made from exponential variogram modeling and OK. Using spherical variogram modeling and OK, relatively high levels of DO were found west of the West Bay around Binan and Sta. Rosa and in the Central Bay of Laguna de Bay with values ranging from 7.42 mg/L to 8.10 mg/L. Low levels of DO with values ranging from 0.05 mg/L to 5.62 mg/L were found around Taguig, Paranaque and Muntinlupa. Overall, DO values around Binan and Sta. Rosa, and in the Central Bay of Laguna de Bay passed the WQGs for Classes A to D for water supply, recreation, fishery, agriculture, and navigable waters, whereas areas around Taguig, Paranaque and Muntinlupa failed.

D. Inorganic Phosphate (IP)

The most unbiased and accurate model for IP, as shown in Figure 2d, was made using Gaussian variogram modeling and OK, while the least unbiased and accurate model was made from Gaussian variogram modeling and UK. Using Gaussian variogram modeling and OK, relatively high levels of IP, with log-IP values ranging from 0.17 to 1.94, which roughly translates to 0.54 mg/L to 1.16 mg/L were found in the West Bay, specifically around Taguig, Paranaque and Muntinlupa, and in rivers around Rizal. Relatively low levels of IP, with log-IP values ranging from 0.04 to 0.07 that roughly translate to 0.03 mg/L to 0.43 mg/L, were found west of the West Bay around Binan and Sta. Rosa and in areas in the South and East Bay. Overall, IP values in the area have all passed the WQGs for Classes A to D for water supply, recreation, fishery, agriculture, and navigable waters.

E. Nitrate

The most unbiased and accurate model for nitrate, as shown in Figure 2e, was made using Gaussian variogram modeling and UK, while the least unbiased and accurate model was made from Exponential Variogram Modelling and UK. Using Gaussian variogram modeling and UK, high levels of nitrate, with log-nitrate values ranging from 1.35 to 2.79 that roughly translates to 2.7 mg/L, were found north of the Central Bay, specifically in Rizal. The rest have relatively low levels of nitrate, with log-nitrate values ranging from 0.05 to 0.82 roughly translating to 0.05 mg/L. Overall, nitrate values in the area passed the WQGs for Classes A to D for water supply, recreation, fishery, agriculture, and navigable waters.

F. pH

The models generated for pH were identical among the three variogram models for both OK and UK, though OK was more unbiased and accurate overall. This might be due to pH levels having closely similar values. As shown in Figure 2f, using OK, relatively higher pH values of 8.17 to 8.70 were found in the South Bay and south of the West Bay while relatively low values of 6.94 to 7.87 were found north of the West Bay and north of the Central Bay. Overall, pH values in the area have all passed the WQGs for Classes A to D for water supply, recreation, fishery, agriculture, and navigable waters.

Despite the local government and the LLDA's efforts to monitor water quality and police stakeholders, the local aquaculture industry and the rapid urbanization of the land around Laguna de Bay have significantly affected its health, as the areas with poor water quality were zoned for fish pens and cages as well as surrounded by communities with high population densities. Though laws and programs, such as the DENR WQGs, are in place to avoid these issues, their implementations are evidently insufficient due to external factors like the limitations caused by the pandemic, lack of urgency among government agencies, and more. There is a need to prioritize and improve the implementation of these laws not only in the aquaculture industry, but also among the stakeholders that continue to make use of the lake.

4. Conclusion

The ammonia, BOD, and DO values of the western portion of the lake did not meet the requirements of the DENR WQGs for water supply, recreation, fishery, agriculture, and navigable waters based on the prediction maps generated through geostatistical analysis. These findings further emphasize that Laguna Lake is in a state of decline and that more efforts towards its sustainable development should be implemented.

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Chapter 3. Governance

The chapter on governance includes studies, analyses, and research on the theoretical and practical discussion of applicable policies, management and organizational structures dealing with water issues. And, very importantly, how the governance of natural and artificial lakes is accomplished through policy, legislation, and financial management.

Conserving the ecosystem of Lake Rawa Pening in Indonesia

SUPRIYANTO[1]

Abstract

The objective of this study is to propose the strategies on how to conserve Lake Rawa Pening as an integrated ecosystem so as to achieve sustainable water resources in Indonesia. The methodology of this study is literature reviews from govermental reports, journals and conducting interviews with key individuals. To overcome the problems in Lake Rawa Pening government should initiate the programs as follows: 1) adding forest vegetation in water catchment area to reduce water pollution and erosion; 2) providing public land to increase open green space; 3) controlling water hyacinth in surface water; 4) establishing sewage systems to reduce grey water pollution; 5) constructing community waste treatment facilities; 6) implementing hotel and restaurant waste treatment facilities; 7) improving agricultural cummunity drainage facilities; 8) building water quality stations; 9) installing water purification parks to improve the level of water quality before flowing into lake; and 10) implementing an organic fertilizer subsidy for farmers to reduce water pollution. To accelerate those programs under limited budget, government should select the most impactful programs such as afforestation, water hyacinth removal, and a water quality station.

[1] Affiliation: Directorate of Inland Water and Mangrove Rehabilitation, Indonesia Ministry of Environment and Forestry.

Keywords: *Ecosystem, Lake Rawa Pening, water hyacinth, afforestation, water quality*

1. Introduction

Anthropogenic activities in the lakes lead to the pressure of water ecosystem to produce ecological services to human being (Jorhensen & Vollenweider, 1991)[1]. Lake Rawa Pening in Indonesia also faces this situation where human activities directly affect the quality of the water ecosystem. For instance, fishery using fish cage method causes increasing eutrophication and agriculture using artificial fertilizers prompt water pollution and erosion (KLHK, 2018)[2]. On the contrary, many people in Lake Rawa Pening basin base their economics on that lake, in the form of as hydropower, drinking water, irrigation, husbandry, fishery and tourism (Balitbang, 2020)[3]. This causes dillemna on how to integrate economic activites without damaging the lake ecosystem.

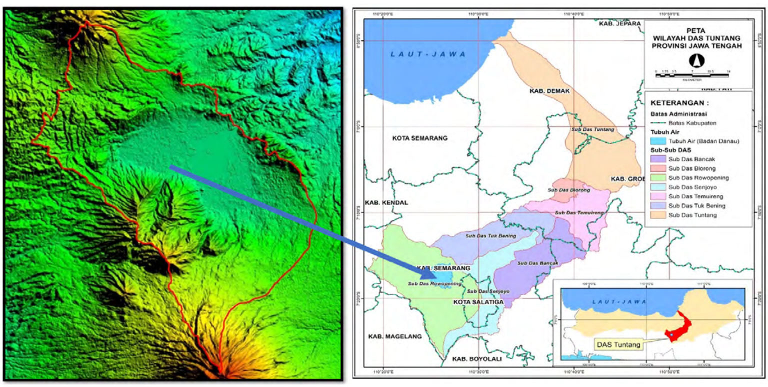
According to the the current data from Environmental Agency of Semarang (2021)[4], trophic status of Lake Rawa Pening was in mesotrophic-eutrophic that causes massive quantities of water hyacinth (*Eichhornia crassipes*) to cover water surface by more than 70%. This algae species can threaten the lake ecosystem and reduce the capacity of lake to accommodate water. Every year, Ministry of Public Work and Housing has tried to remove water hyacinth and Ministry of Environment and Forestry has also rehabilitated lake basin by planting many trees. Those efforts have yet to solve lake issues because many problems come from the upstream, and the capacity of government to tackle that issue is limited. Therefore, it needs more strategies to improve the quality of aquatic environment so as to achieve a sustainable lake. The objective of this study is to analyse how to preserve the ecosystem of Lake Rawa Pening.

2. Materials and methodolody

2.1 Study area

The study area is in the Lake Rawa Pening basin. The size of that lake basin is approximately 24,457.15 ha with total size of surface water of 1,850.10 ha located in the Central Jawa Province, Indonesia (KLHK, 2018)[5]. The altitude of the lake is about 455-465 meters above sea level and it is surrounded by three mountains: Merbabu, Telomoyo, and Ungaran. Figure 1 is an illustration of Lake Rawa Pening.

Figure 1. *Map of Tuntang Watershed (KLHK, 2011)[6].*



2.1 Data and processing

This study uses secondary data from government and journals. To validate those data, it also conducts interviews with the key people of lake management such as from Ministry of Environment and Forestry, Environmental and Forestry Agency of Central Java Province, and Environmental Agency of Semarang Regency. To analyze this study, it uses Integrated Lake Basin Management (ILBM) approach which encompasses six pillars of lake governance including institution, policy, partisipation, technology, information, and finance (Nakamura & Rest, 2012)[7].

3. Results and discussion

3.1 Utilization of Lake Rawa Pening

Lake Rawa Pening provides multifunction both to human beings and to the ecosystem. According to this study, this lake is already used by people as follows: 1) tidal land agriculture in lake shore of 1,030.51 ha, and produces rice as much as 2.5-5 tons/year (Sittadewi, 2008)[8]; 2) floating net cage aquaculture of 1,395 units with fish production of 1.324,99 tons in 2019 and capture fishery with total production of 933.99 tons in 2019 (BPS Kab. Semarang, 2020)[9]; 3) Jelok Hydropower with the capacity of 20.48 MW and Timo Hydropower with the capacity 12 MW (Indonesia Power, 2019)[10]; 4) domestic and industrial water; 5) irrigation; and 6) tourism.

3.2 The challenges of conserving Lake Rawa Pening

The pressure impased by people living in Lake Rawa Pening has widely changed the shape of that lake. There are several issues about that lake as follows 1) large part of upstream area is exploited as agricultural land. That activity brings much nutrients from the waste of artificial fertilizers. However, This land also plays an important role for socio-economic society because of producing primary commodities such as vegetables, fruits and rice (Hidayati & Soeprobowati, 2017)[11]; 2) waste from floating net cage aquaculture. The number of net cages is beyond the carrying capacity of Rawa Pening to absorb externality of that fishery (KLHK, 2020)[12]; and 3) water hyacinth blooming. This invasive species has destroyed the lentic ecosystem. Study from Indrayati and Hikmah (2018)[13] shows that the growth of water hyacinth is expanding which causes sedimentation: whereas in 2008 it had a maximum depth of 18.4 meters, in 2017 the depth was only around 5-8 meters.

3.3 Existing regulation

Indonesia is very concerned regarding its water resources. This milestone has been achieved since 2009 when in the First National Lake Conference held in Bali, nine ministries agreed to sign off the mutual agreement regarding Determination of Joint Programme on the Sustainable Lake Management and Establishment of the Fifteen National Priority Lake I and the Fifteen National Priority Lake II. Two years later, Indonesia held the Second National Lake Conference in Central Java, and launched GERMADAN[14] (the Movement of Indonesia Lake Convervation). In this event, Lake Rawa Pening has been a pilot project of GERMADAN.

In 2012, Indonesia initiated the Grand Design of Indonesia Lake Conservation and Rehabilitation in Jakarta. This document was a general guidance on how to manage sustainable lake in Indonesia. During 2013-2014, Indonesia released 14 GERMADAN, including Lake Toba, Lake Singkarak, Lake Maninjau, Lake Kerinci, Lake Rawa Danau, Lake Batur, Lake Sentarum, Lake Cascade Mahakam, Lake Tempe, Lake Matano, Lake Poso, Lake Limboto, Lake Tondano and Lake Sentani. This was the first step of Indonesia to make grand planning of the Fifteen National Priority Lake I. Lake conservation for the first time became one of the Medium-term Indonesia Development Plan in 2015-2019 by targeting increasing both water quality and water quantity in the Fifteen National Priority Lake I. To strengthen the effort of Indonesia to save the lake, in 2018 Indonesia launched the Lake Management Plans in fifteen lakes. Finally, to accelerate those programs, Indonesia's President stipulated Presidential Decree No. 60 in 2021 regarding Conservation of National Lake Prioity I.

3.4 How to conserve Lake Rawa Pening

Decreasing water quality, especially eutrophication, is the main issue which could threaten sustainable water resources in Lake Rawa Pening. The state of eutrophication can lead to the proliferation water hyacinth, and it will be the problem to the capacity of Lake Rawa Pening to regulate water. To overcome this challenge, the project should be implemented such as adding forest vegetation in water catchment are, reducing non-point source pollution, decreasing water hyacinth and improving water quality.

To translate those projects above into reality, it will be used Integrated Lake Basin Management (ILBM) approach to analyse it. This methodology consists of six pillars of lake basin government including institutions, policy, stakeholders participation, technology, information, and funding. Table 1 presents the analysis of proposed strategis of conserving the ecosystem of Lake Rawa Pening.

Table 1. *Analysis of proposed strategies of conserving the ecosystem of Lake Rawa Pening.*

Projects	**Institutions**	**Policy**	**Participation**	**Technology**	**Information**	**Finance**
Afforestation	Y	Y	Y	A	Y	Y
Acquiring forest land	A	A	A	A	A	A
Water hyacinth removal	Y	Y	N	Y	Y	Y
Sewage system	A	A	A	A	A	A
Community waste treatment facility	A	A	A	A	A	A
Hotel and restaurant waste treatment facility	A	A	A	A	A	A
Agricultural community drainage facility	A	A	A	A	A	A
Water quality station	N	Y	Y	Y	Y	A
Purification pond	A	A	A	A	A	A
Organic fertilizer subsidy	A	A	A	A	A	A

Note:
Y : yes/it has institution/policy/participation/technology/information/finance.
N : no/it does not have institution/policy/participation/technology/information/finance.
A : no data regarding institution/policy/participation/technology/information/ finance.

It is apparent from Table 1 that there are only 3 projects which meet ILBM approach. Those projects are afforestation, water hyacinth removal and water quality station. Whereas, the rest of the projects could not be analysed because of the absence of the data. Therefore, we only can propose 3 projects for actual programs to achieve sustainable water resource in Lake Rawa Pening. In the following paragraph, each of them will be discussed.

3.4.1 Afforestation

Afforestation is the process of planting more trees or sowing seeds, specifically endemic tree species, to increase vegetation cover in water cathment area. The major reasons of proposing afforestation are: 1) forest cover in the Lake Rawa Pening basin is only 5.06% (KLHK, 2018)[15]. This means the amount of total vegetation cover is not enough to regulate flow water or to refrain rain water, and causes erosion and landslide which lead to sedimentation in the lake; 2) mix plantation is more than 30%. In other words, many people living in the water catchment area rely their livelihood on plantation; and 3) Around 11.21% of the land in the upstream are designated for agriculture activities. It may be those sectors supply many waste from their fertilizer with high nutrient that is brought by the rain into water. Therefore, to control eutrophication in the lake is indispensable to improve water quality. One of the solutions to tackle this issue is to convert agriculture into forestry. Generally speaking, we need longer time to harvest forest products, for example more than 5 years, whereas agriculture could harvest three times in one year. To connect between short-term needs and long-term needs, agroforestry could be a solution. In agroforestry, we select agicultural species which have an ability to survive among big trees. For example, herbs and spices that have economically value in the market. The trigger of alteration agriculture into forest is that young generations mostly do not want to be farmers, they leave their land, and prefer to look for jobs in the city. There are two main institution to implement this action plan, namely Ministry of Environment and Forestry and Agency of Provincial Environment and Forestry. Each of them has their main job. For example, seed plants are provided by ministry and selecting location comes from agency.

3.4.2 Water hyacinth removal

It is undeniable that water hyacinth leads to the ecosystem disruption because the sunlight can not penetrate into water. This also cause high evaporation which leads to the depletion of water volume. Furthermore, the dead water hyacinth will sink to the bottom of the lake and gradually will be siltation, and indirectly the capacity of the lake to accommodate water will go down. According to the analysis of satellite image, 70% of water surface is covered by water hyacinth[16]. This is critical condition for the sustainability of Lake Rawa Pening. Although Ministry of Public Work and Housing has dredged water hyacinth since 2010, the growth of this weeds is much faster than the ability of machines to remove it from water. This is caused by eutrophication in that lake, especially high concentration of total phosphorus and total nitrogen. As a result, using appropriate technology is very important to control water hyacinth. Ministry of Public Work and Housing, and Agency of Provincial Public Work are the institution in charge to manage water hyacinth.

3.4.3 Water quality station

Even though every year Agency of Provincial Environment and Forestry has conducted water quality monitoring in Lake Rawa Pening, the results of that monitoring have yet to provide live data from the lake. What is to say, it takes sampling from the lake, and then bring those water samplings into laboratory in this city. This is not effective and efficient to collect accurate data regarding water quality. Moreover, we need a research institute which specializes in monitoring the lake. To obtain this project, we must collaborate with regulators, especially Ministry of Environment and Forestry and Agency of Provincial Environment and Forestry, university as institution to provide human resource to operate water quality devices and industry to supply sophisticated technology.

3.4.4 Monitoring and evaluation

In order to ensure that the goals of the programs could be achieved, we need to conduct regular monitoring and evalution. That is why we propose establishment of a water quality station. However, construction of station does not directly affect the quality of Lake Rawa Pening ecosystem, this could be achieved with tools or technology to support the project. To provide information regarding the progress of the programs, there are few indicators to understand us the change of lake state such as reduced agricultural pollution, reduced water hyacinth, and reduced silt and sediment into the lake. In spite of many parameters to illustrate the envisioned future of the lake, it does not mean we will reach it in the short-term period. For example, problems in the lake will be finished in one or five years only by these strategies. The main reason is that ILBM is the cyclic process which continuously will develop based on the situation and condition from the physical state of the lake as well as other attributes such as increasing population or climate change. Therefore, the proposed programs will be implemented in the flexible way and adjusted with the needs of the lake, and then in the regular time, annualy or five years, we will review the project.

4. Conclusion

To conserve Lake Rawa Pening, we propose the project of afforestation, water hyacinth removal and water quality station. Are those projects able to overcome Lake Rawa Pening problems? The answer is that it depends on a number of factors. For few lakes, the traditional approach without explicit reference to the concept of ILBM may be adequate to tackle their issues. These proposed programs are not merely a project, but a long-term government improvement process. Thus, it should grow over many years toward sustainable water resource. Furthermore, the success of Lake Rawa Pening management needs a continuous our commitment to improve it. Because of limited budget to finance action plan, we should prioritize the program which will directly affect the lake. For example, afforestation and water hyacinth removal are urgently needed to improve water quality. Those are the first steps to achieve sustainable water resource. After that, if we have adequate funding, we can use it for construction of water quality monitoring station to support them. Therefore, every activity regarding the effort of improvement of the lake will be recorded, and it will be used to review and propose the next action plan.

No one knows what the future will be, especially in Lake Rawa Pening. There might be implementation challenges which may influence the process of action plan. For example climate change will affect the pattern of rain fall or earthquake will alter the physical characteristic of the lake basin. Therefore, we must be ready to every possible challenges which might come during implementation. Moreover, stringent procedures should be implemented to ensure that all efforts relating improvement of water quality in Lake Rawa Pening could work properly and effectively. To fill the gap between current situation (limited newest accurate data, lack of knowledge and skill, and old technology) and all possible challenges during implementation, we can promote human resource development programs such as training and research.

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Governance and water management in Tomatlan, Jalisco, Mexico: a geospatial approach

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Abstract

Talking about governance is a complex issue because, for its exercise, the balanced participation of the state, civil society and the market is necessary. In Mexico, the administration of national resources is exercised by the executive power through centralized agencies such as the secretariats that are administered by the federation and decentralized agencies such as councils, commissions, centers, banks, institutes and prosecutors, which are self-administered or are administered by the state or the municipality according to their exercise; these are organized in a vertical format to ensure the correct management of natural resources such as water.

With the objective of understanding the strengths and weaknesses of governance in terms of the management and use of water resources in the

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Tomatlan River basin and the area of influence of the irrigation district 093, a total of 24 public administration institutions were georeferenced. Institutional reach was measured according to their political hierarchy and institutional participation was valued according to the ILBM (Integrated Lake Basin Management) methodology proposed by the ILEC (International Lake Environment Committee Foundation). Our results show a high synergy in the coastal region of the study area, demonstrating good horizontal communication between institutions and antagonism communication in the upper part of the Tomatlan River basin. This assessment offer an approach toward the strengths, opportunities, weaknesses and threats in terms of water resource governance.

Keywords: *ILBM, comprehensive management, institutional participation*

1. Introduction

Governance is defined as the ability of the state to efficiently control society and the market through its institutions [1] and to provide public goods to society [2] through laws, regulations and norms that govern collective action [3] and where society defines its interests and priorities [4].

In Mexico, the political organization is headed by the federation, the state, and the municipality.

The federation in turn is divided into the executive, legislative, and judicial powers. The executive branch enforces compliance as established by legislation, while the judicial branch is responsible for sanctioning noncompliance with regulations [5]. The executive branch is responsible for representing the republic and managing national public goods [6] through centralized bodies such as the secretariats of state and administrative departments, which are the responsibility of the nation [5], and decentralized organizations such as companies, credit institutions, auxiliary organizations, insurance institutions and trusts, which are under the jurisdiction of the state.

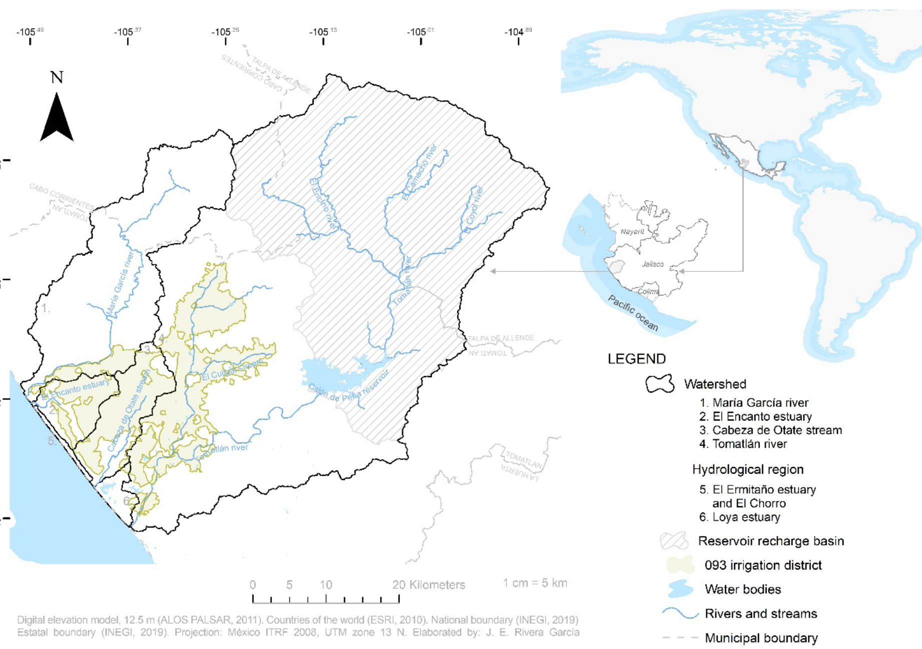
In turn, the state creates its own regulatory agencies that are decentralized in favor of the municipality, achieving autonomy and giving municipalities the power to make decisions according to the objectives of each [7].

To achieve proper administration, these entities must communicate continuously, following the political hierarchy. Thus, the municipality communicates with the federation through the state and vice versa (vertical communication). However, communication between organizations of the same hierarchy (horizontal communication) is necessary to ensure proper communication between institutions [8]. However, it is currently difficult to measure the efficiency of communication and the outcome of governance [9] due to the number of interactions carried out at different levels of government and the objectives of each institution [10].

In 2005, the ILEC (International Lake Environment Committee Foundation) proposed a comprehensive method for the management of lakes and reservoirs, in which six basic pillars of governance were established that, when balanced, represent the integral management of a given body of water.

The ILBM (Integrated Lake Basin Management) framework has been widely theoretically applied in various documents, articles, and conferences;

Figure 1. *Area of influence of Irrigation District 093-Tomatlan and the Cajon de Peña reservoir.*



however, this research spatially addresses the method, being one of the first documents addressing the ILBM framework. In this way, the institutional network that influences the management and administration of the water resources of the Cajón de Peña reservoir (Tomatlan, Jalisco) and its area of influence, comprising the basin of the reservoir and Irrigation District 093-Tomatlan, located downstream and one of the largest users of water in the region, is analyzed to determine the state of institutional interaction and the governance landscape according to the framework proposed by the ILEC to identify deficiencies and opportunities in the governance of water resources and to lay the foundations for comprehensive management of the reservoir and its area of influence.

1.1 Study area

The study area includes the watersheds of the Maria Garcia River (41,688 ha), El Encanto estuary (6,481 ha), the Cabeza de Otate Stream (10,746 ha) and the Tomatlan River (196,116 ha) and the hydrological regions of the El Ermitaño estuary (634 ha) and Estero Loya (2,243 ha), which cover a total of 257,911 hectares.

Since its establishment in 1987, the Cajon de Peña Reservoir has favored the cultivation of large areas of pastures and grains that have yielded large amounts of resources with export quality in the region and the irrigation district. However, in recent years and due to the semiarid nature of the region, there have been problems related to the lack of water, in turn related to the mismanagement of water resources and changes in hydrological regimes caused by climate change, affecting the local economy.

2. Materials and methods

The definition of the quality of governance was carried out through three stages: I. definition of the institutional reach, II. definition of the level of participation, and III. definition of governance quality.

2.1 Definition of the institutional reach

The definition of the institutional reach was carried out in three main steps: I. institutional classification, II. georeferencing, and III. definition of reach.

I. ***Institutional classification***

Based on literature review and interviews with key stakeholders, the public institutions responsible for managing and administering the water resources that influence the Tomatlan River basin and the area of influence of Irrigation District 093-Tomatlan were identified and listed, for a total of 24 institutions. I. National: 1. CNA (National Water Commission), 2. ANUR (National Association of Irrigation Users), 3. SECTUR (Secretariat of Tourism), 4. SEDESOL (Secretariat of Social Development), 5. CONAFOR (National Forest Commission), 6. CONAPESCA (National Commission of Aquaculture and Fisheries), 7. SEMARNAT (Secretariat of the Environment and Natural Resources) and 8. SADER (Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food), II. State: 1. CEA (State Water Commission of the State of Jalisco) and 2. SEMADET (Ministry of Environment and Territorial Development of the State of Jalisco), II. Municipal: 1. Cabo Corrientes, 2. Talpa de Allende and 3. Tomatlan, IV. Regional: 1. CCT (Tomatlan River Watershed Council), 2. CCLC (Lerma-Chapala Watershed Council), 3. CCCP (Pacific Coast Watershed Council), 4. JICOSUR (South Coast Intermunicipal Environmental Board) and 5. UGRT (Regional Cattle Union of Tomatlan), and V. Local Authority: 1. AUAT (Tomatlan Water Users Association), 2. AUR (Tomatlan Irrigation Users Association), 3. AUDR-093 (Users Association of Irrigation District 093), 4. CAPCP (Board of Directors of the Cajon de Peña Dam), 5. CVPCP (Monitoring Board of the Cajon de Peña Dam), and 6. AAFC (Agricultural Association of Fruit Growers).

II. ***Georeferencing***

Once the institutions involved in the administration and management of the water resource were defined, we proceeded to geographically locate each of the institutions according to their fiscal domain or area of influence.

III. ***Definition of reach***

Once the institutions were classified and georeferenced, their reach was defined according to their political hierarchy. Thus, the reach of federal agencies is defined by a circle that contains the entire country, while the reach of state and municipal institutions was delineated by the extension of each entity, while regional instances are defined by the particular reach of each instance (basin, municipality, region, locality, or zone) and the local instances by the size of the locality.

2.2 Definition of the level of participation

The level of participation was defined according to the pillars of the ILBM framework: 1) institutions, 2) politics, 3) participation, 4) technology, 5) information, and 6) financing, proposed by ILEC (2005), evaluated as proposed by ILEC & River-Coastal Science & Engineering (RCSE) (2012), with a series of questions that define the level of participation of each institution according to the pillars of governance and the organized hierarchical level, where 1 represents participation by the institution, -1 represents lack of participation, and 0 represents a state of ignorance.

2.3 Definition of the governance quality

Once each of the institutions was valued according to the political hierarchy and the ILBM framework, under a geographic information system (GIS) environment, each institutional reach was evaluated with its respective value obtained after the sum of the six pillars of governance for each hierarchical level and for each of the 24 institutions evaluated. Subsequently, each raster was added at all hierarchical levels, yielding a single file with lower performance, followed by the state and local hierarchies, which have low levels of technology and participation.

3. Results and discussion

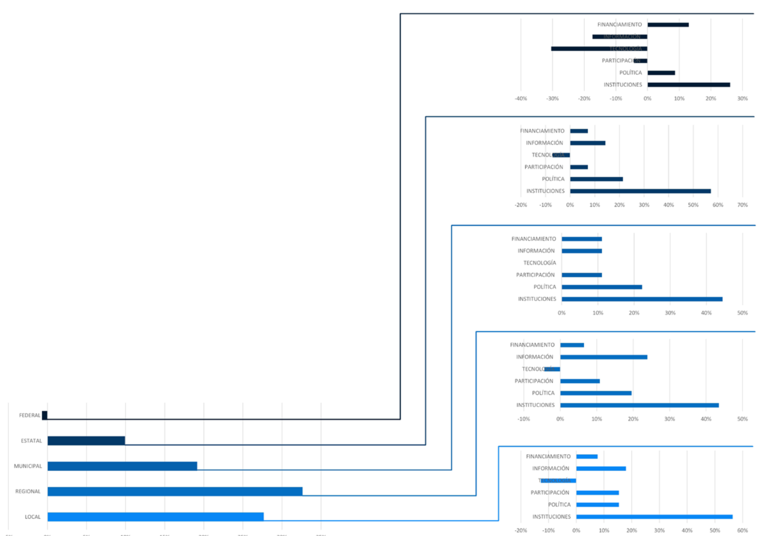
3.1 Level of participation

The results of the assessment of the six pillars of the ILBM framework suggest deficiencies in the technology used by the institutions involved, with the federation being the hierarchical scale that presents the greatest deficiencies in this category, in addition to presenting deficiencies in the levels of information and institutions (Figure 2).

On the other hand, the hierarchical level with the greatest participation is the regional scale, which presents high values for institutions, information, policies, and participation, while at the local level, there are high values for institutions, policies, participation, and information.

Opportunities for empowerment are observed at the local level due to the political support offered by the regional hierarchy through its multiple decentralized organizations.

Figure 2. *Valuation of the different levels of government according to the ILBM framework, proposed by ILEC & RCSE (2012).*



Action that could lead to an improvement in neighboring hierarchies. According to the literature [13], the quality of governance of a given country, region or locality is defined as a function of the level of governance of its neighbors, so an improvement in governance in neighboring hierarchies could influence the continuous improvement in the entire system.

On the other hand, a challenge to technifying the entire hierarchical system is presented by the deficiencies of the technology pillar at all hierarchical levels, limiting the improvement in other pillars. However, in countries such as Mexico, where the system is deficient and resources are limited [14], achieving this represents great challenges not only for the hierarchical scale but also for the entire system, which must be readjusted and reorganized to the changes [9].

3.2 Quality of governance

Quality of governance results according to the territorial reach and institutional participation suggest an average quality of 75% in the 257,911 hectares that comprise the area studied and where dependencies of all hierarchical levels interact, mainly in the region through which Irrigation District 093-Tomatlan extends. Governance quality values are approximately 87% comparing to the average value (123.90) with respect to the overall percentage of the study area. The lowest values (59%) are associated with the localities of La Piedra Pintada (84 inhabitants) and El Guamuchil (64 inhabitants).

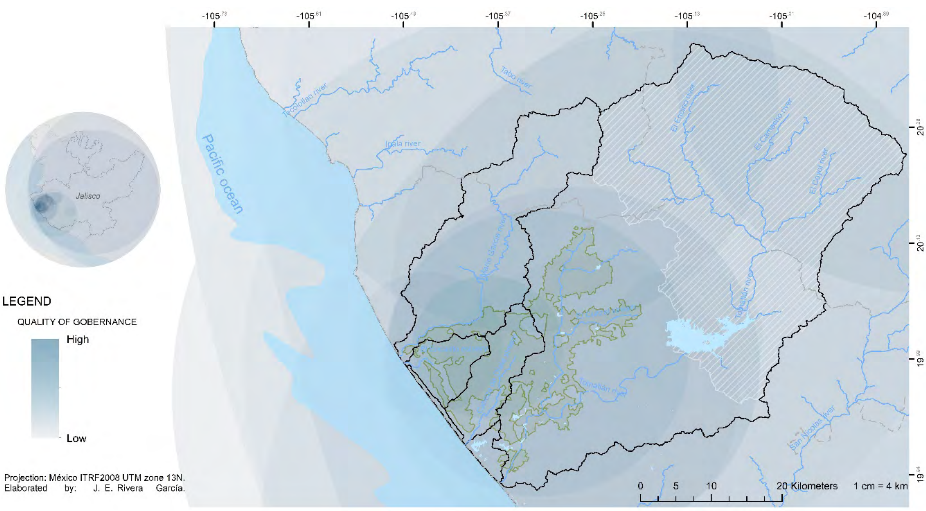
In general, a robust institutional network is responsible for managing and administering water resources based on the Mexican Political Constitution. However, the lack of vertical connectivity between institutions is evident, where the federation and the state have little involvement in the search for solutions and where social needs are unheard.

The involvement of the federation and the state in matters related to the common good and decision-making in municipalities is necessary to strengthen institutional participation and to improve the pillars of governance, taking into account the municipal level as a strategic node for the improvement in the quality of governance throughout the system. Due to the autonomous nature of the municipality, it is possible to create plans that ensure the interests of each municipality and in turn reinforce the particular interests of the agencies at the regional and local levels, which allows improvement in communication and institutional participation at lower levels and thus reinforces the highest hierarchies.

4. Conclusions

One of the problems in the governance of Mexico is the impartiality in the exercise of public power that occurs when public opinion is not considered by public officials in decision-making processes [9]. Promoting social participation through forums, addressing the needs of the population can help to create better bonds of trust between institutions and society, improving the governance quality in general.

Figure 3. *Spatial distribution of governance quality according to the institutional reach and level of participation*



Improving governance will promote the development capacity of societies and can improve conditions of poverty [15], as well as can even improve the governance conditions of neighboring countries, states, or municipalities [16]; we find that governance in one country exhibits a positive relationship with governance in neighbouring countries. Consequently, a change in a single explanatory variable in a particular country not only affects the level of governance in that country itself, but also in neighbouring countries. Using maximum likelihood function values and Bayesian posterior model probabilities, we also find that the spatial arrangement of the countries in the sample is best described by a spatial weights matrix based on the 10 nearest neighbours of every country in the sample. © 2010 the author(s).

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Lake Trasimeno, Italy, responses to climate change and governance policies: present and future scenarios

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Abstract

This study about Lake Trasimeno (Umbria region, Italy) has involved different perspectives as climatology, hydrology, water resource management, environmental and socio-economic point of view. Lake Trasimeno is a shallow water body and it is characterized by a critical balance between water supplies, evaporation losses and use of water resource. The water level of the lake is strongly influenced by the variability of the climate and the related hydrological parameters. In view of this, since Roman times, the lake has been interested by interventions aimed at level regulation. At present, Lake Trasimeno suffers for high critical situations, especially for drought. However, its basin, after a first expansion in 1962, has not been interested by any further structural intervention to increase the water volume flowing into the lake. The present study aims to outline how climate change scenarios could influence the management of the lake levels and the possible governance actions to mitigate the critical impacts of the drought. In particular, two different mitigation measures are proposed, based on the possibility to divert the available volume of Montedoglio or Casanova reservoir for Lake

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Trasimeno restoration. A hydrological lumped model taking into consideration different contributions such as precipitation, evaporation or agricultural withdrawals, allowed to assess the water level monthly fluctuations of Lake Trasimeno. The integration of the hydrological model with a decision support system based on SimBaT model allowed the assessment of the impact of mitigation measures proposed in this work.

Keywords: *Shallow water body, climate change scenarios, water resource management, governance*

1. Introduction

Water shortage is an acute problem regarding many areas in the world, shallow lakes are affected by this problem which could worsen further in the next years. The most recent bibliography shows several works that analyze the problems of shallow lakes in the world, highlighting the inevitable environmental aspects related to the accumulation of pollutants, with anomalous development of algae [1], also considering a scenario that takes into account the effects of possible climate changes [2] [3] [4]. However, the water balance of these lakes always represents one of the focal themes examined, having a direct impact on environmental aspects in the presence of criticalities due to drought periods [7] [6] [7].

To solve critical issue in water resources management (IWRM) an integrated approach is necessary and this method must be adopted also in lake systems management, by assessing the four key dimensions of IWRM: enabling environment, institutions and participation, management instruments and financing. Many case studies develop this approach in lakes spread in the world [8] [9] [10] and the effectiveness of water resources management measures depends on governance effectiveness. To reach this goal the governance measures must be supported by the results of plans and models, which clearly show the effects of these measures.

In this study a first step of IWRM is developed, a hydrological model to evaluate the lake level monthly fluctuations was coupled with a simulation model to study the possibility to divert the available volume of Montedoglio or Casanova reservoir for Lake Trasimeno restoration. The results can support decisions for future management scenarios for Lake Trasimeno.

2. Materials and methodology

In this work, scenarios based on IPCC (Intergovernmental Panel on Climate Change) projections (paragraph 2.1) have been considered.

A hydrological lumped model derived by [11] was used to assess the water level monthly fluctuations of Lake Trasimeno (paragraph 2.2).

The integration of the hydrological model with a DSS (Decision Support System) based on SimBaT (Simulation of Tiber river basin) model allowed the evaluation of the impact of the mitigation measures proposed for Lake Trasimeno on Montedoglio or Casanova reservoir (paragraph 2.3).

2.1 Climate change scenarios

Future scenarios are based on IPCC projections [12] for Southern Europe and Mediterranean - A1B scenario (rapid growth with balanced use of fossil fuels). We considered scenarios with an average temperature increase of 0.35 °C per decade, with a maximum of 0.55 °C and a minimum of 0.22 °C. These data are in accordance with CNR-ISAC data ranging from 1980 to present, that consider an average temperature increase of 0.45 °C per decade [13]. About rainfall, an average annual decrease of -12% is foreseen, with a minimum that leaves precipitation basically unchanged (-4%) and a maximum of -27%. These values were combined in an average scenario (*Pavg Tavg*), a maximum criticality (*Pmin Tmax*) and a minimum criticality scenario (*Pmax Tmin*).

2.2 Hydrological model

Equation (1) evaluates the water level monthly fluctuations (mm). The model considers the precipitation and (mm), respectively over the lake area and the watershed area ; the evaporation from the lake surface ; the water volume V (m^3) entering or leaving the lake such as an external water supply from a reservoir or the amount of water used for agriculture.

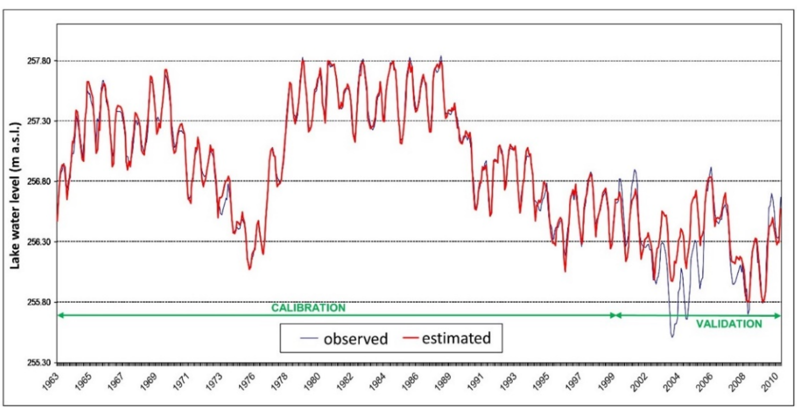
$$A_m = \frac{(P_s \cdot S_s + P_b \cdot S_b \cdot C)}{S_s} - E \pm \frac{V}{1000 \cdot S_s} \quad (1)$$

The model was calibrated (Figure 1) with data ranging from 1963 to 1999 by means of the estimation of the monthly average run-off coefficients. The validation (2000-2010) well reproduces the observed data, except between 2002 and 2005 when different values of the parameter C, related to the occurrence of extreme events, should be considered. The evaporation is calculated by the equation derived by Dragoni and Valigi [14] for lakes located in Central Italy:

$$E = 19.007 \cdot {i_m}^{3.063} \cdot {T_m}^{0.486} \quad (2)$$

where is Thornthwaite insolation monthly index (43° N latitude) and (°C) is the monthly average air temperature.

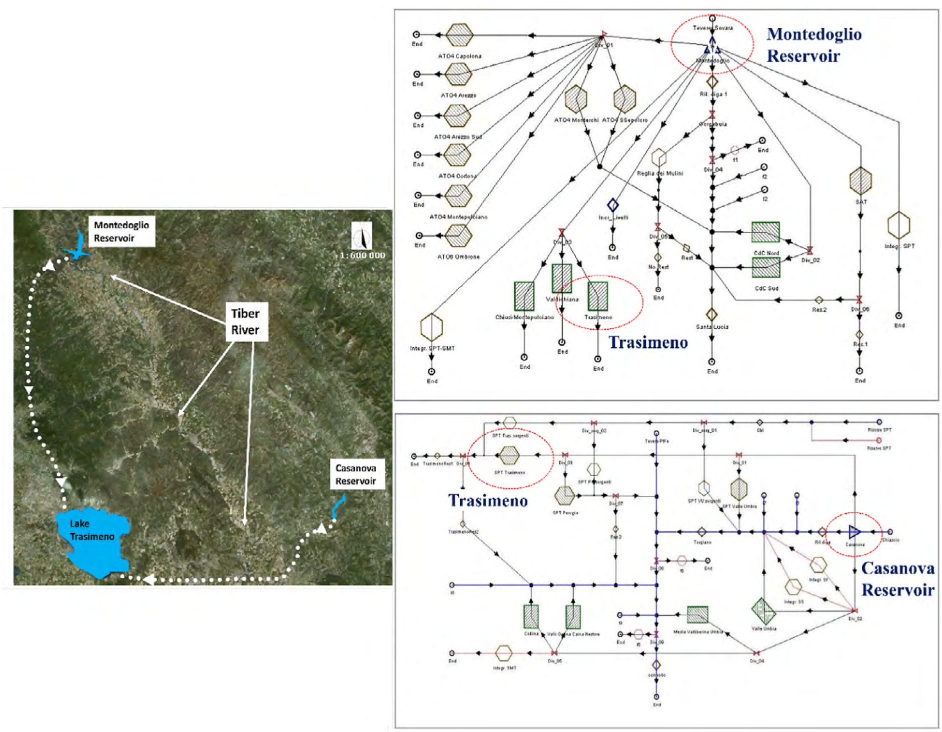
Figure 1. *Calibration (1963-1999) and validation (2000-2010) of the hydrological model.*



2.3 SimBaT-DSS

SimBaT is a non-commercial model originally developed at University of Perugia, Department of Civil and Environmental Engineering. It is based on a network of nodes and arcs. Nodes manage weekly or monthly discharges, arcs manage the link between nodes. In this work the time step is monthly, because of the slow change of the lake and reservoirs level. The sequential topological order of the river network, from upstream to downstream, highlights the different types of water demands: rectangle symbol for irrigation, hexagon symbol for municipal request, rhombus symbol for control nodes. The DSS built on SimBaT (SimBaT-DSS) manages the water resources in Tiber River Basin. An important characteristic of the water management

Figure 2. *On the left: Scheme of the water management system: Montedoglio - Casanova - Trasimeno. On the right: SimBaT river network for the systems: Montedoglio - Trasimeno and Casanova - Trasimeno.*



algorithm is the use of a "balanced priority" to share the deficit. The balances are calculated on a projection of some time steps in advance and the decision whether and how reducing the distribution of water (α_{rid}) depends on the ratio between the Total Requirement Volume (TRV) and the Total Available Volume (TAV) in the reservoir:

$$\alpha_{rid} = TAV/TRV \quad (3)$$

If the ratio is less than 1, it is necessary to reduce the releases for the users in a priority shared form. In Figure 2 the scheme of the water management system Montedoglio – Casanova – Trasimeno is shown.

3. Results and discussion

The hydrological model described in paragraph 2.2 was used to compare the water levels between 2011 and 2050 corresponding to the different climate change scenarios based on IPCC Report. In Figure 3 the average scenario brings the lake close to a drought crisis comparable to the one in 1958 [15]. In the maximum criticality scenario, the lake reaches the complete drainage before 2050.

The comparison in Figure 4 between measured and simulated water levels in the last decade (January 2011- December 2021) lets us evaluate how much the real trends of the lake are close to the considered climate change scenarios. After a first adjustment period of the model, the observed level (blue line) remains close or even higher than the minimum criticality scenario (green line) until November 2019, but, from that point, the level starts to approach the average (black line) and the maximum criticality (red line) scenario.

In the past years the lake has been interested by different types of management measures aimed at regulation of the water level. At the end of the 19th century, S. Savino outlet was built, parallel to the old one dated back to Roman age to manage the frequent floods. However, after this work, the trend of lake levels has been decreasing up to 1958, when a drought crisis hit the lake. To contrast this trend, between 1957 and 1962, the catchment area of the lake has been artificially enlarged, connecting the basins of Tresa, Rigo Maggiore, Moiano, and Maranzano rivers to the lake by means of Anguillara channel [15] .

Despite the management measures previously described, even now Lake Trasimeno is characterized by a delicate and unstable balance and the climate has an important impact on lake levels. Moreover, the results in Figure 3 and Figure 4 show that the ongoing climate change could lead the lake to a condition also more critical than in the past.

In this study, two different mitigation measures are proposed based on the possibility to divert a water volume from Montedoglio or Casanova reservoir for safety of Lake Trasimeno (Figure 2).

In [16] , the different impact of the water diversion on Montedoglio and Casanova reservoir is considered. It is highlighted that in the simulation period the Montedoglio reservoir has reached too often the dead volume, the storage volume of Casanova reservoir has remained largely above the critical threshold and the frequency of water spills has been kept high. Even if a consistent amount of water (for example, 10 Mm^3), in a period of reduced water demand for the reservoir, was moved from Casanova to Lake Trasimeno, the reservoir storage would never reach the dead volume level.

The effects of an additional water volume (between 10 Mm^3 and 15 Mm^3) provided for Lake Trasimeno are evaluated using the equation (1) and can be observed in Figure 5: the water level of the lake decreases its oscillation respect to the observed condition and, at the end of the time series, an increase in the minimum level of the lake of about 90-110 cm is reached.

The volume transferred to Lake Trasimeno would also produce a greater change of water in the lake, to mitigate the problems concerning to the water quality and the biocoenosis of the lake. Between 1989 and 2006, when the lake has experimented a strong drought condition, has been observed an important decrease in water transparency, not explainable in terms of variation in the trophic state of the lake. However, the most evident change in the water quality of Lake Trasimeno during the last decades concerns the salt concentration, mainly due to the closed basin and the low precipitation. A detailed data analysis and discussion can be found in [17].

In Figure 6, the water spilled from the lake is compared in three different situations: graph (a) shows the water spills from the Lake Trasimeno between 1963 and 2010, in the present condition; the graphs (b) and (c) represent the incremented frequency of water spills considering an added volume of 10/15 Mm^3 provided from Casanova reservoir.

Figure 3. *Lake water level simulation for the climate change scenarios (Pavg Tavg, Pmin Tmax, Pmax Tmin) in the period 2011-2050.*

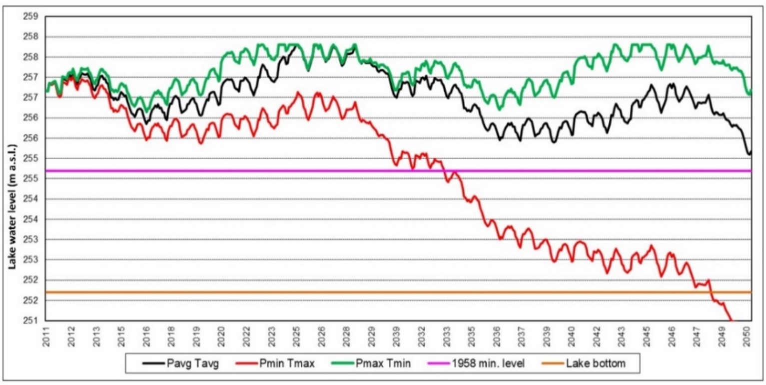


Figure 4. *Comparison between Lake Trasimeno water level corresponding to climate change scenarios and observed water level (January 2011 – December 2021).*

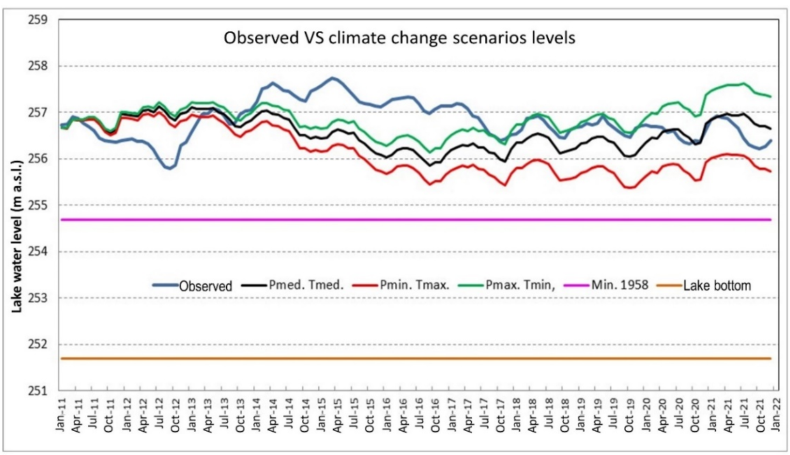


Figure 5. *Lake Trasimeno levels observed and with additional water input of 10 Mm^3 and 15 Mm^3.*

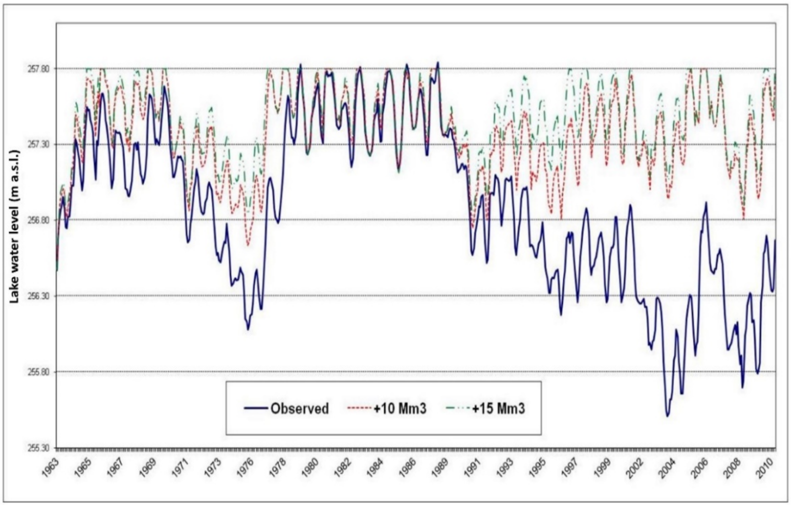
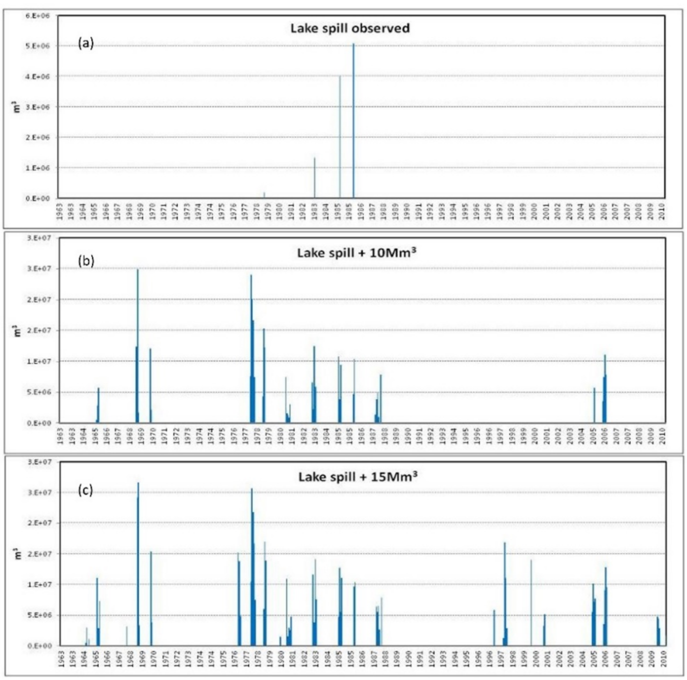


Figure 6. *(a) Observed water spills from Lake Trasimeno; (b) and (c): water spills from Lake Trasimeno with an additional water volume of 10 Mm^3 and 15 Mm^3, respectively (period: 1963-2010).*



4. Conclusions

Future scenarios based on IPCC projections do not exclude high critical and not reversible conditions of the Lake Trasimeno, especially for drought that, currently, would be not acceptable neither sustainable for environmental and economic costs.

In light of this, two possible governance actions to mitigate the critical impacts of the drought have been considered, based on reservoirs of Montedoglio and Casanova.

Nowadays, as Montedoglio is operative, it could be suitable for a short-period test, in order to try out the effects on lake levels. But, for the scarce storage of Montedoglio, it would not be possible to use permanently its water for Trasimeno restoration.

On the other land, Casanova reservoir, for the availability of water also during dry periods, seems to be suitable to increase the water storage of Lake Trasimeno, also in a long-term perspective.

Moreover, in a shallow lake as Trasimeno, the incremented water spills could help the renewal of the water and, consequently, a significant decrease in the salinity, helping the preservation of biodiversity and the ecosystem functions.

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Lake Zapotlan Brief, Mexico: governance diagnosis

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A. E. Michel[1], J. G. Michel[1]

Abstract

The Laguna de Zapotlan is a natural, endorheic lake, in the south part of the state of Jalisco, Mexico, with an area of 1,300 hectares of water and a volume of 27,000,000 m^3. It is a RAMSAR site and member of Living Lakes Network programme, due to its great biodiversity and ecological value. It is a corridor for migratory birds, some of them at risk. The lake represents an important fishing, artisanal, agricultural, livestock, sports and recreational productive area. The Integrated Lake Basin Management (ILBM) methodology was applied for the elaboration of Lake Zapotlan Brief, in order to update relevant information, and as a basis for decision-making in the protection of the wetland, its users and entities involved. It was achieved an analysis in order to strengthen current governance and future challenges. Information for the Lake Brief was generated through interviews with key actors and researching secondary data. In recent years, firm steps have been taken towards the governance and sustainability of the lake through the "Zapotlan 2033 Municipal Plan." Positive results were obtained and others are still

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in process. An important achievement, was the creation of the Environmental Prosecutor's Office. However, one of the main problems is the lack of continuity of projects, due to the rapid changes of municipal governments. In this sense, it is essential to have strong NGOs and educational institutions to take the lead and strengthen the cohesion of the participants, as well as to share a long term vision.

Keywords: *Wetland, governance, development, government*

1. Introduction

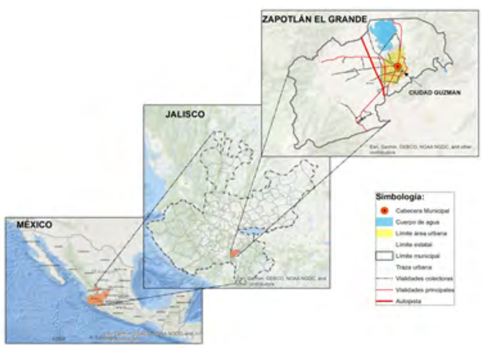
One of the main problems we face worldwide is climate change and global warming, while locally, the growth of the berries and avocado agroindustry has resulted in erosion in the sub-basin and silt in the lagoon. This situation reached the point of continuing economic growth or considering a sustainable development approach, highlighting in this, the protection of wetlands; complex and extremely fragile ecosystems. Previously, different instruments have been implemented such as projects, programs, plans for protection, conservation and management, highlighting those carried out by governments, educational institutions and users [1, 2, 3].

In 2013, the Comité Estatal de Protección Ambiental de los Humedales de Jalisco [4] [State Committee for Environmental Protection of the Wetlands of Jalisco], as well as the Comisión Nacional de Áreas Naturales Protegidas (CONANP) [National Commission of Natural Protected Areas] approved the Programa de Protección, Conservación y Manejo del Humedal de la Laguna de Zapotlan (PCyM) [5], [Program for the Protection, Conservation and Management of Lake Zapotlan Wetland]; this was prepared under the National guidelines of the Ley General del Equilibrio Ecológico y la Protección al Ambiente [6] [General Law of Ecological Balance and Environmental Protection] and the Ramsar Convention for wetlands. Data collection is carried out with the participation of multidisciplinary and intersectoral groups of academics, governments, organized producers and participating society. Since then, the PCyM has functioned as the guide for the lake management.

Lake Zapotlan, also known as Zapotlan Lagoon, is a wetland of international importance, a Ramsar site and member of the Living Lakes Network Programme, due to the biodiversity of migratory birds and the ecosystem services it provides [7,3].

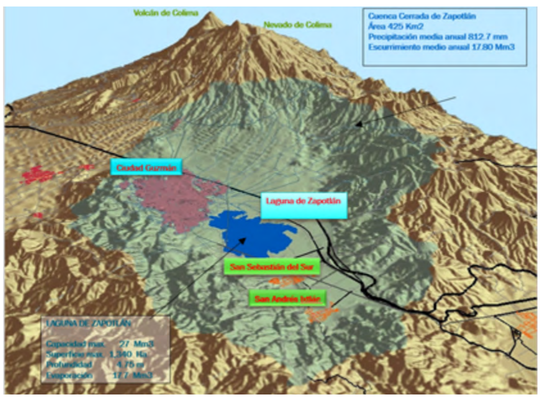
The Integrated Lake Basin Management (ILBM), is a conceptual framework that considers as a basic element, the adequate management of the wetland and its basin, through the strengthening of governance. It is made up of six interrelated pillars, which has allowed the systematic study of water bodies and organisms. They constitute the starting point of scientific knowledge, since recommendations can be derived to achieve the integral use of wetlands. Due to the short-term commitments of municipal governments, governance takes on greater importance and transcendence every day, recognizing the importance of government action at its various levels, but also the need to conjoin to other groups and sectors that interact in a given space through networks of public-private-civilian interaction along local-global axes. With this awareness, the Lake Zapotlan Brief was prepared in order to strengthen governance.

Figure 1. *Geostatistical framework, based on information from INEGI 2018.*



The sub-basin of Lake Zapotlan is located in the Southern Region of the State of Jalisco, Mexico, between the coordinates 19°27'13" north latitude and 103° 27'53" west longitude (Figure 1). The climate is classified as (A) c (WO) W (a) (i) according to the Köpen classification, modified by García [8], being semi-warm. The Lake is located in the territory of two municipalities: Gomez Farias and Zapotlan el Grande (Figure 2) so, the decisions that are made, regarding the water body, involve both of them. In the last fifteen years, the Sub-basin has undergone a radical change in agricultural production, moving from traditional crops such as corn and sorghum, to intensive greenhouse crops such as strawberries, raspberries or blueberries. According to Ezzahra et al. [9], the Municipality of Zapotlan el Grande has gone from having five hectares of greenhouses in the year 2000 to 1,250 hectares in 2015, to these crops are added the changes in land used in forest areas due to avocado cultivation, that has transformed the region, causing deforestation as a consequence, greater erosion, silt in the lagoon and a substantial increase in water consumption for these crops.

Figure 2. *Sub-basin of the Zapotlan Lagoon.*



2. Materials and methodology

The present work was carried out based on the ILEC [10] methodology, Nakamura and Rast, [11], for the integral management of basins and lakes briefs, based on the six pillars: institutions, policies, participation, information, technology and finance, which make possible to improve and strengthen wetland governance. For this, primary information was generated through interviews with key actors and secondary information from various sources such as articles, government documents and technical studies, where disparities in the information were observed.

3. Results and discussion

According to the ILBM, the results of the six pillars are presented.

3.1 Institutions

Thirty institutions currently participate in the sub-basin and Lake Zapotlan, including five higher education institutions, three research centers, four federal government agencies, four state government agencies, the two municipal governments in which the lake is located, four organizations of producers and fishing cooperatives, and an NGO, which is the Patronato del Nevado de Colima y Cuencas Adyacentes [Patronage of Nevado de Colima and Adjacent Basins], this last one has given a great boost to the sustainable development of the sub-basin. In the same sense, the Zapotlan Lake and Basins Research Center of the University of Guadalajara stands out as being a pioneer in the study of the lagoon and is the link between governments and companies.

With the development of intensive greenhouse agriculture and avocado agriculture, in recent years the associations representing these two agro-industries have been incorporated and due to the consequences derived from their actions, the so-called Lagoon's Technical Board was installed with all the aforementioned organizations, in order to address the most immediate problems and contribute to the protection, conservation, management of the ecosystem, sharing a common vision of development.

3.2 Policies

These are supported by the Zapotlan Lagoon Protection, Conservation and Management Program (PCyM). In 2016, the Municipality carried out a citizen consultation seeking a long-term vision, doing this in governance, and the population shared their ideal city by the year 2033. All age groups were covered; in the cultural, academic, business, and civil spheres. This was done based on five strategic development axes, these were: city of knowledge, agri-food city, inclusive city, city of arts and sustainable city. Within this last axis of the Zapotlan 2033 Plan, it was promoted the work for the lagoon and the sub-basin. In the Municipality of Zapotlan it was accomplished the modification of the environment and sustainable development regulation, in which the Environmental Prosecutor's Office was created and also the implementation of the license of environmental feasibility for any line of business in order for them to make proper use of natural resources [12]. For the time being, this regulation needs to be applied. In this same tenor, the update of the Ecological Planning of the Municipality and the elaboration by experts of the Master Plan of the Sub-basin of the Zapotlan Lake were promoted. Finally, a wastewater treatment plant is built for the Municipality of Gomez Farias. Despite the effort made in recent years, the implemented policies have been insufficient to address the dynamics of the lake and the sub-basin due to the lack of supervision and enforcement by federal and state government authorities, but also due to the lack of coordination between the different institutions that care for the lagoon.

3.3 Participation

There is a Basin Commission, made up of a president, who is the delegate of the Comisión Nacional del Agua (CONAGUA) [National Water Commission] Lerma-Chapala-Santiago Pacífico, and seven commissions, one for each municipal council where the basin is located, they are: the municipal president of Zapotlan el Grande and Gomez Farias, a commission for agricultural and livestock users, industrialists, service providers and academics. However, the strategies and solutions proposed are at regional level and on many occasions users do not see them reflected in their area. There is the Junta Intermunicipal del Río Coahuayana (JIRCO) [Intermunicipal Board of Coahuayana River], made up of twelve municipalities that make up the river basin, it has made significant progress, however, it has a partial vision, since it is only made up of the municipalities. As of 2018, the Lagoon Technical Board was installed, coordinated by the Municipal Government of Zapotlan with a strong impulse to address local and short-term problems.

This is an instance of informal governance and with an intense participation of higher education and research institutions, civil society and companies. However, being an informal instance, it is subject to recognition by the government in turn, in which there was no continuity with the recent change in 2021. This makes us realize that stronger NGOs and academic institutions are required to allow the continuity of long-term policies.

3.4 Information

The information for decision-making is obtained from the state government, the municipal government, and studies from higher education and research institutions, as well as non-traditional information, however, this information is dispersed and frequently, with the changes in municipal government, it goes astray. Given this, an institutional digital repository of public access information is being implemented, based in the Library of the Centro Universitario del Sur [Southern University Center] of the University of Guadalajara.

Among the agencies that carry out regular monitoring of the water quality of the Lagoon, is the Comisión Estatal del Agua (CEA) [State Water Commission] and the Sistema de Agua Potable de Zapotlan (SAPAZA) [Zapotlan Potable Water System]. Those who monitor the birds of the Lagoon through the University of Guadalajara, is the Laboratory of Tourism Studies for Sustainability.

With this information, bird guides have been published [13], including one with the common names of birds in Braille [14], as well as 100 videos on a YouTube channel of birds of the Lagoon [15]. This has allowed us to have a better knowledge of the lagoon, the quality of the water and to increase the number of birds registered as a reservoir of biodiversity. Currently, 142 species of birds have been registered in the lake, of which sixty are aquatic and eighty-two live in the wetland environment; of these, according to NOM-059 [16] and normative annex III of NOM-059 [17], there are ten species of birds in the risk category, seven in special protection, two threatened and one in danger of extinction. As of 2017, a decrease in the population of migratory birds has been observed, mainly those that come from

North America. This decrease in populations, among other factors, could be linked to the lack of continuity of medium and long-term policies in the lagoon and the sub-basin, and this could be very difficult to achieve if there is no robust governance.

3.5 Technology

Among the technological interventions introduced, biological control has been carried out for the lily through two species of beetles (*Neochetina eichhornia* and *Neochetina bruchipara*) and a species of phytopathogenic fungus (*Acremonium zonatum*); after three years, results are being seen in the reduction of the lily population, this is complemented by the mechanical extraction of lily and floating cattail in which the fishermen's cooperatives participate. The reduction of chemical fertilizers is in process, in collaboration with farmers. In this sense, the state government has promoted the installation of a biofactory for soil restoration. Similarly, the installation of an artificial wetland for the treatment of wastewater from the town of Atequizayan (750 inhabitants) has been promoted. The rainwater harvesting pilot project was carried out in a secondary school in order to save water and to be a demonstration and environmental education area, it is expected to expand the program to other schools. The creation of forest islands has begun in three avocado orchards with the aim of creating spaces for biodiversity in this type of crop. In collaboration with the federal and state governments and companies, a five-year reforestation program has been implemented, resulting in 40 hectares in the protected natural area of Las Peñas Ocotillos in the upper part of the basin.

3.6 Finance

Lake Zapotlan is sustained by its users, by the contributions of the municipal, state and federal governments, through the JIRCO. Economic resources and responsibilities have been allocated by the Secretaría de Medio Ambiente y Desarrollo Territorial (SEMADET) [Secretary of the Environment and Territorial Development]; however, this funding is insufficient. Another extraordinary sources of important financing, are the subsidies put out to tender by the federal and state governments, with these resources the following have been carried out: The Atequizayan wetland, the rain school, the Lake Sub-Basin Master Plan and the update of the ecological ordering of the Municipality of Zapotlan. A relevant way of financing is going to be when the environmental feasibility license is implemented.

4. Conclusion

The Lake Zapotlan Research Center of the University of Guadalajara and the Patronato del Nevado de Colima y Cuencas Adyacentes (NGO) must play a greater leadership role in order to strengthen cohesion among the participants and share a long-term vision.

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Media Luna Lagoon, Mexico. A cultural, archeologycal and recreational heritage

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Abstract

Media Luna Lagoon is located in the ejido "El Jabali" in the municipality of RioVerde, State of San Luis Potosi, Mexico. Its name refers to the crescent moon shape of the system of water springs whose effluent is a series of irrigation channels. The lagoon has very high importance for Mexico because of its scientific, historical, ecological and economic value. It is made up of six small craters from which a deep lagoon derives [1], made up of several channels from which a wetland system is formed [2]. The Media Luna Lagoon was decreed by the Commission of Protected Natural Areas (CONANP) as a protected natural area in June 2003, because of its high ecological value on biotic and abiotic components, Media Luna Lagoon represents a refuge for endemic species, aquatic and migratory birds. However, environmental problems have increased, outstanding the loss of biodiversity, soil compaction of surface water, due to the anthropogenic activities that take place in the area, mainly agriculture and tourism.

Keywords: *Mexican lagoon, watershed management, Media Luna lagoon, governance*

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1. Introduction

In Mexico there are numerous wetlands; among which the Media Luna Lagoon stands out for being the largest system of water springs in the Rio-Verde Valley. It is located in the north-central region of the country, 120 km from the capital of the State of San Luis Potosi in the "Ejido El Jabali" (Figure 1). It is made up of six small spring craters from which bluish and crystalline thermal water flows, forming the main lagoon with a water surface of 1.5896 ha [3].

The name "Media Luna" comes from the shape of the lagoon, although internationally it is known as Mammoth Lake because at the bottom of the lagoon there are remains of two preserved mammoth skeletons [4].

Its origin dates back to the Late Pleistocene [5], which is why it was home to large mammals that dominated its lands and traces of their passage through the area can still be found today. On the other hand, it is recognized for being the largest system of springs in the region with crystal clear blue waters. Due to the above, it was an important ceremonial center during pre-Hispanic times.

Hydrologically the lagoon belongs to the Panuco Hydrological Region (RH-26), the Tamuin River basin (CH-26) and the RioVerde-Santa Isabel sub-basin, integrating several micro-basins due to its large territorial exten-

Figure 1. *Location of Media Luna Lagoon, San Luis Potosi.*

sion, classified as a Priority Hydrological Region (RHP). The El Capulin micro-basin, to which the lagoon corresponds, is located entirely in the municipality of RioVerde, and has a total surface area of 7,113.481 ha and a perimeter of 55.7357 km.

In 2003 it was declared as Protected Natural Area (ANP) "Media Luna Manantial State Park" due to its ecological, economic and cultural importance, although the surface of this zone has undergone various modifications. Initially it had a surface of 305 ha, however the current surface is 284.605 ha [6]; managed by a social organization "Ejido El Jabali" with supervision of federal government personnel in compliance with current laws and regulations.

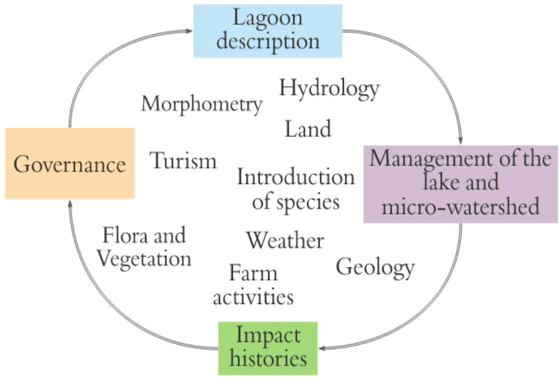
The environmental and physical conditions of the region including extensive plains are favorable for the development of agriculture, an activity implemented since the first human settlements, for which irrigation and rain seasonal agriculture is one of the economic activities of the region, being the Media Luna Lagoon the source of water supply through irrigation channels of the Irrigation District 049.

The lagoon is a very important ecotourism attraction due to its landscape and biological diversity, it has a diversity of native bird and fish species, outdoor attractions such as freshwater diving, snorkeling, swimming, camping and recreation. These activities significantly increase the economic benefit for the region.

2. Materials and methodology

A documentary research was carried out to collect information on the environmental, economic, social and cultural dimensions, based on the guidelines for the preparation of information technical sheets on lakes (ILEC) (Figure 2) to identify the changes that have occurred over time and carry out a comprehensive diagnosis of the current state of the Media Luna Lagoon and its micro-basin.

Figure 2. *ILEC topics*



2.1 Environmental diagnosis

A comparison of data of different periods of time and analyzing some deterioration evidence of the ecosystem was developed on the availability and quality of water, fertility, soil compaction and erosion, diversity of flora and fauna. Additionally, an evaluation of the economic and social impact of the region was made.

2.2 Water balance

The estimation of the water balance was based on data collected by Sistema Meteorológico Nacional (SMN-CNA) and the application of the principle of conservation of masses. This establishes that, for any arbitrary volume, and for any period of time, the difference between the input and output will be conditioned by the variation of the volume of stored water.

The water balance was estimated using the following expression:

Equation 1. *Water balance equation.*

2.3 Water optical properties

A field campaign to measure optical properties of the Media Luna Lagoon was made using an underwater irradiance meter for vertical light attenuation and a horizontal light transmissometer meter to measure horizontal light attenuation coefficient. Simultaneously Secchi disc readings were taken to estimate water transparency.

3. Results and discussion

3.1 Environmental diagnosis

Morphometry

The El Capulin micro-basin is located at a maximum elevation of 1,381 masl and a minimum elevation of 889 masl. It occupies a total area of 71.13481 km^2, a perimeter of 55.7357 km, a maximum length of 7.12 km and a maximum amplitude of 6.90 km (Table 1).

Table 1. *Morphometry of the micro-basin of the Media Luna Lagoon, San Luis Potosi.*

Parameters	Value
Total area	7,113.481 ha
Micro-basin area without water mirror	7,111.8914 ha
Maximum elevation	1,381 m.a.s.l.
Minimum elevation	889 m.a.s.l.
Perimeter	55.7357 km
Maximum length	7.12 km
Maximum amplitude	6.90 km

The lagoon has a maximum depth of 35.0 m and a mean depth of 8.43 m [3] (Table 2), the volume derived from the lagoon, measured by occasional gauging from the El Capulin, Fernandez, Potrero de Palos, RioVerde and San Jose canals, show a total annual average flow rate of 5.5 m^3 s-1 [7].

Table 2. *Morphometry of Media Luna Lagoon, San Luis Potosi.*

Parameters	Value
Lagoon area	1.5896 ha
Maximum length	193.58 m
Maximum amplitude	119.89 m
Mean amplitude	82.12 m
Coastline	638.01 m
Coastline development	0.87 m
Maximum depth	35.0 m
Mean depth	8.43 m
Median depth	8.0 m
Volume	134,015.67 m^3

Water balance

Average annual precipitation registered at the meteorological station Manantial de Media Luna SMN 00024172 is 549.1 mm and the annual evapotranspiration is 1,673.7 mm. The micro basin of El Capulin receives a total of 4,168.05 Mm^3 of rainwater annually, whereas the evapotranspiration rate is 11,905.83 Mm^3, which means a water deficit of 65.0%.

By contrast the Media Luna Lagoon maintains a negative hydrological balance due to the internal thermal water springs located at the bottom of the lagoon; the input is estimated at 137.1903 Mm^3 coupled with 8,728.5 m^3 of rainfall (Table 3)

Water quality

The main temperature in the lagoon is 30.0 °C. Internal springs have a pH interval of 6.95 to 7.16 with a slight acidic tendency, the water channels have a pH value of 7.9 with an alkaline tendency [3] (Table 4).

Table 3. *Water balance of Media Luna Lagoon, San Luis Potosi.*

Input (Mm^3)		
Precipitation	0.0087	0.005%
Media Luna spring	173.470	99.995%
Input	**173.479**	**100.00%**
Output (Mm^3)		
Evaporation	0.0266	0.015%
Irrigation	173.470	99.985%
Lagoon volume	0.1340	—-
Output	**173.496**	**100.00%**
Water deficit	**-0.017**	**0.009%**

Table 4. *Water quality of the Media Luna, San Luis Potosi. [3].*

Parameter	2007 (Chacón *et. al*., 2007)
Temperature (°C)	30
Turbidity (NTU)	0.0
Electric conductivity (µS/cm^2)	1869.93
Total alkalinity (mg/L)	212.89
Total hardness (mg/L)	1184.0
Total phosphorous (µg/L)	8.7
Ammonium (mg/L)	0.01
Total nitrogen (mg/L)	1.75

Water transparency

The Media Luna Lagoon has been recognized as one of the clearest aquatic ecosystems in the world. Optical parameters have been measured by [3] reporting a vertical light attenuation coefficient (Kd) of 0.14 m-1; horizontal light attenuation coefficient (c) of 1.14 m-1. To simplify these measurements Secchi disc transparency has been simultaneously recorded with a value of up to 22.0 m.

The clarity of this lagoon is derived from the continuous flow and water movement inside the lagoon which also substantially decreases the hydraulic residence time which is estimated at 8.5 hours.

Vegetation

Between 1961 to 1978 it has been registered up to 90% of plant species, however at present only 56% of these species have been observed. It is possible that some of these species have been lost possibly due to the modification of the ecosystem [8].

At present the local vegetation is composed of a total of 51 species distributed in 25 families [8][9]; it is dominated by scrubs, followed by aquatic submerged vegetation [9].

Land use

From 1617 to 1960 important modifications were made in the landscape due to the growth of agricultural activity, which replaced livestock in the region. This led to the construction of the Rio Verde, Villana and Potrero de Palos channels to irrigate surrounding crops. Orange and sugar cane crops were introduced, which induced a change in land use and the desiccation of some water springs.

The main impacts generated by tourism are soil compaction, infrastructure, erosion of the shoreline and deterioration of channels, decrease in water flow, solid wastes generation, damage to fauna and water pollution.

3.2 Governance

Main challenges for the effective management of the Media Luna Lagoon are active social participation, generation and dissemination of scientific and reliable information, financing of innovative and sustainable projects, environmental policies and programs, ecological innovation of infrastructure and application of an effective plan for waste management (Figure 3).

Media Luna has developed unique characteristics as an aquatic ecosystem. It was also an important ceremonial center during the pre-Hispanic period.

The progressive growth of agriculture using the advantage of extensive plains in the region induced the construction of irrigation channels with a very intensive use of available freshwater sources including Media Luna Lagoon.

The fact that the Media Luna Lagoon is one of the clearest aquatic ecosystems in the world with a very reasonable maximum depth of 35.0 m has made it the main attraction for scuba freshwater diving. Additionally, some parts of the shoreline have some attractive caverns made by the natural aquatic vegetation which receive hundreds of scuba divers for recreation. This activity associated with swimming, snorkeling, camping, represent a very important economic income for the people of the Ejido El Jabali.

Figure 3. *Governance of the Media Luna Lagoon, San Luis Potosi.*

Environmental policies applied in the lagoon have been diverse and have focused mainly on water resources and tourism. Some policies have caused negative effects for the lagoon, such as the introduction of exotic species and the drying up of springs due to the construction of ditches.

Ecotourism

The Parque Estatal Manantial de La Media Luna represents an important natural resource in the tourism activity. It is considered the most important thermal spring in the State of San Luis Potosí. It is also an important source for aquatic archeology with potential attractiveness for international and national tourists [10].

For this reason, environmental and management regulations for the access and recreation at the lagoon should be modified and be adapted for sustainable actions to improve the conservation of natural resources of this valuable aquatic ecosystem.

4. Conclusion

Media Luna Lagoon is an important Mexican aquatic ecosystem with remarkable optical properties, endemic fish fauna, and attractive sites for scuba diving, snorkeling, swimming and recreation. It is important to build capacities in the community of Ejido Jabali administrators of this Natural Protected Area to improve environmental management programs for conservation of water quality, efficient management of wastes and to improve landscape for sustainable development with environmental, social and economic benefits.

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Authors gratefully acknowledge the members of Panorama Ambiental A.C. for their contribution in research and fieldwork. We also thank the young professionals from the Mexican Federal Program of Jóvenes Construyendo el Futuro attached to the LIMNOS Environmental Consultant for their valuable work in computing and field work.

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The municipal governance of the Great Lakes and the St. Lawrence River in the context of the creation of the Canada Water Agency

Lauren Touchant[1]

1. Introduction

There is growing international scholar recognition that municipalities play a growing role in water governance in Canada, despite the fact they are entities of the provinces/territories, and do not hold any status in the Canadian Constitution. Municipalities have been involved in water governance for decades. They joined municipal networks to meet and collaborate with other municipalities, access best practices and expertise, and receive support. Since 2019, over 2,000 worldwide jurisdictions including local governments have signed climate emergency declarations, signalling a growing awareness and commitment from local governments to address climate change. Municipalities understand they are an important player to protect water ecosystem, they economically depend on water related activities. They manage infrastructure to provide drinking water to millions of people, and they protect their local community during flooding events. Canada does not have a coherent national water policy. The governance and management of fresh water is fragmented and not adequate to address urgent freshwater issues. An opportunity to restructure water governance in Canada emerged when the Government of Canada announced in 2019 the creation of a

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Canada Water Agency (CWA) to "keep Canada's fresh water safe and clean, even in a changing climate" (Liberal Party of Canada, 2019). This paper asks, what are the existing municipal networks in place to support governance of fresh water in Canada, and what are the opportunities for collaboration, particularly in the context of the creation of the Canada Water Agency? We argue that the municipal institutional arrangements are already in place in the Great Lakes and St. Lawrence River Basin. The Canada Water Agency (CWA) confers an opportunity to reduce the complex governance and fragmentation of fresh water governance in the region. Great Lakes and St. Lawrence River Cities Initiatives submitted key recommendations to the Environment and Climate Change Canada, advising staff to connect with existing institutional arrangements and the Great Lakes and St. Lawrence River Cities Initiative. The CWA must further collaboration and alignment towards collective impact, and should not increasing overlaps, complexity, and bureaucracy.

2. Methodology

Our research is a qualitative empirical-based analysis exploring the case of the Great Lakes and St. Lawrence Cities Initiative (network) and the Climate Ready Infrastructure and Strategic Sites Protocol, an adaptation instrument aimed to help municipalities build their resilience to floods. We adopted a multi-level theoretical framework: policy instruments (micro), policy networks (meso), and governance (macro) supported by an interpretative methodology that included three methods: documentary analysis, 30 semi-directed interviews, and a 3-day direct observation to conduct our field research. We will first introduce our case study and present the results for each of the level of analysis, policy instruments, policy networks, and governance.

2.1 Case study: The Great Lakes and St. Lawrence Cities Initiative

The Great Lakes and St. Lawrence Cities Initiative was born from the International Association of Great Lakes and St. Lawrence Mayors established in 1986 in Quebec City. In 2002, the Mayor of Chicago, Richard Daley, and the Mayor of Toronto, David Miller created the Cities Initiative by merging the International Association of Great Lakes and St. Lawrence Mayors and the Great Lakes Cities Initiative. Their goal was to create a political space within which municipalities could discuss common environmental concerns and speak as one voice to other governments. The Cities Initiative is a political network, with intent to participate in the decision-making process and the governance of the Great Lakes and St. Lawrence River. The organization was officially incorporated as a not-for-profit in Canada and in the United States in 2005. The Cities Initiative is led by a bi-national Board of Directors comprised of eight American Mayors and eight Canadian mayors. It currently represents 128 American and Canadian municipalities from eight American states (Wisconsin, Illinois, Minnesota, Indiana, Pennsylvania, Michigan, Ohio, and New York) and two provinces (Ontario and Québec).

The network is directly involved in the selection and design of policy instruments to help municipalities address water related issues. It is central to the dissemination of policy instruments, information, and best practices. It also fosters policy learning by leveraging a diversity of learning mechanisms available to the network. The network helps build municipalities' policy capacity. It also provides a safer political space to policy entrepreneurs, whether they are elected officials or a municipal employee, who want to advocate for policy change, and introduce new policy solutions.

The network initiated a climate resilience program in 2014 at the request of the Board of directors, with the intent to develop an adaptation instrument that would be readily available to municipalities who need to protect their community infrastructure from floods in the Great Lakes and St. Lawrence Basin. The purpose was to develop an instrument that would be easy to use, and that would help municipalities evaluate the potential vulnerabilities of municipal infrastructure as well as the flood risks and impacts on the community. The Climate Ready Infrastructure and Strategic Sites Protocol (CRISSP) was developed by an environmental engineering company, AECOM, in partnership with the City of Gary (Indiana), who piloted the matrix during its development phase. Simultaneously, the network established an advisory committee comprised of four American municipalities (Evanston, Illinois; Niagara Falls, New York; Milwaukee, Wisconsin; and Traverse City, Michigan). Interestingly, the policy instrument was not widely adopted in the United States and in Quebec, but it was adopted as a best practice by the Ontario Centre for Climate Impacts and Adaptation Resources, a community of practice in climate adaptation, and Great Lakes & St. Lawrence Cities Initiative Municipal Adaptation & Resilience Service.

Map 1. *Cities Initiative's member municipalities.*

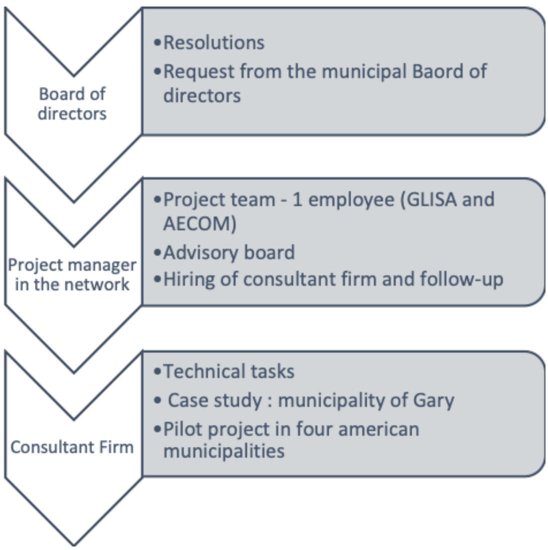
* Source: Great Lakes and St. Lawrence Cities Initiative (2021).

3. Results

3.1 Results from the micro level analysis: Policy Instruments

The selection of CRISSP is not a neutral act. CRISSP is a policy instrument that was developed by a specialized engineering firm upon the request of the Board of Directors in the Board Resolution 01-2014M. The instrument is a matrix. Municipalities mostly answer *yes* or *no*, but in some cases, they must answer open questions. These questions aim to assess municipal practices, processes, and policies. Questions imply socio-political choices with the intent to orient and guide municipal action in one specific direction. Research findings indicate that the Cities Initiative tried to legitimize the adoption of the policy instrument. This instrument has a technical-scientific legitimacy; it was developed by an expert company and tested in one municipality during its conception, and four municipalities once the instrument was finalized. The instrument has a normative legitimacy because it encapsulates a set of norms, values and principles such as sustainable development, good vs. bad, efficient vs. inefficient, effective vs. ineffective. Finally, the instrument is presented by the technical paper[1] (published by AECOM) and the White Papers (published by the network)[2] as the right instrument to protect municipal infrastructure. The diagram below summarizes the development of the policy instrument.

Diagram 1. *A technico-administrative instrument – problem variable.*

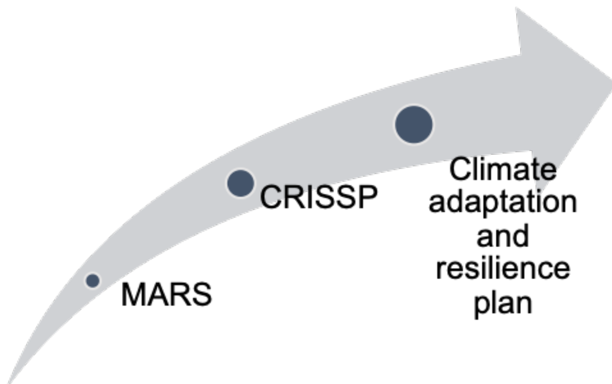


The project pilot in four other municipalities increased the normative legitimacy of the instruments. The network wanted to facilitate the transfer of the instrument amongst municipalities. This effort assumed that if the success of the instrument was proven by members of the network, other communities would adopt it, triggering a domino-effect. One interviewee

1 See: http://glslcities.org/wp-content/uploads/2016/06/CRISSP-Technical-Paper_FINAL_121815.pdf
2 See: https://glisa.umich.edu/media/files/projectreports/GLISA_ProjRep_GLSLCI_CRISSP.pdf

shared that "the piloting of the project in various communities was particularly important because it would be a demonstration of feasibility to validate the demand for an instrument to evaluate and measure the progress" (interview with an administrator from the network, 2017). CRISSP is a one size fits all instrument that is part of a continuum of policy action to build coastal resilience.

Diagram 2. *GLSLCI - Build Resilient Coastal Cities.*



Resilience building is transcoded in different stages. The program Municipal Adaptation and Resilience Services[3] is a program outlining the "practical steps that may be implemented over the short term in both small towns and large cities" (OCCIAR & CAP, 2021). The MARS CoP Portal includes a library of climate change adaptation resources, case studies on municipal adaptation, case studies, fact sheets, adaptation tools, climate data, articles, and events. CRISSP is an instrument of MARS. The instrument itself is divided into six categories (site, geography, risk, capacity, flooding, and strategic sites). CRISSP identifies gaps and enables municipalities capacity to increase the resilience of the local infrastructure. In return, CRISSP informs the Municipal Resilience and Climate Change Adaptation Plan. These instruments appear to be depoliticized, but they are not. In fact, their deployment is strongly changing the degrees of collaboration and coordination between municipal departments. Staff must "assemble a CRISSP Team

[3] See: https://www.ccadaptation.ca/en/MARS

across municipal departments and engaging members to determining the scope of the evaluation" (AECOM, 2014:3). Instruments change the power relationship amongst municipal departments, ignite collaboration and tensions as it challenges organizational and behavioural barriers. CRISSP is designed to generate new knowledge informing further municipal policies and initiative to increase resilience.

3.2 Results from the Meso-political level: Networks, the enablers of municipal action

The network is a not-for-profit organization run by a board of directors which implements the network's mandate. Findings show that the network is a catalyst for information sharing, socialization, and policy learning. Information is shared horizontally amongst municipalities: best practices, instruments, activities implemented by other municipalities.

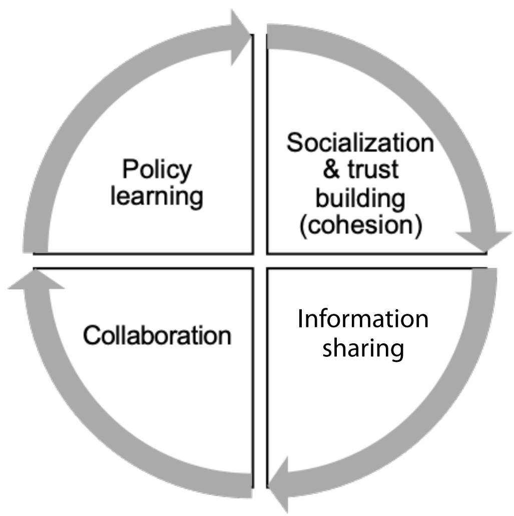
Vertically (top-down) from the network's administration to municipalities: relevant information coming from different sources of information (e.g., other networks, governments.

Vertically (bottom-top) from municipalities to network: municipal initiatives, needs and challenges.

The network relies on the information shared by municipalities to remain relevant and respond to members' needs. Information become a precondition for learning, but municipalities share only if they trust other municipalities and the network.

This learning process involved information transcoding. The network collects, produces, and gather information from different sources of knowledge including other networks and in-house research, consultation, partnerships, various forums, etc. Administration learns to ensure are always up toto provide relevant support to municipalities. They transcode the information for municipalities. They simplify technical information and make it easily accessible. The network leverages communication-based and information-based instruments, staff disseminate information and encourage environmental literacy. They also facilitate the internationalization of information to foster collective knowledge within the network. Employees play a significant role in fostering policy learning through trust building and information sharing. The network structures the deliberative and learning space. It also creates conditions to transfer policies, ideas, and instruments, and encourages the emulation of best practices or what they determine to be “good examples” to advance policy convergence. One key element is municipal leadership. Networks play a significant role in encouraging municipalities to manage and protect fresh water. They determine the criteria for leadership and build a municipal image of leadership that expands the municipal role in Canada fresh water governance with awards, and leadership discourse and narrative.

Diagram 3. *Learning process within networks.*



3.3 Results from the Macro-political level: The effect CRISSP and the Cities Initiative.

The Cities Initiative has increased the influence of municipalities in Canada. It has also significantly increased their confidence. The network brings political value to municipalities in the Great Lakes and St. Lawrence River Basin. The network advocacy activities on Parliament Hill in Ottawa, at the National Assembly of Québec, at Congress in Washington are critical activities for mayors who can meet with ministers, congressman/women, members of parliament to discuss priority issues in the Great Lakes and St. Lawrence watershed. Municipalities particularly appreciate to be able to speak in one voice. Since municipalities are creatures of the province, municipal-federal relationships have been limited. The Cities Initiative offers an alternative to municipalities to directly engage with the Federal government without talking to the provincial government. For many municipalities, the status quo in Canada water governance is unsustainable considering the current water crisis. This is the reason why Mayor Daly and Mayor Miller started the Cities Initiative network. Over the years, the Cities Initiative successfully gained representation in the decision-making process within key binational entities such as the International Joint Commission, the Great Lakes Fishery Commission, the Great Lakes Commission, the Great Lakes Advisory Board, the Great Lakes Executive Committees, etc. One of the priorities of the Cities Initiative has been to increase collaboration in the region and develop strategic partnerships with other governmental entities in Canada and the United States, Indigenous communities, and bi-national subnational stakeholders involved in the Great Lakes and St. Lawrence region. More recently, the Cities Initiative was one of the five stakeholders forming the Great Lakes and St. Lawrence Collaborative. The collaborative drafted the 2020-2030 Action Plan to Protect the Great Lakes and the St. Lawrence River. As part of this effort, the Cities Initiative participated and submitted a written statement to the Federal Department of Environment and Climate Change Canada (ECCC). The network also officially supported the creation of the new Canada Water Agency but asked ECCC to adopt and integrate 30 recommendations outlined in the 2020-2030 Action Plan to Protect the Great Lakes and St. Lawrence. The plan endorses a collective approach toward agreed outcomes. In fact, the newly created policy instrument establishes a "common and integrated vision" (The Great Lakes and St. Lawrence Collaborative, 2020) for the management and the governance of the Great Lakes and St. Lawrence Basin. The Cities Initiative ask ECCC to address the current governance gaps (e.g, lack of capacity, expertise, and resources) and build on the new proposed institutional arrangements, instead of reinventing the wheel. The proposed governance is highly decentralized connecting the Federal Government to four local implementation teams, comprised of a diversity of stakeholders, dedicated to shoreline resiliency, nutrients and algae, beach quality and shoreline access, and reducing toxic exposure. The new institutional arrangements propose the creation of a Federal Intergovernmental taskforce to better coordinate the twenty federal departments and agencies with shared responsibility over freshwater. The leading department has a seat on the Great Lakes and St. Lawrence Collaborative Commission. This taskforce is overseen by the Federal Commissioner of Environment and Sustainable Development. In parallel, the members of the Great Lakes and St. Lawrence Collaborative[4] will guide and coordinate the implementation of the Action Plan. The collaborative is supported by a Secretariat responsible for implementing and evaluating the strategy. This Collaborative includes Indigenous communities, businesses, nongovernmental agencies, academic representatives, and municipal representatives. Both the taskforce and the Collaborative are informed by the Indigenous Great Lakes St. Lawrence organization, which represents indigenous organizations and communities who live in the Great Lakes St. Lawrence Region. This proposal for new institutional arrangements constitutes a governance innovation that results from a lengthy and extensive deliberative process. It also highlights the influence of the Cities Initiative and its ability to contribute to changing the governance of the Great Lakes and St. Lawrence River ecosystem.

4. Conclusion

A changing water governance in Canada: the rise of municipalities

The proposal for new institutional arrangements in the Great Lakes and St. Lawrence region initiated by local stakeholders and municipalities shed

[4] "The Great Lakes and St. Lawrence Cities Initiative, in partnership with the Great Lakes Fishery Commission, the Council of the Great Lakes Region, Freshwater Future, and Stratégies Saint-Laurent, has been leading an inclusive, stakeholder-led process to arrive at a common vision and an action plan to amplify and accelerate collective actions and investments to protect and restore the Great Lakes and St. Lawrence waters and ecosystem. This project, called the Great Lakes and St. Lawrence Collaborative Strategy, is inspired by the U.S. Great Lakes Restoration Initiative and would focus on the nexus of water, economy, and climate resiliency in the Great Lakes-St. Lawrence region, with special consideration to First Nations and Metis needs" (Great Lakes and St. Lawrence Cities Initiative, 2021).

light on a changing governance in the Great Lakes and St. Lawrence Basin. It reveals a growing bottom-up municipal movement in the region that is influenced by the critical role of the Cities Initiative. The network has successfully fostered policy learning, increased municipal capacity and leadership enabling municipality to engage in multilevel governance. New institutional arrangements and municipal leadership are pressuring both the federal and provincial governments to work with municipalities beyond the archaic legal structure that compels them to a rather limited function as creatures of the provinces. Municipalities are undeniable actors in the management and protection of fresh water in Canada. The future Canada Water Agency cannot ignore the growing role of municipalities, Indigenous Communities, and regional perspectives as it develops its programs and policy instruments. It provides the opportunity to reduce the fragmentation of the current water governance in Canada by fostering collaborative governance towards collective impact in the region.

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Use of research findings in strengthening Integrated Lake Basin Management (ILBM): A case of Lake Nakuru, Kenya

J. A. Raini[1], T.M. Kiogora[2]

Abstract

Lake Nakuru (36° 05' E, 00° 24' S) lies at an altitude of 1,759 m asl in a catchment basin of approximately 1,800 km^2.

The lake's water quality was determined by analyzing physico-chemical parameters, ions, anions, nutrients and heavy metals. The physico-chemical parameters as well as major ions and anions indicate significant dilution due to rising water levels. The lakes' salinity has reduced from a range of 22 to 62 g/l to below 2 g/l. Dissolved oxygen recorded a mean of 1.7 mg/l in the mid lake. The results indicate that heavy metals in the lake water are within acceptable standards except Molybdenum. An assessment of the lakes' biota reveals that the lake has faced major ecological restructuring as a result of rising water and dilution.

This research is very important in terms of strengthening the pillar on information & knowledge within the Integrated Lake Basin Management (ILBM) framework. Significant amount of research data on Lake Nakuru exists, but to a large extent research data has not been utilized to improve Lake Basin's governance. Firstly, most of the available research data is not integrated and comprehensive since it was not initially collected with the

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aim of resolving particular identified lake management problems Second, most research projects have been conceived and implemented without participation of lake basin managers and the local community. Third, the research findings are written and presented in a manner that is not easily understood by non-scientists and the managers have not appreciated the importance of data in basin management.

Keywords: *Lake Nakuru, heavy metals, lake basin, governance*

1. Introduction

Lake Nakuru lies about 1 km South of Nakuru City and forms the centrepiece of Lake Nakuru National Park. The Park was designated as Kenya's first Ramsar site (Wetland of international importance) in 1992 and a UNESCO World Heritage Site in 2011 because of its outstanding universal value.

Since May 2010, the lake level has been rising from an annual average level of 0.7 meters to the highest level of approximately 10.5 meters recorded in June-July 2020 (Kiogora et al., 2020). This has resulted in a significant increase in lake area from 43.3 km^2 in 2012 to the highest lake area of 70 km^2 recorded in April 2020 consequently, inundating about 26.6 km^2 of the park area. Flooding impacts include, submerged buildings, road infrastructure, flooding of town sewage lagoons, displacement of over 800 people as the water continues to flood adjacent farms in Barut ad Mwariki settlements.

The main driver to the rising water levels is climate change with mounting evidence from the level of rainfall in the catchment areas as documented at the various rainfall gauging stations (Olago et al., 2020, Kiogora et al., 2021). There has been an increase in water supply due to increased runoff brought about by another variable of land use characteristics. The fragility of the lakes' ecosystem has created instability in the ecology of the lakes through the increased input of freshwater, impacting on species resilience and distributions. The severity of land degradation due to anthropogenic threats has resulted in higher rainfall runoff from land, and less percolation into the groundwater systems, leading to larger volumes of water flowing directly and rapidly from the land surface into the lake.

The strategic objective of this research is to contribute towards encouraging relevant agencies to build the capacities to generate, store, and share knowledge and information as well as to implement cost-effective and continuous monitoring of lakes, rivers and their catchments to guide decision-making in the short to long-term.

2. Materials and methodology

The physico-chemical parameters were measured *in-situ* using an YSI Professional Plus handheld multi-parameter meter. The YSI meter provides extreme flexibility for the measurement of a variety of combinations for dissolved oxygen, conductivity, specific conductance, salinity, resistivity, total dissolved solids (TDS), pH, ORP, pH/ORP combination, ammonium (ammonia), nitrate, chloride and temperature. The 10 metre cable was used for measuring the Vertical Profiles at one (1-2 Metre) interval at two mid-lake control sites. Water transparency was done using a Black & White Secchi Disk. Water sampling depth was obtained by dipping a weighted cable and measured using a one metre ruler.

Heavy metals were analysed using ISO17025 Accredited Test Method CN-TM-W14; nutrients were anaysed using Methods CN-TM-W06/07 and ions and cations using Method CN-TM-W08.

Fish samples were captured by laying the fishing nets at the four sites a night before. The nets were laid at 100 m length using a boat at four sites namely: R. Njoro Mouth, Sewage Release Area Kampi Nyati. The samples were preserved in a cooler box and transported to the laboratory. Fish muscle was extracted using a surgical blade. Samples were stored in glass vials with caps prior to analysis. Samples were digested with analytical grade nitric acid. Heavy metal concentrations were determined in the processed samples using direct aspiration by Electro thermal Atomic Absorption Spectrophotometer (AAS-S Series, UK).

3. Results

Table 1. *Physico chemical parameters.*

	pH	Temp. (°C)	Cond. (mS)	DO (mg/l)	Salinity (%o)	TDS (mg/L)
Kampi Nyati	8.74	-	2.00	-	1.01	1.30
Sewage Release Point	9.24	24.1	3.81	2.1	2.04	2.51
Njoro River Mouth	9.34	26.2	3.76	3.42	1.93	2.41
Sarova Lion Hill	9.26	29.2	5.86	5.25	2.97	3.24

Temp: temperature, DO: dissolved oxygen, TDS: total dissolved solids.

Table 2. *Mean Physico chemical parameters in Lake Nakuru.*

Site	**pH**	**Temp (oC)**	**DO (mg/l)**	**Cond. (mS)**	**Salinity (‰)**	**TDS (mg/l)**
Njoro-Mid	9.3	24.1±1	2.0±2.6	5.2±0.8	2.7±0.1	3.3±0.1
Mid-lake (centre)	9.3	24.4±2	1.7±2.6	5.4±0.8	2.8±0.1	3.4±0.1
Four Near Shore Sites	9.3	26.5±2	3.6±1.3	4.5±1.0	2.3±0.5	2.7±0.4

Temp: temperature, DO: dissolved oxygen, TDS: total dissolved solids

3.1 Vertical Profiles of Physico chemical parameters in Lake Nakuru (Mid lake)

1. pH of Lake Nakuru Water

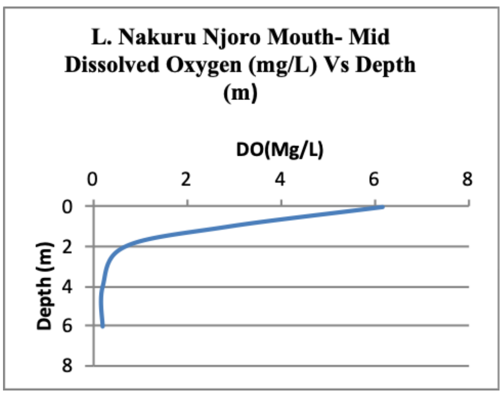
The lake water pH the lake shore and mid lake sites recorded a mean of 9.3. The mean pH between 1972-1979 was 10.5 as recorded by Vareschi (1978, 1982) and is reported as the only environmental factor which remains "exceptionally constant" and unsusceptible to alkalinity and conductivity. This is due to the high buffering capacity of the lake.

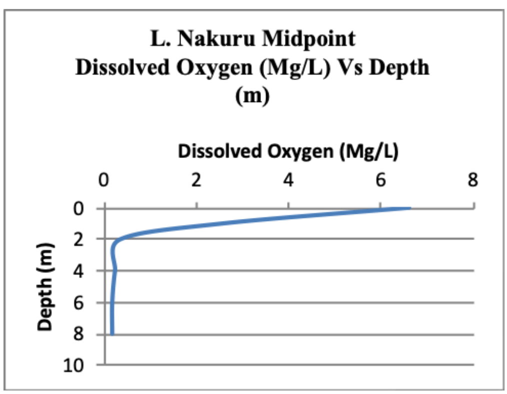
More recently, the mean long-term pH of the lake over the period 1981-2015 and measured at 8 lake sampling sites was 10.14 (Kiogora et al., 2020).

2. Dissolved Oxygen levels in Lake Nakuru

The sites located near the shore recorded mean dissolved oxygen levels of 3.6 ± 1.3 mg/l. The mid-lake sites recorded a mean of 2.0 ± 2.6 mg/l at Mid-R. Njoro Mouth and 1.7 ± 2.6 mg/l at the mid-lake point respectively. The DO vertical profiles indicate a sharp decline of dissolved oxygen from 6 m/l at the surface to below 0.3 mg/l just one meter from the surface indicating completely anoxic conditions in the entire mid of Lake Nakuru.

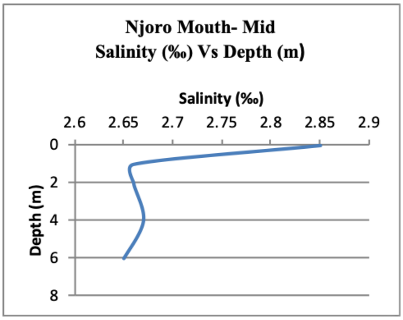
The fish in L. Nakuru, *Sarotherodon alcalicus grahami,* is known to tolerate DO levels as low as 3 mg/l. Similarly, *Arthrospira fusiformis* productivity is lowered significantly at DO levels below 2 mg/l (Vareschi, 1982). The extremely low (anoxic) levels of oxygen in Lake Nakuru is attributed to a combination of organic waste contamination of the lake by urban discharges such as raw sewage and storm water as well as natural biological decomposition.

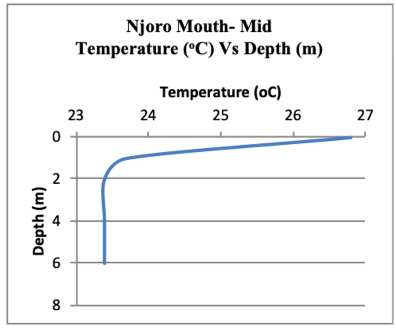


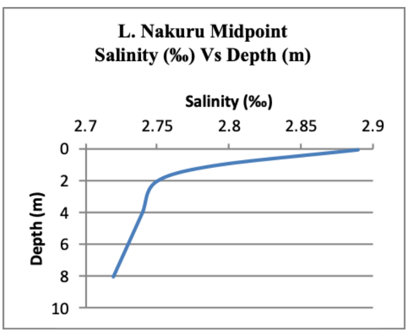


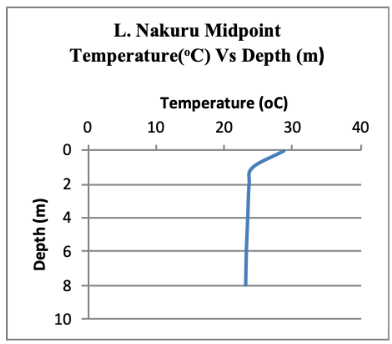
3.2 Salinity of Lake Nakuru water

The salinity at four nearshore sites was very low with a mean of 2.3 ± 0.5‰. The mid-lake sites also recorded low salinity means of 2.7 ± 0.1‰ at Njoro Mouth Mid and 2.8 ± 0.1‰ at the Mid-lake point respectively.









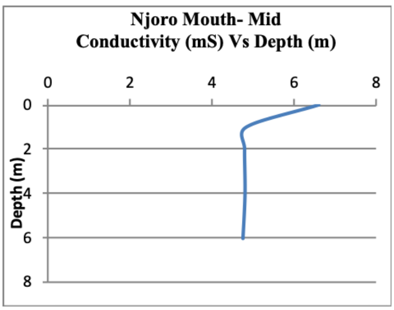
3.3 Temperature

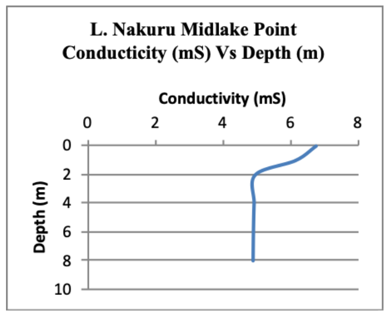
The near shore sites recorded a mean temperature of 26.5 ± 2.1 °C while the mid-lake sites 24.1 ± 1.5 °C at Njoro Mouth Mid and 24.4 ± 2.2 °C at Mid-lake point respectively. Surface water temperatures are typically 25-27 °C (Vareschi, 1982, Odada et al., 2004) and have not changed much in the last three decades (35-year mean = 27.3 °C). The temperature vertical profile at both mid-lake sites recorded a sharp thermocline as indicated the charts below.

3.4 Electrical conductivity

The mean conductivity at the near shore sites was 4.5 ± 1.0 mS/cm. The pelagic sites recorded a mean EC of 5.2 ± 0.8 mS/cm at Njoro Mouth-Mid and 5.4 ± 0.8 mS/cm at the Mid-lake Point respectively. The vertical profile shows a slight decline of conductivity with depth as shown in the charts below.

The mean of 4.5 ± 1.0 mS/cm is extremely low compared to the long term mean electrical conductivity (44.7 ± 39.8 mS/cm) also comparable to historical values; Vareschi (1979, 1982) recorded a range of 8,500-165,500 μS/cm.





3.5 Total dissolved solids

The mean TDS recorded at the four nearshore sites was 2.7 ± 0.4 mg/l. The pelagic sites recorded a mean of 3.3 ± 0.1 mg/l at Njoro Mouth-Mid and 3.4 ± 0.1 mg/l at Mid-lake respectively. Lake Nakuru is moderately alkaline with a dominance of Na^{+}>Si>K^{+} >Ca >Mg^{2+} in cations and CO_3^{2-}>HCO_3^{-}> Cl->F >SO_4^{2-} in anions. The lake also exhibited high concentrations of Mo, As and Fluoride. There is a significant reduction from concentrations recorded during periods of low lake levels.

Table 3. *Concentrations of major ions in the Lake Nakuru Water (previous compared with current).*

			Cation		
	Symbol	Results		Symbol	Results
Sulphate	SO_4^{2-},	**37.1**		Na^+	**1,150**
	H^+	-		K^+	**53.4**
Chlorides	Cl^-	**323**		Ca^{2+}	**2.71**
Bicarbonate	HCO_3^-	**2,400**		Mg^{2+}	**0.34**
Carbonate	CO_3^{2-}	-		SO_2	**72.1**
Phosphate	PO_4^{3-}	-			
Phosphorous	P	**0.40**			
Fluoride	F^-	**18.8**			

Results Heavy Metal (ppm)

Parameter	Sewage Discharge Area	Njoro River Mouth	Sarova II Point	Mid Lake
Molybdenum (Mo)	**0.099**	**0.071**	**0.099**	**0.099**
Arsenic (As)	<0.007	<0.007	<0.007	<0.007
Cadmium (Cd)	<0.002	<0.002	<0.002	<0.002
Chromium (T-Cr)	<0.004	<0.004	<0.004	<0.004
Lead (Pb)	<0.009	<0.009	<0.001	<0.001
Nickel (Ni)	<0.003	<0.003	<0.003	<0.003
*Mercury (Hg)	*<0.001	*<0.001	*<0.001	*<0.001
Selenium (Se)	<0.01	<0.01	<0.01	<0.01
Cobalt (Co)	<0.001	<0.001	<0.001	<0.01
Boron (B)		-	-	-
Copper (Cu)		-	-	-
Zinc (Zn)		-	-	-
* Below the detectable limit.				

4. Discussion / Conclusion

The physico-chemical parameters as well as major ions in Lake Nakuru indicate significant dilution from the rising water levels. The salinity has reduced from 22 to 62 g/l (ppt), which is optimal for growth performance of *Arthrospira fusiformis,* to below 2-5 g/l. This has completely changed the lake ecology, with fresh water phytoplankton such Coccoids and zooplankton such daphnia magna being dominant.

In the past, several factors contributed to lack of use of research findings in Lake Basin Management. Firstly, most of the available research data is not integrated and comprehensive since it was not initially collected with the aim of resolving particular identified lake management problems. Second, most of the research projects have been conceived and implemented without adequate participation and involvement of lake basin managers, planners and local community. Third, most of the research findings are written and presented in a manner that is not easily understood by non-scientists such as planners and lake basin managers. Fourth, the managers have not recognized and appreciated the importance of data and information in lake basin management.

The aspects of knowledge and information transfer/dissemination that are relevant to the Integrated Lake Basin Management include:

- Formal education - this can be achieved through environmental and water clubs in schools;
- Community education - on protection and conservation of the environment;
- Sensitization of industry and other pollution-generating sectors, and encouraging the installation and use of state-of-the-art and effecient technologies, accompanied by economic incentives and pollution deterrents supported by appropriate policies and legislation;
- Establishing and maintaining strategic environmental and water monitoring stations, equipped with appropriate, adequate and cost-effective technologies for data collection; and
- Developing centralised lake-basin database systems that store and provide necessary and quality data to users, including through GIS platforms.

The findings will be used to promote the Integrated Lake Basin Management (ILBM) as an approach for achieving sustainable management of Lake Nakuru through continuous and holistic improvement of basin governance, including sustained efforts for integration of institutional responsibilities, policy directions, stakeholder participation, scientific and traditional knowledge, technological possibilities and funding prospects; including evaluating and strengthening the concept of payment for ecosystem services.

Acknowledgements

We thank the County Government of Nakuru for funding the study.

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Chapter 4. Science and Technology

This topic addresses issues related to the removal of various pollutants present in different bodies of water through technologies that help preserve, restore and recover water quality.

Anaerobic digestion of water hyacinth juice in upflow column bioreactor for production of biogas and nutrient recovery

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Abstract

This research aimed to study the anaerobic digestion of water hyacinth juice in an up-flow bubble column bioreactor for the production of biogas and nutrient recovery from digestate. Fresh water hyacinth was collected, cut, grind into small pieces, and then compressed to extract the juice and solid residue. The juice was digested with active anaerobic sludge from a biogas plant that uses cow dung as a feedstock. Up-flow anaerobic sludge blanket reactor was used for the experiments, performed at a pH range of 6.5-7.5, a temperature of 37ºC (mesophilic conditions). The effect of hydraulic retention time (HRT) at 3 and 6 days was investigated. The result showed that the total production yield of biogas was 38.42 L for a period of 90 days. The maximum biogas production rate was 2.35 L/day at HRT of 3 days. The percentage of CH_4 and CO_2 were found to be 50-75% and 5-45% respectively. While other gases were estimated as low as 5%. The phosphate content of the digestate was measured and increased to 7.5 ± 4.1% from the influent concentration of 4.0 ± 1.2%. This study demonstrated that anaerobic digestion of water hyacinth biomass could be a potential candidate

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for the production of biogas energy and recovery of organic nutrients. Nevertheless, further research is needed to understand the complex interplay of the biochemical action with different biomass pre-treatments and inoculum types.

Keywords: *Anaerobic digestion, water hyacinth, bubbled column bioreactor, biogas, nutrient recovery*

1. Introduction

The worldwide energy need has augmented radically due to industrial growth and population rise all over the world over the last century [1]. Energy security concerns struggle to alleviate the environmental impact of fossil fuels, and progress in a dominant role in encouraging renewable options has led to the radical increment in the utilization of renewable energy [2]. Biomass is the first energy source harnessed by humankind. It had been the primary energy source for more than half of the world's population, accounting for 14% of the total energy consumption in the world [3].

Anaerobic digestion (AD) is a biological process to degrade organic matter by a collection of microorganisms under oxygen-free conditions to produce biogas composed of predominantly methane (CH_4) and carbon dioxide (CO_2) [4]. This process can decrease chemical oxygen demand (COD) and biological oxygen demand (BOD) that makes to be extensively used in the management of wastes from agriculture, food consumption, and water sludge [5] liquid anaerobic digestion (AD).

Water hyacinth (WH) is a perennial free-floating aquatic plant. It is classified as one of the ten most invasive aquatic plant species in the world [6]. It is prevalent in tropical and subtropical water bodies where nutrient levels are often high due to agricultural runoff, deforestation, and insufficient wastewater treatment facilities [7]. In recent years, WH has spread faster, and become the most serious infestation in Ethiopia, including Lake Tana.

Lake Tana is the largest lake in Ethiopia and the source of the Blue Nile, the surface area ranges from 3,000 to 3,500 square kilometers, and is located between Latitude: 11°25’07” N - 12°29’18” N and Longitude: 36°54’01” E - 37°47’20” E. The lake is the habitat of many fish and bird species and was registered by UNESCO as a Biosphere Reserve in 2014. Unfortunately, WH on Lake Tana posed a great threat and became an acute problem since 2011. The weed covers over 197 km in seven districts of the Amhara region, and various efforts have been done to reduce the severity of the weed, mainly mechanical ones (manual harvesting).

Controlling the fast-growing weed is fundamental and to aid this aim it is imperative to convert the weed into valuable products. WH is a valuable feedstock for producing energy in the form of biogas. Moreover, WH is used as an organic source of nutrients, especially nitrogen and phosphorus, as its biosorption capacity of nutrients and heavy metals make it particularly useful in wastewater treatment [8].

According to the work of Soeprijanto et al. (2020), a mixture of natural WH and water inoculated with cow dung in a plug flow anaerobic reactor with a hydraulic retention time of 14 days, generates a biogas yield of 0.398 l/g volatile solids (VS) composed of 70.57% CH_4, 12.26% CO_2, 1.32% H_2S. The squeezed out water as WH juice (SWWH) was used to produce biogas with microorganisms at a ratio of 1:1. A total of 458.44 liters of biogas was produced consisting of 68.67% CH_4, 18.23% CO_2, and 13.10% other gases [10]. Shah et al. (2015) reported that WH was a successful substrate for mono-digestion, which resulted in its highest biogas production rate among other feedstocks. Pig manure (PM) mixed with three different types of WH juice in five loading ratios PM: WH juice 0, 25, 50, 75, and 100% indicates that WH is potentially a supplement to pig manure in biogas digesters [12]. Based on these findings there is no implication for nutrient recovery and also the use of an up-flow anaerobic sludge blanket (UASB) reactor. Most of the researchers use the batch-type reactor with solid biomass of WH as feedstock during AD.

To improve biogas production from lignocellulosic biomass, a pre-treatment process is necessary to disrupt the naturally recalcitrant carbohydrate – lignin shields that impair the accessibility of enzymes and microbes to cellulose and hemicellulose [13]. Various techniques were applied to WH such as physical [14], chemical [15], thermal [16], thermochemical [17], electrical [18], and microbial [19]. Due to the high moisture content of WH, crushing and extracting the compressed juice can give a fast treatment method as compared with the common pre-treatment methods and can provide an insight for a novel pre-treatment method. Therefore this work aims to study the AD digestion of water hyacinth juice in a UASB for the production of biogas and nutrient recovery from digestate.

2. Materials and methodology

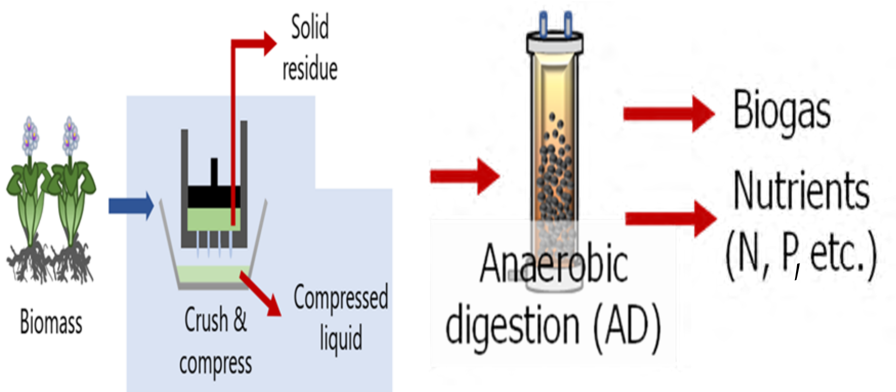
2.1 Materials

WH, manually collected from the infected parts of Lake Tana, chopped, crushed into small pieces by a crusher, and then compressed to juice extract, which was used as a substrate. The compressed WH juice characteristics are given in Table 1. Activated sludge was taken from a biogas plant reactor that uses cow dung as inoculum and was collected from a village nearby and mixed with water in a 1:1 ratio. The process description of the experiment is presented in Figure 1.

Table 1. *Characteristics of the feedstock.*

Parameters	Feedstock
Total solids (TS), %	5.53 ± 0.72
Volatile solids (VS), %	46.1 ±9.5
Chemical oxygen demand (COD), mg/L	2011 ±211
Nitrate (NO_3), mg/L	54.05 ±11.32
Phosphate (PO_4), mg/L	3.97 ±1.92
pH	7.08 ±0.59

Figure 1. *Flow diagram of the anaerobic digestion of compressed water hyacinth juice.*

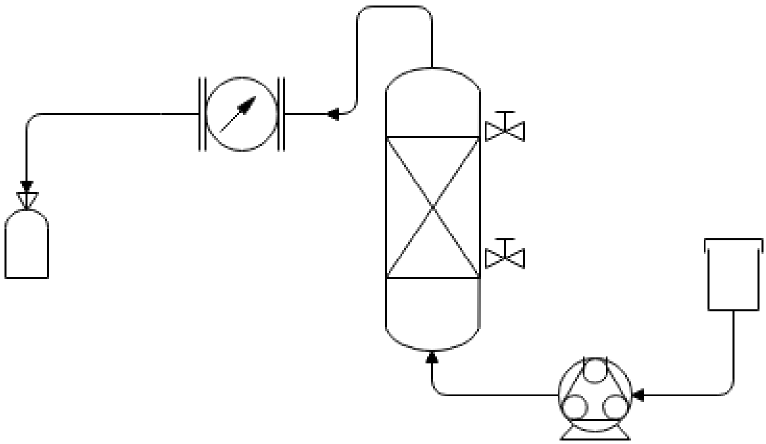


2.2 Experimental set-up and description

The experiments were conducted in a continuous liquid phase UASB reactor which has a total volume of 7 L with a working volume of 5 L, as shown in Figure 2. It consists of a gas-liquid-solid separation device and equipped with a feedstock inlet, a sludge sampling point, an effluent outlet, and gas outlets.

A peristaltic pump was used for feeding the substrate into the reactor. The digester was inoculated with 5 L anaerobic sludge by mixing the digested manure with water in a 1:1 ratio. After 3 days, the substrate began to feed into the reactor by adjusting the COD through dilution with water. The temperature was maintained at a mesophilic temperature of 37°C controlled by an electric heater wrapped around the column of the reactor. The substrate was added to the reactor according to the hydraulic retention time (HRT) (6 days initially and three days afterward). The HRT of the UASB reactor was controlled by adjusting the speed of the peristaltic pump before each step. The digester fed with a maximum of 2 L of substrate per day. Biogas generated from the anaerobic digestion was passed through an Erlenmeyer flask, and then a wet type gas meter (model W – NK 0.5B), to measure the flow rate. Finally, the gas was collected in aluminum airbags (model AAK – 10).

Figure 2. *Experimental set-up.*



2.3 Analytical methods

The substrate, WH juice, and effluent were characterized for volatile solids (VS) [20], and total solids (TS) contents [21]. Samples were taken once in three days regularly by opening the valves on the column of the reactor. COD of both substrate and effluent were determined using a pack test with a standard color (COD with KMnO4). Phosphate content was determined following the colorimetric method [22].

The percentage of CO_2 was determined by using a detector tube, gastec injection type (No. 2HH). The methane content was estimated as:

$$\%CH_4 = 100 \quad (\%CO_2 + others) \qquad (1)$$

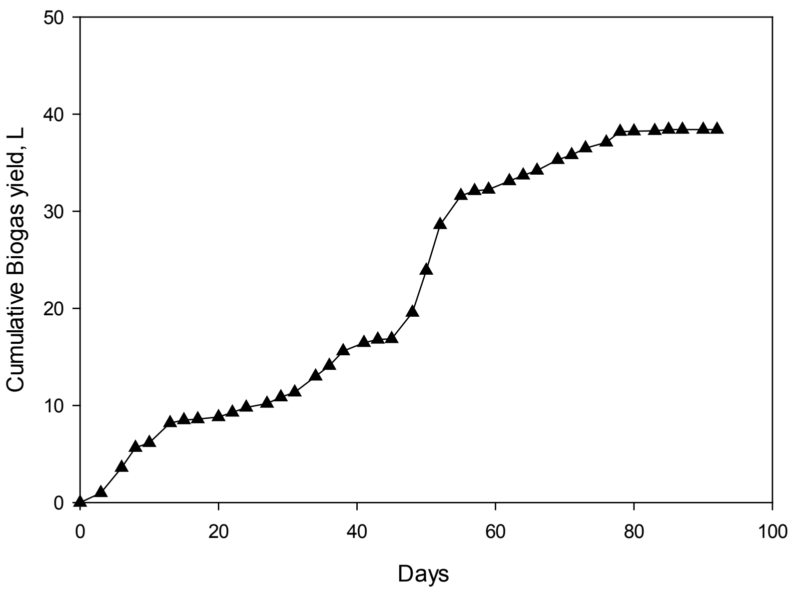
3. Results and discussion

3.1 Biogas production

The cumulative biogas yield per day is presented in Figure 3. As can be seen in the figure, biogas production starts in the early stage and increases to reach a cumulative amount of 38.42 L in 90 days. The digester was operated at a HRT of 6 days until the 31 the daytime on stream and became 3 afterwards. A total amount of 458.44 L of biogas was produced from compressed water hyacinth juice consisting of 68.67% CH_4, 18.23% CO_2, and 13.10% other gases for 60 days on stream [10].

The CH_4 and CO_2 composition of the biogas ranges from 50 – 75% and 5 – 45% respectively. According to Soeprijanto et al. (2020), the composition of biogas was 70.57% CH_4 and 12.26% CO_2 during AD of solid biomasses of natural WH, whereas 64% methane was achieved when compressed water hyacinth was digested with microorganisms, from actively digested dairy cattle manure slurry, in the ratio of 1:1 [10].

Figure 3. *Cumulative biogas yield.*

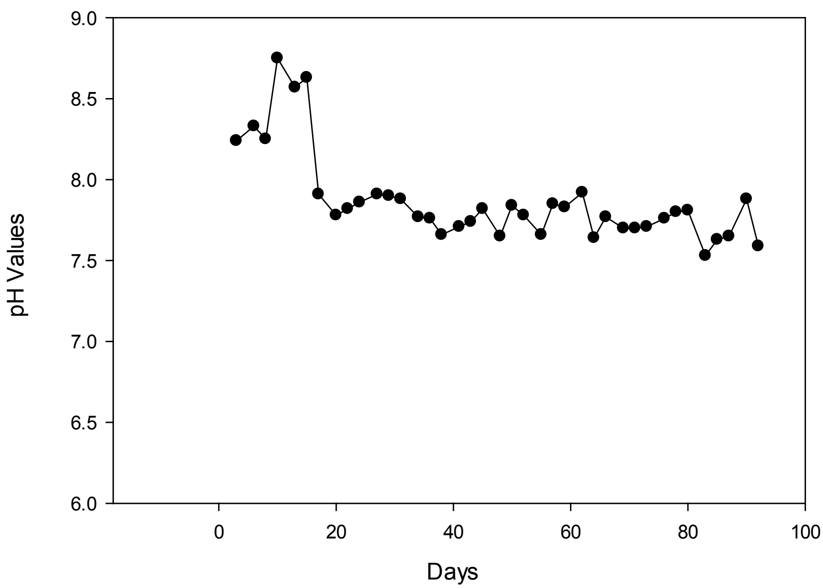


3.2 Variation of pH and COD during AD

The variation of pH during the AD experiment was recorded and is shown in Figure 4. As shown in the figure, pH initially was around 8.2 and it increased to 8.8, and then gradually decreased to 7.5. The ideal pH for methanogenesis ranges from 6.8 to 7.6, and its growth rate will be greatly reduced below pH 6.6. A pH of less than 6.1 or more than 8.3 will cause inhibitory performance, eventually leading to the termination of the AD process [23].

COD removal is an essential parameter that is used to determine the efficiency of the continuous AD system, and its variation is presented in Figure 5. In this work, the COD was reduced from an average value of 2011 mg/L to 392 mg/L in 90 days of fermentation. This indicates that a COD removal efficiency of 80.5% was achieved suggesting most organic carbon is degraded via the AD process. A COD removal efficiency of 83.5% was reported in the work of Xu, (2010) where WH juice was digested anaerobically in a refitted anaerobic reactor system.

Figure 4. *pH variation with AD time.*



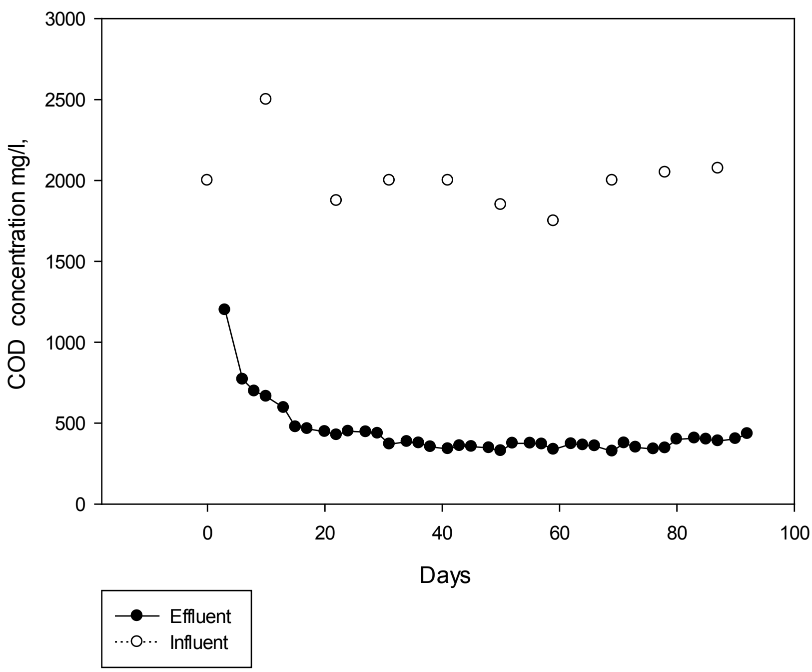
3.3 Nutrient recovery

The nutrient content was measured through phosphate concentration. The average concentration of PO_4 in the effluent was found to be 7.47 mg/L compared to the influent concentration of 3.97 mg/L. This shows a net increase of 88% respectively. According to G. Li et al., (2019) nutrients obtained from the AD of WH can be used for plant growth and fed to microalgae. Based on Subhadra, (2011), especially *Chlorella* species microalgae need 6.21mg/L PO_4.

4. Conclusion

The AD of compressed water hyacinth juice results in a total of 38.42 L of biogas in 90 days of operation, a methane content between 50 – 75%. In addition, a COD reduction of 80.5% and phosphate content increment of 88% was observed.

Figure 5. *COD of substrate and effluent through time.*



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Assessment of India's largest inland saline lake during the time frame of COVID-19 pandemic using GEE platform

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Abstract

Saline lakes are unique but highly ignored compared to their freshwater counterparts. They are considered as blue lifelines of drylands. India has the world's 17th largest desert holding four major inland saline lakes, out of which Sambhar Salt Lake is the only Ramsar site where the current study is conducted. The study is conducted in reference to the COVID-19 lockdown period. The analysis years are 2019 (pre-COVID lockdown), 2020 (COVID lockdown) and 2021 (post-COVID lockdown) using Google Earth Engine. Landsat satellite images were cloud mosaiced, Soil Salinity index and Surface Algal Bloom index were calculated, and the final generated spatial results were map composed. The result states that algal indices values ranges from -0.432 to 0.555 in 2019, 0.136 to 0.696 in 2020 and 0.020 to 1.094 in 2021. The values of salinity index states -0.076 to 0.740 in 2019, -0.459 to 0.20 in 2020 and 0.012 to 0.261 in 2021. The results clearly state the dubious state of its existence due to ongoing illegal saltpan encroachment.

Keywords: *Biodiversity, human interventions, inland saline waters, geospatial modelling*

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1. Introduction

Saline lakes are present in all the geographic regions including Antarctica [1]. Most of them are inland saline lakes either due to their disconnection from the sea, excessive evaporation than precipitation or through their geochemistry developmental stages. Saline lakes occupy 44% and 23% of volume and area respectively of all lakes [2]. Globally, they are clustered in ~30 million km^2 [3]. Interestingly, one-third of these are located in Europe and Central Asia region [4]. These lakes occupy 0.008% of Earth's total water volume which is slightly less than their freshwater counterparts occupying 0.009% [5], however, these are least considered. These lakes are the critical habitats for riparian, semi-aquatic, aquatic wildlife providing shelter to numerous endemic, threatened and endangered species [6]. They are the sources of many minerals (magnesium, potassium, sodium lithium, bromine,) and biological resources (*Artemia sp.; Spirulina sp*. fishes) worth $billion in the global market. However, these lakes are subject to overexploitation of minerals, groundwater, land use land cover (LULC) change, habitat alteration, pollution, and invasive species [7]. It is predicted that these lakes might suffer from reduced hydroperiod, extended dryness, partial or complete desiccation by 2025 as already seen in Lake Urmia. The primary reasons for negligence could be their remote locations, rapid seasonal fluctuations, no direct use of saline water, no recreational activities during non-monsoonal seasons [8]. Assessment of these lakes was traditionally tedious, expensive, time-consuming, and hence discouraging, However, with the onset of Landsat satellite mission in 1972, mapping and monitoring at different spatio-temporal scales have been possible. Though these data sets have immense capacity to monitor dense forests but limit themselves to identify and map sparse vegetation of semi-arid to arid regions [9]. However, current advancements and availability of Unmanned Aerial Vehicles (UAVs) and small satellite flocks are providing high spatio-temporal but lower spectral resolution datasets. But further affordability of such sensors and high-end computational facilities requirements are the biggest challenge.

Surprisingly, these challenges have been solved by the availability of cloud-based platforms like Google Earth Engine (GEE). With its reduced cost of computing, there are new prospects for monitoring the globe's saline lakes of semi-arid and arid ecosystems on a regional to global seasonal scale. It can store datasets at petabyte scale supporting handy environment for interactive algorithm development, curation of own data for processing [10]. It facilitates time-series analysis due to provision of continuous data sets of different satellite missions through both traditional classification methods and enhanced machine learning tools.

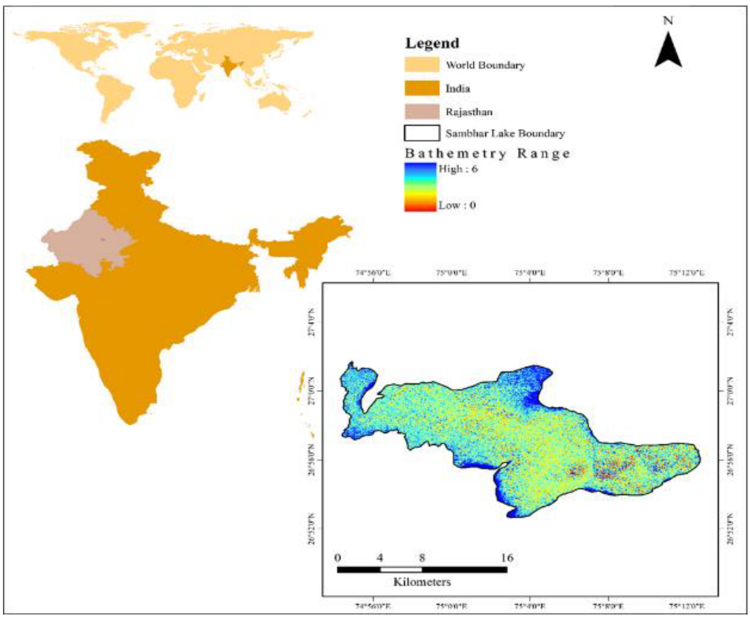
The main objective of this paper is to analyze soil salinity and algal status of the study area Sambhar Salt Lake (which is India's largest inland saline wetland) during COVID-19 period using the cloud computing platform Google Earth Engine.

2. Materials and methodolody

2.1 Study area

Sambhar Salt Lake is an inland wetland situated to the east of Thar desert of India. It is believed to be a part of Tethys's Sea, currently 1,980 km away from its nearest coast of Arabian sea [11]. However, it differs from the seawater due to absence of $MgCl_2$, $MgSO_4$ and KCl [12]. In 1717, British Govt. decided the lake's official boundary. The pollen study records state that it was a sweet water lake 2000 years back [12]. However, the conversion of the lake from sweet to saltwater lake can be referred to as the time frame of formation of Iranian deserts Dast-e-Lut and Dast-e-Kavir [13]. Nevertheless, in the mid-20^{th} century, the lake had a catchment area of 53,000 km^2, an average depth of 0.6 m, and a volume of 414×10^6 m^3 [14]. The lake experienced two well-defined phases as favorable (July-February) and unfavorable (March -June). Salinity fluctuated from 9.6-164 mg/l, carbon dioxide from 34.9 to 135.4 mg/l, pH from 7.4-9.5, dissolved oxygen from 47-13.8 mg/l, and stenohaline-euryhaline biota during favorable to unfavorable phases, respectively [14]. As the water level was intimately linked with its 4 main ephemeral tributaries, Mendha, Roopnagar, Khandel and Kharian, during favorable conditions, aquatic species richness was high, and the fauna was divided as mud animals, surface animals and shore animals, however during unfavorable phases, aquatic associations were taken over by terrestrial animals [12]. The lake had a complex food-web at five trophic levels in which algae, diatoms, bacteria, and protozoans were the producers, whereas copepods, nauplii of crustaceans, were primary consumers, *Artemia sp., Branchinella sp., Anisops spp.* were secondary consumers, and birds, *Cybister sp*. and *Eretes sp.* were the tertiary consumers [11]. However, from the last two decades the lake has been shrinking approximately at a rate of 4.23% from 30.7 to 3.4% till 2019 due to illegal salt pan encroachment, extensive ground water extraction and increasing settlement area which has led to increase in barren land and decrease in salt crusts. If the same decreasing trend goes on, 40% of the remaining wetland area might be lost by 2059 which is legal lease period of salt extraction. The study area map is shown in Figure 1.

Figure 1. *Study area map.*



2.2 Methodology

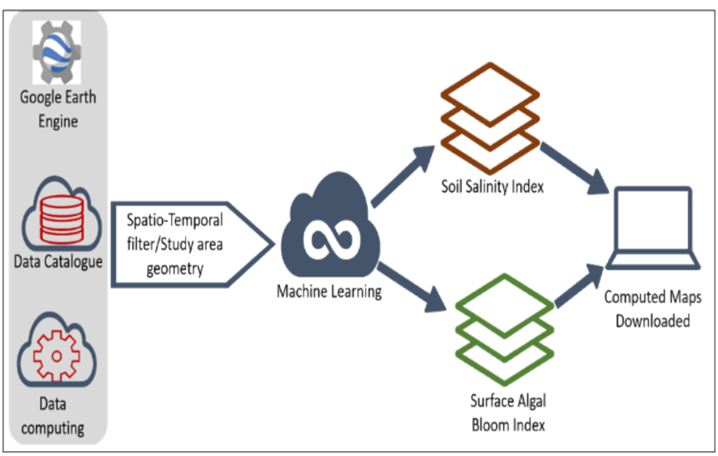
Because our study is conducted during pandemic situation when research laboratories are closed, we opted for the use of Google Earth Engine (GEE) as it is a freely available platform with huge cloud data catalogue and computational capability. This platform has not been used for soil salinity and surface algal bloom of inland saline lakes as shown in Figure 2.

The current study used the data of longest satellite mission Landsat which started in 1972 and subsequently Landsats 2, 3, 4, 5, 7, 8 were successfully launched in 1975, 1978, 1982, 1999, 2013 and 9 launched in 2021 [15]. It has 49 years of mission and has commissioned seven satellites (Landsats 1, 2, 3, 4, 5, 7, 8) with four types of sensors [Multispectral Scanner (1972–83), Thematic Mapper (1984–2011), enhanced Thematic Mapper (1999–2016), Operational Land Imager (2013–present)] [17]. It provides spatio-temporal historical dataset which help to monitor, detect, infer, and analyze based on the sensor. Band 1 with 0.433-0.453 μm range are useful for shallow water imaging. Indices are calculated using band ratios like Normalized Difference Vegetation Index, Normalized Difference water Index, Surface Algal Bloom Index, Soil Salinity Index for unveil different hidden properties of nature. Landsat data were used in this study for the year 2019, 2020 and 2021. For the study years, GEE was used. Two indices were used Soil Salinity Index (SSI) [16] and Surface Algal Bloom Index (SABI) [17] whose equations are as follows.

$$Soil\ Salinity\ Index = \sqrt{Blue * Red} \quad (1)$$

$$Sur\ face\ algal\ Bloom\ Index = \frac{NIR-Red}{Blue+Green} \quad (2)$$

Figure 2. *Methodology flowchart.*

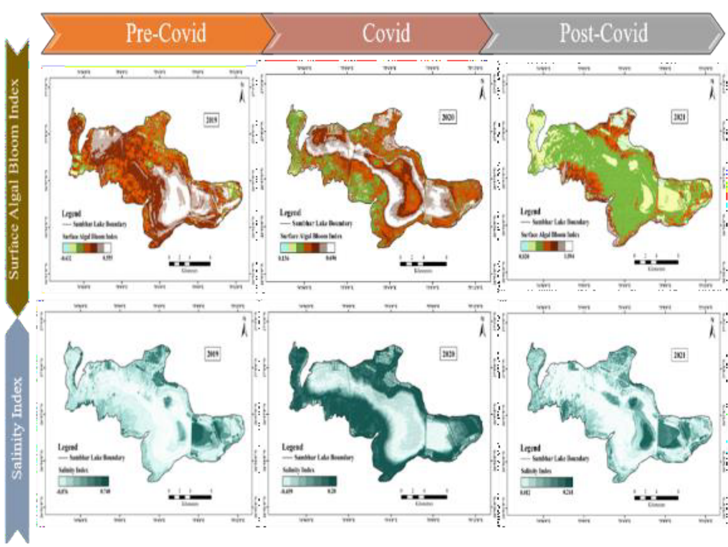


3. Results and discussion

From the figure given above, it is observed that in 2019, SABI value ranged from -0.432 to 0.55, in 2020 it ranged from 0.136 to 0.696 and in 2021 it ranged from 0.020 to 1.094. SABI in 2019 ranged from -0.076 to 0.740, in 2020 it ranged from -0.459 to 0.20 and in 2021 it ranged from 0.020 to 0.261. The values of both indices clearly state the vast change in values in all three phases concerning COVID-19 lockdown.

Comparing the SSI maps, 2019 had the worst situation. In 2019, ranged from -0.076 to 0.740, in 2020, from -0.459 to 0.20 and in 2021 from 0.012 to 0.261. In 2019, salinity was so negative, indicating extensive illegal activities of salt mining, converting this wetland to a wasteland. Due to lockdown, the status started reviving. However, the lake activities were allowed after three months of lockdown, and again illegal activities have started. Though the values of 2021 are more positive as compared to last two years, they could have been restored even more by its resilience capabilities. In 2019, from the image, it is very clear that almost whole lake has bright tone except the eastern part which is official Sambhar Salt Ltd. In 2020, surpris-

Figure 3. *Comparative maps of Pre and Post COVID (2019-2021).*



ingly the whole lake has a dark tone indicating increased soil salinity value, except where water is there in the core area of the lake, which has increased algal biomass as it is observed in its counter-image of SABI. Finally in 2021, again the lake has dried, and extensive mining is done, the darker tone is visible only in official part of the lake.

It is clearly understood that during the COVID lockdown 2020 the status of the lake increased and became very good. It seems there is no requirement for external investment for the lake restoration. It has water during winter and monsoon periods. With the presence of salinity and water in the lake there is full scope of survival of invertebrates. Invertebrates attract migratory birds from different continents of the lake. There are six vertical gradients of soil in the lake which are currently at stake [20]. After the COVID-19 lockdown when again anthropogenic activities were allowed, in 2021 images it was seen that the lake had again deteriorated. It is due to illegal saltpan encroachment. It contributes with 9.8% of total salt production of India [21], but due to illegal stealing of salt brine worth $300 million today is at stake [22]. Though Sambhar is a critical habitat for many halophiles and halophytes, its ecosystem is on the verge of extinction. Govt. is investing huge amounts of money for making it India's largest solar park, film shooting site, salt tourism site, adventurous sites [23]. But the irony is if there is no water in the lake, how will these activities be done? The main primary concern is, being a Ramsar site and IBA (International Bird Area) site, it is still not considered under any of the protected networks of the country. It used to be a habitat of 279 migratory and resident bird species, which have reduced to 30 to 35 species with only 3,000 bird counts [23]. This is considered only a salt production unit that comes under Minister of Commerce and Textile, Government of India. Looking at the comparative status of the lake in context of COVID scenario and the exact period of UN Decade of Ecosystem Restoration, it can be said that this lake has its self-resilience capacity to restore to its pristine condition without much effort and capital investment. If not, this might become India's dust bowl because geographically it is one of the gateways to Thar desert of India. This lake is a playa lake, and an endorheic basin used to receive water from four major rives as Mendha, Roopnagar, Kharian and Khandel with numerous seasonal tributaries. But around 675 check dams have been constructed and the flow of water to the lake is restricted [23]. If the dams are blocked and water is not allowed to enter the lake, it might not be able to survive. Not only ecology, the economy of the lake is also at stake. Sambhar used to provide livelihood to so nearly thousands of people from all over the country but today sambhar is not able to give economy to its city people residing in Sambhar City. People are forced to migrate and search for other jobs though they do not want to. Because of encroachment, the lake is illegally left with only some people of the area, not providing enough scope to others.

Coming to the technicalities, this lake is a shallow saline inland playa lake. This has been declared a Ramsar site due to its special character. However, there are a few remote sensing techniques, tools, software, and datasets for such lakes. Though SSI and SABI have been used, these are not meant for inland saline lakes. Sambhar lake has unique halophiles also during monsoon when water is available in the lakes. The biodiversity is distributed as shoreline, core buffer and zone. If there were specialized bio-optical models for such lakes, the long term spatio-temporal change detection, chlorophyll estimation, biomass productivity, and nutrient status could be done along with future prediction. Remote sensing has enormous capability to study at large spatio-temporal scale at landscape level, and Google Earth Engine has advanced it further with the cloud computational potential. If proper salinity-oriented techniques are developed, global level assessment with high accuracy is possible. This will be very helpful for the inland saline lakes with even very small surface areas as much as 100 km^2 or even less. With the availability of LiDAR and UAVs technology, this could be achieved furthermore accurately.

4. Conclusion

Sambhar Salt Lake is undergoing partial desiccation due to illegal saltpan encroachment and excessive ground water extraction. The lake requires urgent restoration strategies. During COVID-19 lockdown, the lake has shown its self-resilience capability of restoration; however, it has further shrunk after allowance of salt mining.

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Characterization of pellets from lignocellulosic waste for use in the treatment of water contaminated with arsenic and mercury

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Abstract

This work shows the features of the pellets of lignocellulosic waste coming from different crops that are in the region of Xichu, Gto., Mexico, with the purpose of an alternative sustainable method in emarginated communities for the treatment of waters contaminated with arsenic and mercury. The average values of humidity of 4.58%±1% were obtained, eliminated organic material of 45.36% ±4% organic remainder material of 39.84% ±3%, total of organic material 85.17% ±4.5% and inorganic material (ashes) 14.83% ±2%. No trace of arsenic and mercury were found in any of the control pellets. This preliminary study contributed a possibility of the lignocellulosic materials to be used in a direct form without encapsulating or containing them in a container when they are located in direct contact with contaminated water; due to their compacted structure it is not necessary to make the physicochemical process in order to take away the material of the

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water before its use; the majority of the materials of activated carbon and other common used materials to eliminate arsenic and other toxic elements of the water do not have this advantage. The base of the elaboration of the material are sawdust pellets, straw of wheat, sorghum and agave, these are residues of low cost and easy to obtain, the material can be fabricated inexpensively and employed in various regions of the country without the need of having big installations for the water treatment, allowing a viable alternative to obtain water that fulfills with regulatory standards in order to classify it like drinking water and this to avoid harm to the health occasioned by contaminated water with arsenic and/or mercury.

Keywords: *Water quality, biomass, organic matter.*

1. Introduction

Many studies have been carried out on the environmental fate and behavior of arsenic (As) and mercury (Hg), due to various cases of contamination with these elements throughout the world and the dangers associated with them. The chronic intake of inorganic As present in concentrations higher than 50μg/L in drinking water, can develop different types of skin lesions (e.g., hyperpigmentation, hyperkeratosis) and cancer (e.g., skin, lung, kidney, bladder), which together are called arsenicosis [1]. In the case of organic and inorganic mercury in concentrations above the maximum contaminant level (MCL) established by the EPA, it is absorbed into the gastrointestinal tract and cause skin rash and dermatitis, mood swings, memory loss, mental disorders, muscle weakness, etc. The most affected populations are rural areas or dispersed populations that do not have drinking water systems that send good quality water to their homes or drinking water treatment plants to treat the region's water.

The World Health Organization, with the aim of protecting public health, has considered the limit of 10μg/L for As and 1μg/L for Hg in drinking water as the maximum permissible [2]; however, achieving a reduction of this amount of As and Hg in drinking water requires more effective and locality-specific methods every day.

Technologies employed for the removal of metals and metalloids include separation techniques such as: coagulation and electrocoagulation; membrane methods such as: reverse osmosis, nanofiltration and electrodialysis; sorption methods using: activated alumina, iron or iron-coated sands; adsorption techniques using: activated carbon and both inert and living biomasses; some technologies perform oxidation pretreatments in order to increase removal efficiency by oxidizing As (III) to As (V) [3]. Some of these technologies have limitations such as high costs, low selectivity, incomplete removal, high energy consumption and leaving out large amounts of toxic sludge [4].

In the last decade, bioadsorption through biomasses available in abundance as by-products of various processes, has emerged as an alternative of great interest for the treatment of toxic elements present in water, and advantages have been found over other technologies due to their lower operating cost, easier and safer handling, compact and unsophisticated treatment facilities, and a significant reduction in the use of chemicals in the treatment processes [5].

Among the biomaterials that have been studied are algae, activated carbon, alumina, synthetic resins, carbonates, fly, ash, clay, moss, agricultural waste, mud, among many others [6].

1.1 Fe treatment in samples to adsorb As

Iron-based adsorbents have shown good efficiency in the removal of the different arsenic species present in water, including zero-valent iron (ZVI), bimetallic oxides, iron-doped adsorbents, among others [7]. The nature of iron salt, concentration, pH and treatment time are experimental factors involved in the adsorption capacity of arsenic. Adsorption mechanisms are associated with electrostatic attraction, ion exchange, and surface complexation [8]. Some adsorbents such as granular ferric hydroxide and ZVI are produced on a commercial scale, however these adsorbents are rarely used for applications at contaminated water sites. The anions Cl^-, NO_3^-, SO_4^{2-}, CO_3^{2-}, have not shown a significant influence on arsenic adsorption due to the specific chemical reactions between iron and arsenic [9] [10].

Several investigations show a high arsenic removal efficiency in Activated Carbon (AC) doped with iron compounds, on the one hand, the AC provides a large surface area and acts as a solid support, the AC has functional groups of negative charges so it is not very efficient by itself to remove arsenic, however, the iron molecules come into contact with these groups and then an electrostatic attraction is generated with the arsenic ions removing them from water [11]. The iron charge attached to the AC is correlated with the carboxy and hydroxyl functional groups [12].

2. Materials and methodology

Pellets made from vegetable biomass were used: sawdust, sorghum, straw and agave were all made from agricultural waste from the municipalities of Salamanca, Abasolo, Irapuato and Pénjamo; none were generated from marketable raw material.

Reagents

Standard arsenic (Golden Bell), sodium hydroxide (high purity), nitric acid (Fermont), ferric chloride (Fermont), phosphoric acid (Fermont), acetic acid (Fermont), distilled water (Ecopura), diluted 5% acetic acid commercial brand and hydrogen peroxide commercial brand.

Equipment

The equipment used was the following: Vortex (Scientific Industries), Analytical balance (Ohaus mod. AX224), Mufla (Arsa), Incubator (Felisa), Potentiometer (Ohaus, mod. ST-3100), Atomic Adsorption with hydride generator (Perkin Elmer).

2.1 Biomass characterization methodology

1.- The density of the pellets was determined by measuring their volume and weight.
2.- To calculate the percentages of moisture, organic and inorganic matter of the pellets, the fresh, dry, carbonized and ash weights were used, obtained as described below:

Pellets were weighed using an analytical balance to obtain the fresh weight, dried at a temperature of 70°C ±10 for 24 hours, allowed to cool to room temperature in a desiccator and weighed to obtain dry weight. They were carbonized in a muffle according to the following temperature ramp: 115°C ±10 for a maximum of 30 minutes, 205°C ±20 for about 60 minutes and 285°C ± 28 for at least 10 minutes; they were cooled to room temperature in a desiccator and weighed to obtain carbonized weight. Finally, they were placed in a muffle at a temperature of 560°C for 1 hour, allowed to cool at room temperature in a desiccator and weighed to obtain ash weight.

The percentage of moisture was calculated using the following equation (1):

$$\%H = ((PF - PS) / (PF))*100 \quad (1)$$

The percentage of organic matter removed, remaining organic matter and total organic matter were calculated using the following equations (2), (3), (4):

$$\% MOe = ((PS-PC) / (PS))*100 \quad (2)$$

$$\% MOr = \%MOt - \%MOe \quad (3)$$

$$\% MOt = ((PS - C) / (PS))*100 \quad (4)$$

The percentage of inorganic matter (ash) was calculated using the following equation (5):

$$\% MI = (C/PS) * (100) \quad (5)$$

2.2 Activation process for carbonized pellets

The following acids were used to activate the carbonized pellets: 4.85M phosphoric acid, 4.85M acetic acid and 5% diluted commercial acetic acid (vinegar). During the activation process, pellets (previously carbonized) were placed in a solution of each of the acids for three periods of contact time: 2, 4 and 6 hours. At the end of the respective contact time, the pellets were removed from the acid, placed in a crucible to carbonize them at 200°C to 300°C for 30 minutes to 60 minutes, allowed to cool to room temperature and stored for later use.

2.3 Treatment to add Fe(III) to previously activated pellets

The Fe(III) addition process used was a modification of the method proposed by Jang et al. (2010) and is described below:

1.-The iron precursor (FeCl3 6H2O) was dissolved in distilled water at a concentration of 15% Fe(III).

2.- Subsequently, 0.5 ml of the Fe(III) solution was dispersed on a dry and activated pellet (0.3 g approximately) and allowed to stand at room temperature for approximately 24 hours.

3.-The material was dried in an oven at 50°C for 24 hours, after which it was allowed to cool to room temperature.

4.-Finally, the material was washed with distilled water to eliminate excess Fe (III); if the pH is lower than 7, it has to be washed with a 0.1% NaOH solution with agitation of 100rpm during 5 hours, changing the solution every hour until reaching a final pH of 7. It was left to dry again in the oven at 50°C for 24 hours (13).

3. Results and discussion

3.1 Biomass characterization

Several tests were required to obtain the appropriate temperature ramp for the carbonization of the pellets because the typical temperatures used to generate activated carbon according to the literature did not have good results for the proposed materials. Optimization of the temperature ramp for pellet carbonization was achieved by having the following conditions: 115°C ±10 for a maximum of 30 minutes, 205°C ±20 for about 60 minutes and 285°C ± 28 for at least 10 minutes.

Figure 1 shows the agave, sawdust, straw and sorghum pellets subjected to the carbonization methodology, where it can be seen that the material has not lost its mechanical properties; a rigid and porous material can be obtained.

Figure1. *Carbonized materials (agave, sawdust, straw and sorghum).*

The temperature used for the activation process was 200°C-300°C, which is low compared to temperatures reported in the literature for chemical activation of forest or other lignocellulosic materials, where the temperature range used for chemical activation is 400°C - 1000°C [14] [15] [16].

The lignoselulosic residues with the highest percentage of moisture were sawdust, while wheat straw, agave and sorghum residues had the same percentage (4%); in addition, the organic matter content in each of them is higher than 60%. The amount of inorganic matter for sorghum was the highest reported, being 30% (Table 1 and Figure 2). Table 2 shows the results of atomic absorption spectrometry for the determination of elements present in the lignocellulosic residues and the presence of As and/or Hg is not observed in any of them. Figure 3 shows the structure of the lignocellulosic residues through stereo microscopy (Figure 3).

Table 1. *Characterization of sawdust, wheat straw, agave and sorghum pellets.*

Parameter	Sawdust	Straw	Agave	Sorghum
% Moisture	6.02	4.26	4.14	3.92
% Organic matter removed	56.54	51.78	40.56	32.56
% Remaining organic matter	37.79	33.71	50.41	37.36
% Total organic matter	94.33	85.49	90.97	69.92
% Inorganic matter	5.67	14.51	9.03	30.08
As Concentration (ppb)	0	0	0	0
Density (g/cm³)	1.17	1.11	1.09	1.41

Figure 2. *Percentage composition of organic and inorganic matter in pellets.*

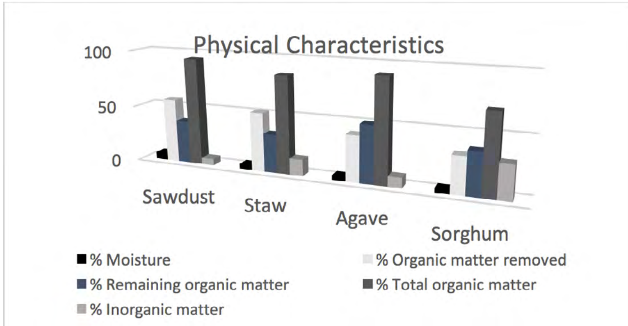

Table 2. *Analysis of elements in LR pellets, by AAS.*

Elemento	Cu	Mn	Na	As	Hg	Pb
[mg.gr-1]	0.44 ± 0.12	1.22 ± 0.42	43.48 ± 5.32	N.D.	N.D.	N.D.

Figure 3. *Images at 10.5 X (a, b) and 45X (c), of the pellets obtained.*

(a) (b) (c)

4. Conclusions

The methodology proposed by Muñoz, 2016 is an alternative with significant advantages to obtain a low cost and environmentally friendly material to remove arsenic and mercury present in contaminated water, its production consists of simple steps of activation and Fe coating.

Nomenclature

H= moisture
PF= fresh weight
PS= dry weigth

PC= carbonized weight
C= ash weight
MOe= organic matter removed
Mor= remaining organic matter
MOt= total organic matter
MI= inorganic matter
LR= lignocellulosic residues

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The first approach for water quality assessment of Lake Atotonilco, Mexico

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Abstract

Lake Atotonilco is an intermittent playa lake located in an endorheic watershed near the city of Guadalajara in western Mexico. The lake is protected by the Ramsar Convention on Wetlands. The typical biodiversity of the continental wetlands of western Mexico is well represented (2,850 hectares), including endemic and migratory waterfowl. However, due to an increase in agricultural activities and the development of urban areas in the watershed, the original habitats of wildlife surrounding the lake are gradually disappearing. Additionally, the intensive use of surface waters and the over-exploitation of groundwater for agricultural and public use has endangered the ecosystem and the biodiversity within. Furthermore, the water quality has been significantly degraded as a result of raw or partially treated wastewater, as most of the communities in the watershed do not have sewage sanitation facilities. Since the lake's watershed is mainly used for agricultur-

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al activities, significant quantities of fertilizers and agrochemical compounds, in addition to sewage, reach the lake through channels and streams. Given the importance of this lake in sustaining local and migratory biodiversity, it is relevant to understand how anthropogenic activities impact the physicochemical and biological features of the lake's water and its tributary streams. This knowledge is crucial for managers of the water source to introduce sustainable agriculture practices in the watershed and to improve treatment plans to preserve one of the most important aquatic ecosystems of western Mexico.

Keywords: *Lake Atotonilco, Lake Villa Corona, endorheic watershed, playa lakes, water quality, heavy metals, Mexico*

1. Introduction

Playa lakes are shallow depressions that provide essential habitats for wildlife, including migratory birds. Therefore, there is a great concern regarding the loss of these habitats since several anthropogenic activities, such as agriculture and the overexploitation of groundwater, affect them (Anderson et al., 2013).

Lake Atotonilco was designated as a Ramsar site in 2006, with a protected area of 2,850 hectares of continental wetlands (SEMADET, 2005). The lake is located in an endorheic watershed at the southwest of Guadalajara, the third largest metropolitan area in Mexico. The lake provides environmental services, such as recharging the local aquifer, flood control, protection for local flora and fauna, regulation of the local microclimate, and supporting economic and recreational activities, such as fishing, canoeing, and bird watching, for the local inhabitants and tourists (SEMADET, 2005). Furthermore, Lake Atotonilco is a habitat for endemic and migratory aquatic birds, fish, amphibians, reptiles, and mammals. Despite the environmental and economic services that the lake provides, large volumes of raw wastewater are introduced to the lake as runoff through rivers, streams, and channels. Additionally, important amounts of fertilizers used for agricultural activities around the lake are transported to the lake during the rainy season (De Anda, 2021). These factors affect the water quality of the lake and therefore affect the endemic and migratory aquatic birds and other species living in the lake.

This work presented the first approach for the assessment of the physical, chemical, and biological features of Lake Atotonilco and the effect of water regime on the overall water quality. The values measured for the water quality parameters were also compared with the limits established in the applicable regulation and the literature for the protection of aquatic life.

2. Materials and methodology

2.1 Area of study

Lake Atotonilco is located southwest of the metropolitan area of Guadalajara, Jalisco. It can be considered a playa lake because when the lake dries up, it leaves large visible areas of plains that give the appearance of being beaches (Arche, 2008; Last, 2002). According to recent geomorphological studies, the total size of the catchment area of this lake is approximately 755.32 km^2 (Figure 1). The predominant climate is temperate and warm with a medium temperature of 18°C. Lake Atotonilco is shallow and endorheic, with an average depth of 0.5 m and a maximum depth of 1.0 m (SEMADET, 2013). The size of the lake fluctuates with the season, depending on temperature and rainfall. Its maximum surface area is 2,252 ha. Lake Atotonilco is included in the physiographic province of the Trans-Mexican Volcanic Belt (FVTM) and is characterized by the presence of volcanoes with thermal activity, and the soils are saturated with pyroclastic and alluvial elements (SEMADET, 2013).

2.2 Sampling and monitoring

Ten sampling points were selected for monitoring water quality: four points within the lake (L1–L4); five channels (C1–C5); and one sampling point where the wastewater treatment plant (WWTP) discharges (Figure 2). The sample collection was carried out on February 19, 2021.

Figure 1. *Geographic location of the closed basins of Atotonilco, Cajititlán, San Marcos, Sayula and Zapotlán, in the state of Jalisco, Mexico.*

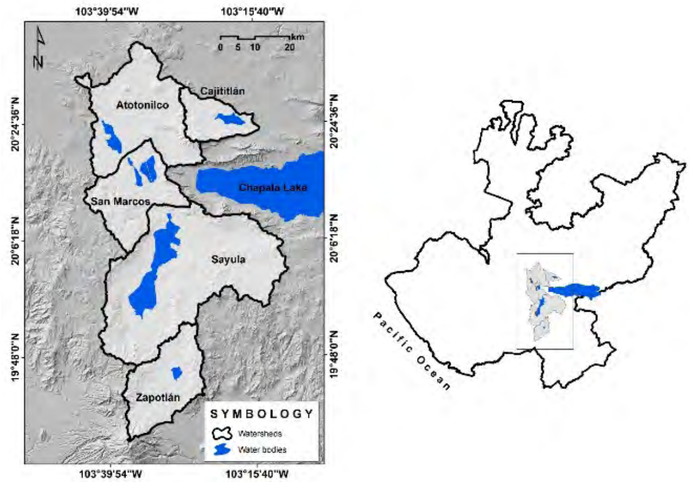
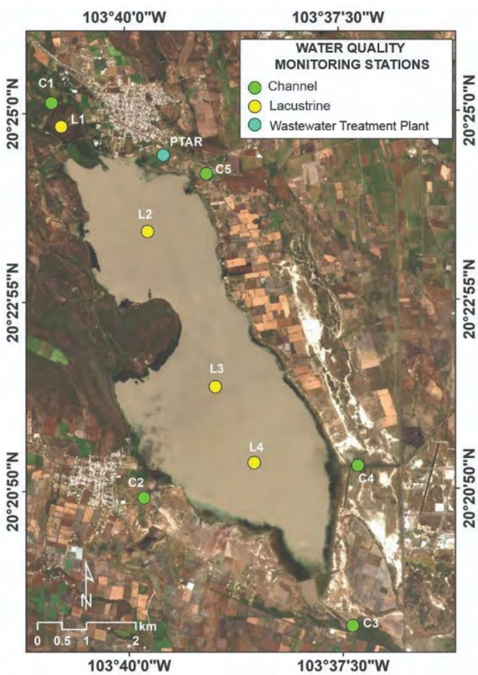


Figure 2. *Map of sampling points for water quality monitoring of Atotonilco Lake where C: waterways and storm channels; L: lacustrine sites and WWTP: wastewater treatment plant.*



2.3 Physical, chemical, and biological parameters

Physicochemical parameters, namely as biological oxygen demand (BOD_5), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammoniacal nitrogen (NH_3), organic nitrogen (ON), total suspended solids (TSS), settlement solids (SS), activate substances of methylene blue (SMB) and total phosphate (TP), were considered at each sampling point. Similarly, helminth eggs were collected only at the L2, L3, and WWTP sampling points. Heavy metals were analyzed in sediments of L1, L2, L3, and L4 and in the water for all sampling points (within the lake, channels, and WWTP). All samples were collected in plastic bottles except for sediment and microbiological samples, which were collected in glass bottles and sterile bags, respectively. The samples were preserved and analyzed by Analytical and Meteorological Services Labs of the CIATEJ Public Research Center. Analyses were performed following the methods published by the Water Environment Federation and the American Public Health Association (APHA, 2005; Federation & Association, 2005; WEF, 2005). Temperature (T), dissolved oxygen (DO), pH, electrical conductivity (EC), oxidation reduction potential (ORP), and salinity were measured using a multiparameter probe (HI 9828, Hanna) and Secchi disc (SD) at the moment of the campaign (Hanna equipment reference).

2.4 Assessment criteria

Four criteria were used to assess the water quality of Lake Atotonilco: the Federal Law of Rights (LFD for its acronym in Spanish; LFD, 2020), official Mexican standard NOM-001-SEMARNAT-2021, official Mexican standard NOM-003-SEMARNAT-1997, and the Organization for Economic Co-operation and Development (OECD; OECD, 2008).

3. Results and discussion

The sampling points for water quality monitoring (Figure 2) within the basin were selected to cover the entire lake and the water supply channels coming from nearby towns. Notably, the current WWTP based on a facultative lagoon stopped working several years ago; for this reason, effluent without previous treatment arrived at the lake.

Two sampling points (L1 and C3) were discarded as they were dry. The results indicate that an alkaline environment predominates in the lake with an average pH value of 9.54; this value was higher than the values reported by the LFD (2020) and OECD (2008; Table 1). This alkaline feature of surface waters could be attributed to the natural composition of the soil and sediments within the basin since Lake Atotonilco is located in a volcanic zone (Pecoraino et al., 2015). Additionally, the evaporative process drives the evolution of the lake to an alkaline composition since the evaporation induces oversaturation and the first components that precipitate are alkaline-earth carbonates, breaking the equilibrium between CO_2 and carbonates, which are the most prevalent solubility components at major concentrations in the lake (Grant & Jones, 2016; Spencer et al., 1990). Furthermore, the average value of electrical conductivity (EC) was 3.06 mS/cm within the lake, indicating that the water body has a high salinity level and therefore a high concentration of dissolved salts. Ochieng et al. (2007) mentioned that conductivities in lakes in Kenya are influenced mainly by carbonate salts, and higher values can be presented due to the evaporative process in endorheic basins (no outlets). High values of EC and pH are determined by the carbonates present in the water column.

The lake waters had an average temperature of 18.20°C, DO of 2.99 mg/L, COD of 63.48 mg/L, and BOD_5 of 32.42 mg/L. These values were within the regulation, except BOD_5, which was slightly higher than the limit of LFD (2020). No nitrogen forms (TKN, NH_3, and ON) were detected within the nutrients in the lake. However, a higher concentration of TP was present with an average value of 4 mg/L. Similarly, the average value of TSS (315.15 mg/L) was significantly higher than that indicated by LFD (2020) and OECD (2008). The higher concentration of TSS in the water was the

Table 1. *Physicochemical parameters for water quality during the dry season (February 2021).*

Parameter	Unit	LFD,2020	NOM 001-2021 Monthly average	OECD, 2008	Lake sampling points				Canal sampling points					WWTP
					L1	L2	L3	L4	C1	C2	C3	C4	C5	
BOD_5	mg/L	30.00	-	5		36.47	36.47	24.32	109.42	36.47		48.63	72.95	85.11
COD	mg/L	-	100	7		78.80	73.87	37.76	157.59	62.38		93.57	108.35	159.24
TP	mg/L	0.05	5	0.2		2.91	3.84	5.26	1.82	1.78		4.30	1.25	2.52
TKN	mg/L	-	15	4		< 0.50	< 0.50	< 0.50	< 0.50	< 0.50		< 0.50	< 0.50	0.87
NH_3	mg/L	0.06	-	0.4		< 0.25	< 0.25	< 0.25	< 0.25	< 0.25		< 0.25	< 0.25	0.29
ON	mg/L	-	-	-		< 0.25	< 0.25	< 0.25	< 0.25	< 0.25		< 0.25	< 0.25	0.58
CN	mg/L	0.005	1	-		< 0.02	< 0.02	< 0.02	< 0.02	< 0.02		< 0.02	< 0.02	< 0.02
TSS	mg/L	30.00	20	-	Dry sampling point	392.11	290.00	263.33	109.04	13.71	Dry sampling point	13.83	55.63	370.00
SS	mL/L	-	-	-		0.50	0.50	0.50	0.50	< 0.50		< 0.50	< 0.50	0.50
SMB	mg/L	0.10	-	-		< 0.20	< 0.20	< 0.20	< 0.20	< 0.20		< 0.20	< 0.20	< 0.20
Temp	°C	NC+1.5	35	≤28		16.96	15.90	21.72	18.27	13.09		17.33	17.10	12.49
DO	mg/L	5.00	-	≥7		2.41	3.69	2.88	0.84	1.34		1.00	0.93	1.02
pH	-	6.5-8.5	6-9	6.5-9.0		9.85	9.21	9.55	7.45	8.78		8.54	7.31	9.53
EC	mS/cm	-	-	-		3.03	3.08	3.09	0.75	0.66		0.95	0.68	0.89
ORP	mV	-	-	-		-208.53	-231.47	-237.90	-244.67	-238.10		-263.30	-421.97	-202.30
Salinity	PSU	-	-	-		1.59	1.61	1.61	0.37	0.33		0.47	0.33	0.44
SD	cm	-	-	-		9.00	4.67	5.17	-	-		-	-	-

NC: Natural conditions; BOD5: biological oxygen demand; COD: chemical oxygen demand; TKN: total Kjeldahl nitrogen; NH_3: ammoniacal nitrogen; ON: organic nitrogen; TSS: total suspended solids; SS: settlement solids; TP: total phosphate; SMB: activate substances of methylene blue; Temp: temperature; DO: dissolved oxygen; pH: hydrogen potential; EC: electrical conductivity; ORP: oxidation reduction potential; SD: Secchi disc.

result of the shallowness of the lake (about 1.0 m in the deepest zone) and the air currents that maintain the constant motion of suspended solids in the water column.

Nitrogen forms were found under relatively low concentrations in the lake and channels. Sorokin et al. (2014) noted that the high pH of the lake was likely to cause volatilization of NH_3 from the system; for this reason, the N-cycle in saline lakes may be different from low salinity freshwater lakes. However, nitrogen concentrations for WWTP were 0.29 mg/L for NH_3, 0.87 mg/L for TKN, and 0.58 mg/L for O; only the NH_3 concentration exceeded the limits of LFD (2020). For channels, the remaining parameters, such as pH, T, and SS, remained within the regulation limits.

The heavy metals present in the water are shown in Table 2. The concentrations were lower than those expected in sediments. However, the concentrations of zinc, manganese, iron, and arsenic were higher than the limits of the regulations. In particular, iron in the lake and WWTP sampling points exceeded the regulation limits. These concentrations were similar to those found in Lake Chapala, suggesting that they are natural components associated with the volcanic geology of the region.

Additionally, microbiologic parameters, such as total coliforms, fecal coliforms, *Escherichia coli (E. coli*), *Salmonella*, *Pseudomona aeruginosa*, and helminth eggs were analyzed. As a result, total and fecal coliforms and

Table 2. *Heavy metals in the water column of Lake Atotonilco.*

Parameter	Unit	LFD, 2020	NOM 001-2021	(OECD, 2008)	Lake sampling points				Canal sampling points					WWTP
			Monthly average		L1	L2	L3	L4	C1	C2	C3	C4	C5	
Aluminum	mg/L	0.05	-	-	Dry sampling point	**9.550**	**8.138**	**2.476**	**17.93**	**0.494**	Dry sampling point	**0.215**	**0.297**	**9.195**
Arsenic	mg/L	0.20	0.10	-		**0.121**	**0.121**	0.024	< 0.01	< 0.01		0.044	< 0.01	**0.131**
Cadmium	mg/L	0.004	0.10	0.001		< 0.002	< 0.002	< 0.002	< 0.002	< 0.002		< 0.002	< 0.002	< 0,002
Copper	mg/L	0.05	4.00	0.05		< 0.01	< 0.01	< 0.01	0.03	< 0.01		< 0.01	< 0.01	< 0,01
Total Chromium	mg/L	0.05	0.50	-		< 0.01	< 0.01	< 0.01	< 0.01	< 0.01		< 0.01	< 0.01	< 0,01
Iron	mg/L	1.00	-	1.00		**9.203**	**7.856**	**1.509**	**1.85**	**1.078**		0.595	0.722	**9.22**
Mercury	mg/L	0.0005	0.005	0.001		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001		< 0.001	< 0.001	< 0.001
Manganese	mg/L	-	-	0.1		**0.187**	**0.180**	**0.101**	**0.16**	0.02		0.070	**0.195**	**0.280**
Nickel	mL/L	0.60	2.00	0.025		< 0.01	< 0.01	< 0.01	< 0.01	< 0.01		< 0.01	< 0.01	< 0.01
Lead	mg/L	0.03	0.20	0.05		< 0.01	< 0.01	< 0.01	< 0.01	< 0.01		< 0.01	< 0.01	< 0.01
Zinc	mg/L	0.02	10.00	0.3		**0.036**	**0.035**	**0.048**	**0.05**	**0.04**		**0.032**	0.016	**0.048**

E. coli were abundant in the canals (Table 3). However, in the lake, these pathogens were detected in a minimal amount that could be considered negligible. This could be attributed to the high salinity in the water and the exposure to ultraviolet light from the sun that limit the presence of pathogens in the lake.

Table 3. *Microbiological parameters in the water column of Lake Atotonilco.*

Parameter	Unit	LFD, 2020	NOM-001-2021	NOM-003-1996		OECD, 2008	Lake sampling points				Canal sampling points					WWTP
			Monthly average	A	B		L1	L2	L3	L4	C1	C2	C3	C4	C5	
Total coliforms	MPN/100 mL	-	-	-	-	5000	Dry sampling point	23.00	4.50	7.80	1700000	92000	Dry sampling point	13000	160000	92000
Fecal coliforms	MPN/100 mL	1000	-	240	1000	2000		4.50	Not detected	Not detected	1700000	13000		1700	54000	11000
Salmonella	25 mL of sample	-	250	-	-			4.50	Not detected	Not detected	1700000	7900		1700	4000	3300
E. coli	25 mL of sample	-	-	-	-	0.001		Absence	Absence	Absence	Absence	Presence		Absence	Presence	Absence
Pseudomonas Aeruginosa	mg/L	-	-	-	-	0.05		Absence	Absence	Absence	Presence	Presence		Absence	Absence	Absence
Helminths eggs	Eggs/L	-	-	≥1	≤5			< 1	< 1	-	-	-		-	-	< 1

A: Permissible limits of pollutants in treated wastewater for public services with direct contact and B: Permissible limits of pollutants in treated wastewater for public services with indirect or occasional contact

The initial determination of the water quality in Lake Atotonilco showed that an alkaline environment predominates. This characteristic may be due to the phenomenon of salt concentration due to precipitation and evaporation, which has occurred for thousands of years in the lake. The waters flowing in the channels have major pathogen contamination due to the lack of sanitation infrastructure in the communities settled in the basin. The non-treated wastewaters pollute the surface waters, affecting their physicochemical and microbiological features. Notably, pathogens were practically absent once the water flowing through the channels arrived at the lake due to the high saline environment. However, the levels of BOD_5, TP, and TSS in the lake exceeded the permissible limits dictated by national and international standards. A high concentration of total suspended solids (TSS) was expected due to the shallow characteristics of the lake, where wind facilitates the resuspension of sediments. This occurs particularly in the dry season when lake levels are very low. Additionally, it has been suggested that the presence of high concentrations of aluminum, iron, and manganese are due to the geochemical features of the soil that predominates in the basin and in the FVTM (Krasilnikov et al., 2013). However, the presence of arsenic and zinc could be attributed to the natural composition of the groundwater that arises in the watershed in the form of springs or due to the decomposition of some heavy metal content in some pesticides used in agriculture that are dragged to the lake during rains.

4. Conclusions

To restore the quality features of the lake's waters, it is necessary to establish a program to provide sanitation services to the communities settled in the basin. Furthermore, it is necessary to control the agrochemicals used in the agricultural activities of the basin to reduce the contribution of nutrients, especially phosphorus. Finally, it is considered essential to continue with the water quality monitoring program in the channels and in the lake to determine the behavior of the physicochemical and microbiological parameters during an annual cycle. It is also important to consider a hydrological study of the catchment area to determine how to improve the runoff waters during the rainy season and the surface and groundwater management practices to reduce the desertification risk of the lake.

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Chapter 5. Social Ambit

The social scope of this book involves linking lakes and reservoirs with human activities, from civil participation, culture and literature, religion, education, history, anthropology, human rights and social participation.

Collaborative removal of an invasive alien aquatic weed by volunteering university students in collaboration with multiple stakeholder groups around Lake Biwa, Japan

Haruka Tsujino, Kippei Kuroda, Haru Shimada, Toshiya Nakamura[1]

Abstract

Explosive growth and propagation of water primrose Ludwigia grandiflora subsp. hexapetala, an invasive alien aquatic weed introduced from South America, has caused serious problems such as competitive exclusion of native species, obstruction in operation of commercial fisheries, and increased risk of river flooding.

IVUSA (International Volunteer University Student Association), is a pioneering volunteer group in the removal of this invasive weed since 2013. We have carried out 62 removing activities so far, with participation of a total of 12,275 local people from governments, fisheries cooperatives, environmental NPOs, and individual residents. In Lake Biwa, Shiga Prefecture, the area of the lake surface covered with this invasive weed once reached almost 300,000 m^2 in 2016. A variety of stakeholders have carried out activities for its removal, resulting in a marked decrease to some 30,000 m^2 by the end of FY 2018. We will make continuous efforts toward the extermination of this invasive weed. In this presentation, we will make a historical review of our activities, highlighting the removal methods, the results of activity sequence, and the challenges in collaboration with various stakeholders.

[1] International Volunteer University Student Association (IVUSA).

Keywords: Ludwigia grandiflora *subsp.* hexapetala, *Lake Biwa, removal activity, collaboration with various stakeholders*

1. Introduction

1.1 *Ludwigia grandiflora* subsp. *hexapetala*

A water primrose or *Ludwigia grandiflora* subsp. *hexapetala* (hereinafter, called "water primrose") is an amphibious weed introduced from South America. Water primrose is characterized by explosive growth and propagation, which cause problems such as competitive exclusion of native plants, habitat degradation for native aquatic animals, and negative impacts on cruising and commercial fisheries. In 2014, it was assigned as Designated Invasive Species stipulated in Invasive Alien Species Act by Ministry of the Environment.

Water primrose has the ability to regenerate from fragmental roots and stems which may be left even after large-scale removal activities in offshore areas and reed plantations. Thus, it is necessary to carefully remove roots and stems remaining underwater or underground by hand, and a lot of manpower are required to completely remove them.

Figure 1. Ludwigia grandiflora *subsp.* hexapetela

1.2 Measures at Lake Biwa, Shiga Prefecture

Water primrose was first found in Akanoi Bay in the southern basin of Lake Biwa (Moriyama City, Shiga Prefecture) in 2009 with a coverage area of

142 m^2. In 2016, the coverage area of water primrose reached some 300,000 m^2, spreading all over the southern basin of Lake Biwa. Since 2012, collaborative activities to remove water primrose have been carried out by local NPOs, fishermen, residents. In addition, large-scale machinery removal was started in 2014, and patrolling and monitoring along shorelines, in particular where large-scale removal was conducted, resulted in its marked decrease to 32,000 m^2 by the end of FY 2018. Thereafter, its coverage area has been continuously maintained at a similarly low density.

Along with such joint activities, IVUSA started its contribution in 2013. First, we focused on the problem of water primrose in Lake Biwa, and began its activities to remove water primrose. Currently, we are working in collaboration with various stakeholders such as local people from governments, fisheries cooperatives, environmental NPOs, companies and individual residents, taking advantage of their respective strengths. In this article, we will introduce our removal activities in collaboration with various stakeholders.

2. The growing situation of water primrose and removal activities in each period

2.1 The growing situation of water primrose and removal activities from 2009 to 2013

Before the coverage area of water primrose spread to 18,000 m^2 in 2012, its invasiveness was not recognized seriously. In addition, the removal activity is hard enough for most of the people belonging to the environmental NPOs and local fisheries cooperatives.

In March 2013, when some students in our association participated in an activity to remove water primrose, they got a strong sense of crisis and planned a removal activity from the desire that "we want to protect Lake Biwa by the power of youth".

In April 2013, the first removal activity was carried out in Otsu City with 17 participants, including 14 students, Shiga Prefectural Government (hereinafter called "SPG"), Omi Wetland Research Group, and Lago Co., Ltd. We removed about 150m^2 of water primrose and packed them in mesh plastic bags. Thanks to SPG's help such as arranging that temporary storage place to put removed weeds for drying, transport, incineration disposal, and distributing long-bodied boots and long-length rubber gloves for us, our activity was able to start smoothly.

In June 2013, in Moriyama City, 4 stakeholders i.e. Akaoni-Biwako Environmental Citizens Initiative (environmental NPO), the city government, Tamazu-Ozu Fisheries Cooperative, and IVUSA (students) collaborated to form "Water Primrose Removal Project".

Figure 2. *Meeting with NPOs and fisheries.*

More than 90% of water primrose in Lake Biwa was distributed in Moriyama city, and it became recognized that the commercial fisheries and ecosystem were seriously damaged by water primrose.

Removal activities had been planned with the aim of restoring the rich ecosystem in Akanoi Bay, and in the first year, five removal activities had been carried out with a total of 261 people participating.

Figure 3. *Cooperation activity in Akanoi Bay.*

We organized a local collaborative system and tried to carry out efficient activities, but we did not understand the overgrowing strength of water primrose.

2.2 Removal activities from 2014 to 2018

In March 2014, the Council for Controlling Invasive Aquatic Plants in Lake Biwa was established, in which IVUSA was invited to join. The distribution and coverage area of water primrose continued to spread and grow over the entire southern shore of Lake Biwa. However, no control measures for water primrose were taken except for the case in Moriyama City mentioned above. Counter plans were thus required for the entire Southern Lake.

Therefore, in September 2014, we, IVUSA planned and carried out a large-scale removal activity across Otsu, Kusatsu, and Moriyama Cities in an unprecedented large-scale, in which about 600 students participated in three days. As a result, water primrose with a total weight of 120 tons and an area of 6,000 m^2 was removed during 3 days. This large-scale activity could be carried out in collaboration with various stakeholders including the local governments, environmental NPOs, and fisheries cooperatives. This activity in the southern part of Lake Biwa had been carried out every year until 2018.

In addition, mechanical removal began in 2014, patrol monitoring was thoroughly carried out from 2016 by the local council. Furthermore, volunteer activities have been continuously carried out in collaboration with local stakeholders in each region. The area of the lake surface covered with water primrose once reached almost 300,000 m^2 in 2016, resulting in a marked decrease to some 30,000 m^2 by the end of FY 2018.

Figure 4. *Large-scale activity.*

However, the problems had remained with the spread of distribution points throughout Lake Biwa and the lack of a decisive factor for removal measures against in the reed plantation area.

Figure 5. *Mechanical removal.*

2.3 Removal activities from 2019 to 2021

Although the large carpets of water primrose were not found along the shore of the lake since 2019, its spatial distribution spread to the northern basin of the lake, satellite lakes and irrigation ponds. It is technically very difficult to remove water primrose in the reed plantation areas and floating spawning beds for fish located offshore in the reed.

In response to these problems, IVUSA carried out removal activities for this water primrose.

In 2019, a large propagation of this water primrose was confirmed in the reed plantation areas in the northern basin of Lake Biwa in Takashima City.

Considering the danger of spreading throughout Lake Biwa, it was necessary to urgently remove this large propagation, and a removal activity was planned and carried out by 215 students and 87 general participants for three days.

In Moriyama City, many individuals of water primrose were growing in the reed plantation areas and in the floating spawning beds. Since this area is an important fish spawning area and a valuable fishery resource for local fishermen, IVUSA had regularly carried out removal activities 4 or 5 times a year in collaboration with local people from governments (Shiga prefecture, Moriyama city), a fisheries cooperative (Tamazu Ozu), an environmental NPO (Akanoi-Biwako Environmental Citizen's Initiative), private companies, and individual residents.

This invasive weed is also growing in the reed plantation areas in other cities and removal activities are required.

Figure 6. *In the reed plantation.*

Figure 7. *In the floating spawning bed.*

3. Cooperation with various stakeholders

We will introduce how to proceed our collaborative removal activities as follows.

3.1 Removal procedure

1. **Collection of distribution information and consideration of removal area**
   The distribution information of water primrose was obtained from the SPG or the administrator and we select the places where manpower of students in IVUSA can be effectively utilized considering the danger of dispersal and the impact on the ecosystem.
2. **Preliminary field survey**
   Officers of SPG, local administrators and IVUSA students conduct a survey. We check the growing status of the invasive weeds, and how easy and safe removal work will be executed. In addition, we check the procedure and conditions required for the following processes such as temporary storage place, transportation, and disposal.
3. **Discussion with administrators and related parties**
   We explain to the related governments, administrators, and other local organizations about the plan of our removal activities, requesting cooperation, and proceeding prior arrangements such as land use and disposal.
4. **Removal activity**
   In collaboration with all participants, we carefully remove the weed with

a large number of people mainly in the reed plantation areas, floating spawning beds where mechanical removal is difficult.

5. Sun-drying

The removed invasive weeds are dried under the sun at temporary storage sites designated by the administrator so as to lower the incinerator temperature of the disposal facility and reduce the weight of weeds.

6. Transportation

After some weeks for drying, dried invasive weeds are transported to the disposal facility with the aid of governments or administrators.

7. Incineration disposal

The transported invasive weeds are incinerated at the city facility.

8. Patrol and monitoring

In the removed areas, the government and local people patrol and monitor to prevent regeneration of the invasive weed.

Figure 8. *Each process of removal procedure.*

IVUSA and other stakeholders cooperate and divide roles of each in this procedure to remove it.

3.2 Collaboration in each region

To complete removal of invasive weeds, several treatment processes are required: A) Field survey and planning logistics of activities; B) Actual removal of weeds (including their arrangement for sun-drying); C) Transportation to storage site; D) Drying at storage site; E) Transportation to disposal facility; and F) Incineration disposal. Collaboration systems among stakeholders and their related activities (shown in alphabetical labels above) are summarized for respective regions as follows.

- **Kusatsu City**
  IVUSA: A, B, C; SPG: A, B, D, E; Kusatsu City: B, F; Industrial waste disposal company: E.
  Additional information: The removed weed is transported to the disposal facility with the cooperation of an industrial waste disposal company.
- **Moriyama City**
  IVUSA: A, B ; SPG: B; Moriyama City: B, F; Tamazu-Ozu Fisheries Cooperative: A, B, D, E; Akaoni-Biwako Environmental Citizens Initiative (environmental NPO), B; Local residents: B; Private Companies: B,
  Additional information: Local NPOs become regional hubs, and fishermen provide ship operations and ports.
- **Otsu City, Seta River**
  IVUSA: A, B; Biwako River Office of the Ministry of Land, Infrastructure, Transport and Tourism (hereinafter called "MLIT"): A, B, D, E, F; SPG: B; Otsu City: B, F.
  Additional information: Since the Seta River is nationally managed, the regional river office and IVUSA collaborate to manage the activities.
- **Otsu City, Lakeside Parks**
  IVUSA: A, B; SPG: A, B, D, E; Otsu City: B, E; Private companies: B; Local residents: B.
  Additional information: SPG and IVUSA lead and instruct other participants in removal activities based on knowledge accumulated through a lot of activities so far, such as how to distinguish and remove the invasive weeds.

Figure 9. *Instruct company's participants.*

- **Takashima City**
  IVUSA: A, B, C; Kinki Bureau of the Ministry of the Environment (hereinafter called "ENV"): B; SPG: A, B; Takashima City: B, D, F; Private companies: B. Additional information: Since it has a lakeshore with a rich ecosystem, there is a high awareness of the crisis in the area, and the cooperation of Takashima city is positive.

The role of each stakeholder in each region is shown in table below.

Table 1. *The role of each stakeholder in each region.*

	Moriyama City	Otsu City, Seta River	Otsu City, Lakeside Parks	Kusatsu City	Takashima City
IVUSA	A,B	A,B	A,B	A,B,C	A,B,C
SPG	B	B	A,B,D,E	A,B,D,E	A,B
City Government	B,F	B,F	B,E	B,F	B,D,F
Fisheries Cooperative	A,B,D,E	-	-	-	-
Environmental NPO	B	-	-	-	-
Local residents	B	-	B	-	-
Private company	B	-	B	E	B
MLIT	-	A,B,D,E,F	-	-	-
ENV	-	-	-	-	B

In this way, we are working in cooperation with each region by clarifying the division of roles.

4. Challenges for the future

Though the coverage area of this weed in Lake Biwa has reduced by the continuous efforts of various stakeholders, many weeds remain in places requiring manpower to prevent it to spread to the northern part of Lake Biwa and satellite lakes and ponds, the reed plantation areas, and floating spawning beds.

In order to solve such problems, early detection and removal are important. So, we will share the basic knowledge to all generations from kids to adults, researchers or companies etc., to raise awareness, and clarify the roles of each stakeholder such as removal, temporary storage, transport and disposal of this invasive weed in each region.

As IVUSA, we will work on providing environmental learning for children, distributing brochures, and making presentations at forums as dissemination activities.

Also, as a collaborative activity, we work with the local people from governments, fisheries cooperatives, environmental NPOs, and individual residents, and prompt many young people and companies to participate.

We will make a vibrant society with the energy of young people, and we will work for continuous efforts toward the extermination of this invasive weed.

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Investigation of university students' values over environment through mutual educational workshops for Integrated Watershed Management

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Abstract

For more practical Integrated Watershed Management (IWM), people's values regarding the environment should be taken into account in the decision-making process. People's participation is needed for successful IWM because they are the ones who have a strong interest in, knowledge of, and experience with the local environment. Fostering the next generation who have an interest and knowledge is also a challenge in the context of IWM. This research aims to develop a new methodology to investigate the values of university students in relation to the environment through mutual educational workshops and text mining. Workshops to make the journey map (JM) and value graph (VG) were held for the university students to promote an open-ended discussion and to obtain their opinion regarding two environmental topics, specifically water and waste, and the associated problems. The participants discussed "how the problem occurs" and "why the problem has to be managed" while making the JM and VG, respectively. The obtained texts were then analyzed using text mining. As an example of the results, for water quality degradation, university students tend to think that their daily actions, such as throwing away garbage, cause the problem, and that

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such actions are usually triggered by selfish emotions. In addition, they think that marine pollution control is needed to protect the landscape, ecosystem, etc. We hope that the methodology developed in this research can provide time for people to think of the environmental problems together and to learn from one another so then their participation in watershed management activities can be facilitated in the future.

Keywords: *Environmental education, environmental communication, journey map, value graph, integrated watershed management*

1. Introduction

Integrated watershed management (IWM) has been gaining attraction as a comprehensive countermeasure to environmental problems happening in river watersheds all over the world. The concept of IWM includes six factors: information, participation, institutions, policies, technology, and finance [1]. In the IWM context, public participation in management activities and the decision-making process is one of the challenging parts because it needs there to be a proper perception held by the people about their local environment. Although local people have knowledge and experience with the local environment, their intention to join the IWM activities is sometimes low due to the lack of opportunities or proper environmental education [2].

Recently, the concept of mutual education has been applied to the environmental education field as environmental mutual education to integrate public participation and environmental education [2]. In this concept, scientists, who have the expertise but not the local knowledge, learn about the local environment from local people. On the other hand, the local people, who have the local knowledge but not expertise, learn the necessary technical knowledge from scientists. During the process of learning from one another, both scientists and local people can share their knowledge and even create new ideas for the local environmental management.

This research has developed a new methodology that can provide an opportunity for people to think of their surrounding environment based on the environmental mutual education concept. The methodology includes an environmental education workshop applying two brainstorming methods, the value graph (VG) and the journey map (JM), to environmental topics. Text mining is also used in the methodology to quantitatively analyze the participants' perceptions and values regarding environmental issues. In this research, Japanese university students are the target of the workshop and investigation. It has been reported that university students have the lowest intention to engage in pro-environmental behavior in Japan [3]. Since they usually have the highest opportunity for independently choosing their actions, the importance of enhancing environmental education for university students has been emphasized [2].

2. Materials and methodology

2.1 Definition of mutual educational workshop

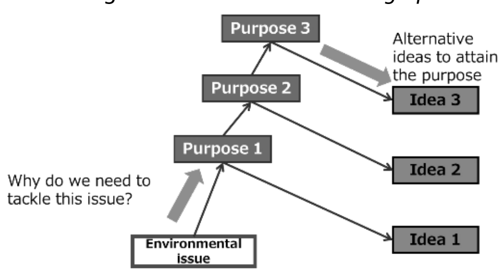
This research applied two brainstorming methods, the value graph (VG) and the journey map (JM), to environmental topics. A workshop using these two brainstorming methods has been defined as the mutual educational workshop in this research. The mutual educational workshop enabled the participants to enhance an open-ended discussion about the specific environmental topic/issue. This research specifically set the topic for two environmental issues, water and waste, and the associated problems. Thus, the mutual educational workshop held in this research was exclusively designed for environmental education purposes. The procedure to make the VG and JM used in the workshop held in this research has been explained in the following subsections.

2.2 Value graph (VG)

Value graphs (VGs) are a brainstorming method that was originally developed for the value engineering field [4]. Recently, it has been modified for environmental education purposes as shown in Figure 1 [2]. This research used a VG in the mutual educational workshop. In this case, the VG method was used by the participants to ponder "why the environmental problem has to be managed" and to clarify the purpose (meaning) of tackling the environmental issue. There are five steps to create a VG as follows.

1. The participants make a group with 2-4 members. They decide on an environmental issue of their interest by themselves and write it down on paper for the purpose of brainstorming using sticky notes.
2. The members put down their ideas about the purpose of the management of their environmental issue (e.g., Purpose 1 in Figure 1).
3. The members also give their ideas on how to achieve the suggested purpose (e.g., Idea 1 for Purpose 1 in Figure 1).
4. The members think about why the previously suggested purpose needs to be achieved (e.g., Purpose 2 and 3 for Purpose 1 and 2, respectively, in Figure 1). They also suggest alternative ideas to achieve each purpose.
5. The members repeat Steps 3 and 4 until they run out of ideas or the end of the workshop time is reached.

Figure 1. *Structure of the value graph.*

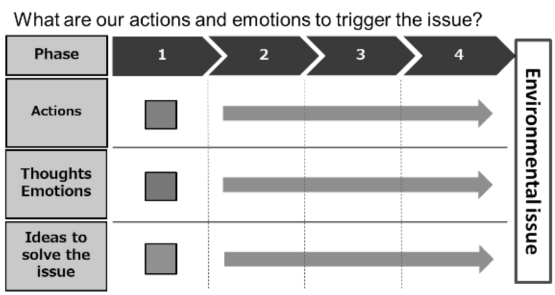


2.3 Journey map (JM)

Journey maps (JMs) are commonly known and used as a customer journey map in service design [5]. It has been applied to the environmental education field to ponder "how an environmental problem occurs" and to design management strategies based on people's experiences, actions, and emotions (Figure 2) [2]. There are five steps to create a JM as follows.

1. The participants make a group with 2-4 members. They set an environmental issue of interest by themselves and write it down on paper as the goal of their brainstorming.
2. The members imagine and give their ideas on the actions that may trigger the environmental issue.
3. The members group the actions based on their similarities. Each group is called a phase as shown in Figure 2. The order or time series of the phases in relation to the environmental issue occurring is also considered and arranged by the group members themselves.
4. The members imagine their emotions (i.e., why they take actions that may trigger the environmental issue) in each phase.
5. The members suggest ideas to improve on the negative actions and emotions and/or to enhance the positive actions and emotions regarding the environmental issue. In this case, they do not need to consider the reality of the ideas and their scientific effectiveness. The important thing in this workshop is that the members suggest the strategies by themselves.

Figure 2. *Structure of the journey map.*



2.4 Text mining

This research held a series of mutual educational workshops for university students who belonged to the same faculty as the authors in Japan. Text mining was then applied to the texts obtained from the completed brainstorming papers to quantitatively analyze the participants' values regarding environmental issues. KH coder [6, 7] was used to conduct the text mining after modifying and correcting any errata. Table 1 shows the numbers of sentences and analyzed words obtained from the completed brainstorming papers with 67 participants. In this paper, the results of the word frequency obtained from each brainstorming method are shown as an example of the analysis using text mining.

Table 1. *Number of analyzed sentences and words obtained from the completed brainstorming papers.*

Number	VG	JM
Participants	67	
Completed brainstorming	40	41
Sentences	682	1,246
Analyzed words	1,844	3,109

3. Results and discussion

3.1 Analysis of the value graph (VG)

Figure 3 shows an example of a completed value graph. In this case, the members of the group set their environmental issue of interest as marine pollution. They were thinking about why marine pollution has to be managed in the example value graph. As one of the first purposes, they imagined "to protect landscape" as being the key part of managing marine pollution. They suggested "to plant more trees (along the coast)" as one of the strategies to protect the landscape.

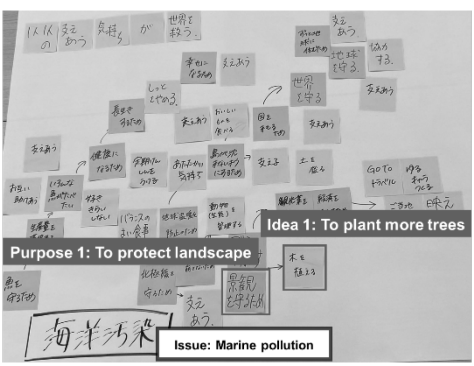


Figure 3. *Example of the completed value graph regarding marine pollution.*

Table 2 shows the results of the text mining for the VG. Aside from the words indicating the topics themselves, i.e., Water and Waste, the word "protect" was the most frequent word extracted from the completed VGs. There were some related sentences (purposes), such as "to protect the ecosystem" and "to protect tourist attractions", found in the completed VGs. This implies that the participants, i.e., university students, tend to put importance on "protection" as the common purpose of water and waste management.

Table 2. *Results of the text mining for the completed value graphs.*

Rank	Word	Ratio (%)	Frequency
1	Water	1.63	30
2	Protect	1.46	27
3	Waste	1.36	25
4	Sightseeing	1.19	22
	Good	1.19	22

3.2 Analysis of the journey map (JM)

Figure 4 shows an example of a completed value graph thinking about the causes of water pollution. The members in this group were thinking about how water pollution occurs in their surrounding environment based on their actions and emotions. For example, they thought that "to buy and eat something packaged by container" and "low level of environmental awareness" caused water pollution. One idea that they suggested was "to design a reusable container that can make them feel they want to reuse it" to prevent pollution.

Table 3 shows the results of the text mining for the JM. Aside from the topic theme of waste, the words describing their daily actions, "buy", "eat", and "throw", were the most frequent words extracted from the completed JMs. This implies that university students tend to think that their daily actions cause environmental issues. However, changing their actions can eventually improve the issues. In addition, there were some similar sentences related to selfish emotions such as "garbage separation is tiring" for both water and waste problems' JMs. The kind of findings obtained from the JM, particularly the ones related to emotions, can be an important factor when designing environmental management strategies since encouragement is the key to enhancing the level of participation in the IWM activities.

Figure 4. *Example of the completed journey map regarding water pollution.*

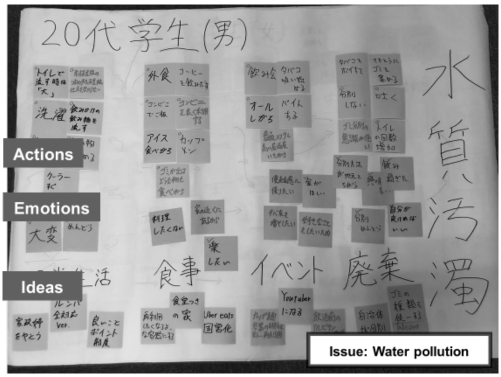


Table 3. *Results of the text mining for the completed journey maps.*

Rank	Word	Ratio (%)	Frequency
1	Waste	2.12	66
2	Throw	1.96	61
3	Eat	1.29	40
4	Buy	1.06	33
5	Separation	1.03	32

4. Conclusion

This research held mutual educational workshops using the VG and JM to enhance a discussion about environmental issues among university students. Text mining was then conducted to quantitatively analyze their values regarding environmental issues. As a result, it was found that the university students put importance on "protection" as the main purpose of environmental management. They tend to think that their daily actions cause environmental issues.

For the participants of the mutual educational workshop, they can deeply think about why we need to take action to improve the environment and to imagine how their actions cause the environmental issue in question. The methodology developed in this research can provide an opportunity for people to think on the environmental problems presented together. Therefore, we hope that the further application of this research can enhance people's participation in IWM activities through a mutual understanding of the necessity of environmental management.

Acknowledgements

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Typical social dilemmas in urban lake governance in India case of Thaltej Lakes in Ahmedabad

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Abstract

The paper exemplifies the typical social dilemma among urban communities in maintaining the commons located in their locality. The paper presents the findings of a survey of the people living around Thaltej lakes asking them about the lakes and their relationship with the lakes.[3] The hundred fifty years old Thaltej lakes, now remaining three in numbers, are located in the Thaltej Gram Panchayat of the city of Ahmedabad. The set of five small traditional rainwater harvesting ponds have reduced by number and size, besides turning into wastewater sinks that are a source of health hazards in the area. The lakes are surrounded by nearly fourteen hundred informal settlements that are slowly encroaching upon the lake area. Two hundred strategically selected households from both informal and formal settlements around the lakes were surveyed in 2018. The survey questionnaire aimed to capture the perception of the people through individual's preference towards the lake management. The questionnaire included qualitative as well as quantitative

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[3] The works lakes and ponds are interchangeably used here because the waterbodies are actually ponds by characteristics, however they are called lakes in the official documents.

aspects of willingness to accept the deteriorating lakes vis-à-vis willingness to contribute as civil participation towards their betterment. From the survey, we find that though the people are trapped in the typical prisoner's dilemma situation of doing/not doing something for the lake, they are watching and waiting for some initiative where they may contribute directly or indirectly towards the lake. This social dilemma pattern in perception and participation of the urban community in the commons management is typically concerning in the Indian cities. We realize that we need to find how we can avert the prisoner's dilemma situation to make urban lake governance more participatory. In other words, how can we make the urban community take the responsibility of the urban lakes and thereby shift the lake management by the government towards a collective lake governance.

Keywords: *Urban lake, social dilemmas, governance, Thaltej, perception, participation*

1. Introduction

The urban lakes in India face implicit discrimination by the urban community. On the one hand, they are left from integrating in the overall city development processes, and on the other hand, they are exposed to all kinds of misuse and abuse from solid waste dumping, wastewater inflow, edge pollution with building wastes, encroachment for housing etc. If they weren't enough, several of them are reclaimed by filling up to construct buildings in the name of development. Besides, the new trend of lake developments after the first National Lake Conservation Plan (in 200) by (MoEF, 2008) is equally concerning because the state of the urban lakes though looks aesthetically beautiful, they are barely addressing conservation of the lakes as ecosystem. Hence, the state of the lakes developed is no different than the deteriorated state as the development is totally anthropocentric with concretization with least or no aquatic life. The urban lakes have become vulnerable to transformation (D'Souza and Nagendra, 2011) with the changing and increasing value of their land components thus resulting in the exploitation as land parcels. The life in water and the life on land are ironically shelved as secondary because of the disconnect of the people with the life cycle of lakes.

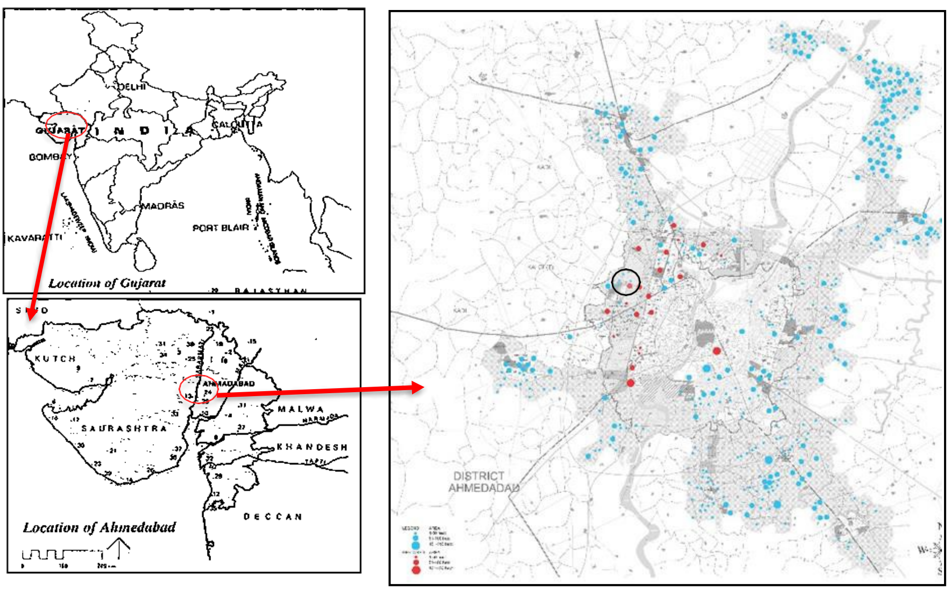
The perception and the preference of the people, thus, on the lake development over a lake undeveloped in poor state are limited to functions like, a clean-green public space for recreation and something that ascribes better real estate value to the adjacent urban development (Bhargava, 2019). If such perception and preference are to be taken at the face value as something driving the past lake deteriorations and the present lake developments, it is pertinent to ask the urban community their willingness to participate in the lake governance that has socio-economic costs and benefits to them. An implicit assumption lays the foundation to this askance which comes from the traditional community water management system (Agarwal, Narain and Khurana, 2001), when historically the community inhabiting around the lakes & ponds maintained and appropriated them judiciously by collective arrangements of do's and don'ts. Understanding the nuances of the modern-day social construction about lakes and ponds in India is the entry point. A social engineering exercise was carried out in a neighborhood of Thaltej Lakes in the city of Ahmedabad. The leading inquiry of the action research pivoted at, *the typical social dilemmas among urban community towards maintaining commons like lakes/ponds.* The classic theories like the tragedy of the commons (Hardin, 1968), prisoner's dilemma and the logic of collective action (Olson, 1965) came in handy to understand the social construction (Ostrom, 1990) as typical governance problems of shared resources (Ostrom, 2005).

The paper is about the experience and learning from a social experiment on the neighborhood of the Thaltej Lakes that exemplify the typical social dilemmas (Dawes, 1980) among urban community in maintaining their common shared resources like urban lakes located in their neighborhood. The paper starts with brief descriptions of the Thaltej lakes and the approach of the study. The main body of the paper elaborates on the findings from the questionnaire survey about the peoples' perception and preference about the Thaltej lakes and analyses those by linking with the classic theories. The paper concludes with an open discussion on how to avert the social dilemmas among the urban community and move towards more community governance of the shared resources.

2. Thaltej lakes

Thaltej lakes are located in the Thaltej Village Panchayat[4] area in the western part of Ahmedabad city. Ahmedabad is among the fast-developing cities of India with an urban population of nearly seven million living in in the jurisdiction of Ahmedabad Urban Development Authority (AUDA) area of 1,866 square kilometers. Ahmedabad has officially designated 122 lakes in its urban area (Bal, 2015) after the mandate by the National Lake Conservation Plan (now called, National Plan for Conservation of Aquatic Ecosystems since 2013) and other allied policies (Jainer, 2020), whereas there were nearly 630 lakes & ponds in the same area two decades ago (Bal, 1999). The deterioration of the lakes augmented with the designation and delineation have led to extinction, in other words transformation of the lakes into land parcels for development.

Figure 1. *Lakes of Ahmedabad and location of Thaltej lakes.*



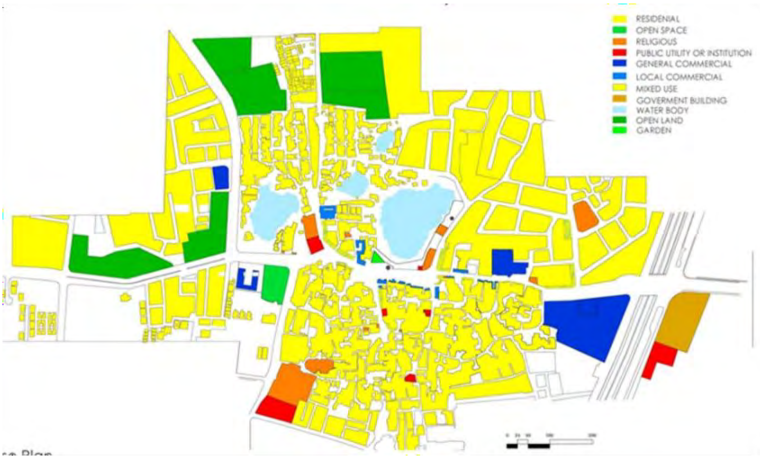
Source: AUDA and Multi Mantech International Pvt. Ltd. 2017.

[4] Gram Panchayat is a Village Council and a smallest unit of governance in the country.

Thaltej lakes are a cluster of four plus two traditional rainwater harvesting ponds built around some 150 years ago and locally referred as, Talavadis. Four of them, are interlocked in an area of 500 × 500 meters approximately north of the Thaltej village. Historically, the two main ponds were used for domestic purposes and the others were used for farming which was spread in the northern sides of the ponds & village. In the last two decades, the ponds have reduced by number and size. Of the two distant ones, one on the east is long reclaimed into governmental housing and the one in the west is in the process of reclamation by dumping building waste by the government. The focus of the study is on the cluster of four ponds as there are the concentrations of people as well as a possibility to engage with them to explore community lake management options. Of them, two ponds are at the verge of reclamation by slum encroachment. There are now two visible ponds namely, Thaltej and Malay and the reduced water spread area of each is around 100 x100 meters approximately. They have turned into waste (solid and water) sinks that are a source of health hazards in the area. In addition, a part of the Malay Talav is to be reclaimed for constructing a metro station for the proposed metro line. So, Thaltej Lakes are classic example showcasing the slow and systematic degradation and diminishing

Figure 2. *The main Thaltej Lake and other 3 Ponds in 2018.*

Figure 3. *Location of Thaltej lakes in Thaltej.*



Source: Bachelor of Architecture Design Studio work at Anant National University Ahmedabad, 2018 and Bal, 1999.

waterbodies in the country. Importantly, the ponds are currently inaccessible physically and also a no-go area psychologically.

The Thaltej village (locally called Gamthal) located on the south of the lakes covers an area of about 14 hectares and the population is about 14,700. The village is located on the higher side of the ponds. It is compactly built and resided by high density living many of which are further transforming into apartments. There are many communities living within the village like, the higher caste community resides on the main Gali as Thakur Vas (local name of residency), Patel Vas, Brahman Vas. The lower caste communities are on the periphery of the village. Each lane (locally called Gali) and cul-de-sac (locally called Khancho) of the village is identified with a community. At an aggregate village level, they still reflect a homogenous community as everyone knows each other. The new development that surrounds the lakes (200 metres radius considered for study) hosts similar population but is totally heterogenous in nature as most of the people are from other parts of the city and even country. Much of the urban development here has happened before the urban planning and laying of the infrastructure, for example, the high density Bhaikakanagar on the east and the farmhouses on the north. There are nearly fourteen hundred informal settlements living around the four ponds including lake edges where poor people from nearby villages have migrated and squatted in search of livelihood opportunities and challenged by inability to afford housing in the new developments. The informal settlements are slowly encroaching upon the edges of the ponds resulting in extinction of two ponds on the north. Although they are provided with formal water supply, the absence of drainage system in the area results in discharge of wastewater into the ponds. The mosaic of this community landscape reflects on the disparity of a the urban facilities besides the difference in the perception and preference about the lakes.

The main catchment area is on the north of the ponds which used to be agricultural land in the past and now hosts the new developments of high real estate value. There are a few patches of farmlands in the area. The main inlet drainage channels connected with the upstream ponds of Sola and Hebatpur villages which have disappeared in the process of development. The waste inlet from the slums is a threat. The tree cover is scarce around the edge of the ponds, however, there are trees in the new developments yet the tree cover and open space per capita in the city is much lower than the national average. There are weed growths at the water edges during the non-monsoon periods. In the monsoons, the area around the ponds gets flooded because, the inlet and outlet drainage channels are non-existent resulting in the water to be stagnant. There are three overhead water tanks located at the main Thaltej pond, from where the water supply is distributed to the village and surrounding area though the majority of the water needs are fulfilled by the groundwater in the area. The physiography helps to understand the transformation of village landscape into the urbanscape.

3. Approach of the study

The action research was carried out over a period of two years in 2017-18 with events carried out with the people of the neighborhood living at the lake environment culminating into a simple 2-page survey questionnaire. The questionnaire was structured in broad sections as, introduction of the respondent, acquaintance/relationship with the lakes, and some aspects of willingness to accept the deteriorating lakes and willingness to participate towards their improvement. A total of 217 households responded the complete survey questionnaire out of the 260 surveys and those are used in the study. The survey data is summarized and analyzed using the classic theories. A set of questions in the survey was on the perceptions and preferences on the lakes. The survey results are collated with the earlier social activities carried out in the neighborhood. The main body of questions started with a general question on when they started living in Thaltej followed by questions on perceptions and preferences. The paper presents the findings of the survey besides the overall experience of engaging with the local community and the university youth in the various matters of the lakes.

4. Findings from the study

When asked about why they shifted to this place, 60% respondents had no specific reason to relocate besides the housing availability & affordability; 15% shifted as they find it convenient and shorter to commute to their workplaces; 7% find the place has better infrastructure and environment (from new development area); 8% shifted because of acquaintance with other people; and 10% found better schemes of housing in this place. This shows how in urban areas, people are indifferent to choose, place to live which directly affects the sense of association & belongingness to the place and thus, affecting the motivation to participate in making the place better. *When asked about* the knowhow of the Thaltej Lake/s, 77% knew about them while surprisingly the remaining 23% of them had no idea about their presence. Those who are unaware of the ponds are mostly migrants and have no visual-physical connection with the ponds in their everyday life. Those who know about the ponds, 43% have no idea about the number of ponds, 37% know the number as 3 ponds, 18% know as 2 ponds, and 2% are familiar with one main pond, i.e., the Thaltej Lake. This is because the ponds are currently invisible amidst the slums and the main pond now hidden behind the high compound wall on three sides except the west side that is squatted by slums. This becomes a beginning of disconnect with the lakes. Ironically, the area does not have parks and gardens in the vicinity due to high density development prior to the urban planning of the areas, yet the presence and importance of the ponds are unrealized by the community.

We continued the survey with the remaining respondents who had no idea of the presence of the Thaltej Lakes because the remaining survey questions focused on the general presence of waterbodies in the city and their perception and preference of their presence, besides their willingness to accept bad condition and willingness to pay/participate for good condition of waterbodies.

When asked about whether the condition of the lake influence the property price, 57% thought that the condition of the waterbody and property prices are directly proportional, whereas 42% found that lake condition have no relation with the property prices, and only 1% had no idea about the property prices in the area and even of the possible relationship. The response of no relation is linked to mostly those who had no idea of the presence of the ponds augmented with their inability to comprehend the relationship of waterbodies and real estate price. *When asked about* whether improving the condition of the lake conditions will change the property price here, 86% believed that improving the lakes will increase the property prices, whereas 13% thought that property prices are independent of lake conditions. This majority perception proves that a lake in good condition will be a win-win situation for them as they benefit with the property price increase and get a good public place.

When asked about the how you and your family may/can benefit from development of the lakes, those living nearer to the lakes expressed that after the development they would be in a better and hygienic environment with access to better facilities and amenities at walkable distance. This will not only change their lifestyle but also provide them and their children with a healthy environment. Cleaning the lakes would also reduce the mosquitoes and the water borne diseases. They also anticipate that the development of lakes will attract more government and private housing schemes and provide them better housing options which will further boost the property prices in the area. Anticipating increase in the greenery after the development, they also perceive reduced water and air pollution that is currently faced. People have also experienced social nuisance from people consuming alcohol by the lake in the night and they hope that after the development of the lakes, this may stop and result into a safe neighborhood. Some also anticipate that the development of lakes may generate local employment opportunities, improve parking facilities, besides having parks, public toilets, and other amenities at walking distance. Few were pessimistic about the "business as usual" development approach which will bring no changes to the area. *When asked about* how the lakes should be developed, nearly everyone suggested the lake area to be neat and clean for public gatherings as a park with sitting and play areas. Some respondents suggested that the lakes be developed in productive way quoting the example of Kankaria[5] Lake. Few also suggested stopping of wastewater discharge into the lake besides need for the process to be participatory through awareness campaign on solid waste, health and hygiene.

When asked about how the local government should ensure the development and maintenance of the lakes, most suggested that the local government must bring in more investment in the area for providing proper infrastructure not only in the lake development but also to surrounding area and for regular maintenance after the lake development. Some suggested that the local government must introduce penalties on the people who throw waste or pollute the lake (polluters must pay). Some also suggested that the local government must have a regular check on the unhygienic conditions leading to rise in mosquitoes and thus health issues particularly the water logging during every monsoon. Respondents from the slum area hinted that if the government provide them with clean water, then in return they are willing to work for them in maintaining the lake and the surrounding area. *When asked about* imagining a situation when the government approaches for community participation for the lake development and maintenance how they like to support the initiative, 67% were optimistic and agreed to cooperate including physical efforts. Interestingly, more women showed interest in participation.

When asked about the other lakes in the city, nearly half of the respondents had no knowledge about the lakes in the city, whereas the remaining half had knowledge about other lakes in the city. This shows the need to increase awareness about the lakes in the city, since if people do not know

[5] Kankaria Lake, located in the eastern part of Ahmedabad, is a traditional rainwater harvesting structure built during the formation of old city of Ahmedabad for the drinking water purpose of the walled city residents. It is redeveloped as a lakefront for recreation and is among the top tourist/recreational space in the city. It is considered as a model lake development.

about the lakes in the city, how will they understand their importance and the need to conserve & manage them? Those who knew were aware of the ones that have gone recent overhaul as lake development like the Kankaria Lake, Vastrapur, Chandola, Vejalpur, Pancheda, Lakhodi Talav and Bopal Lake. This shows that people are unaware of the other historical village ponds located in the hundreds of engulfed villages in the urban development process. The lack of information to the citizens is a serious governance issue that needs addressing should we wish to conserve and manage the lakes better in the future. *When asked about* the opinion on the other lakes in the city to those who knew, the majority opinionated about the bad conditions of the lakes in the city besides the few that are newly developed. People find lakes as hangout place to socialize, public gathering and play area for children. This shows that the ponds are perceived merely as means of recreation as ascribed by its aesthetics (beautiful is referred to clean and green) rather than using ponds for water related functions like domestic use.

When asked about the advantages about residing close to a lake when developed, some criteria were provided in the question for selection like, good quality of life/environment, good view, better facilities, traffic & parking resolved, cleanliness, property price increase. Other 30% of the respondents perceive good quality of life as there will be a better outdoor environment after lake development; 23% find cleanliness as the biggest advantage after the lake development. These indirectly hint that the exiting neighborhood is unclean. 20% perceive provision of better facilities as an advantage after the lake development; 11% think that after development they will have a better view; and 6-9% think that the property prices will boost, and traffic issues will be resolved after the lake development.

When asked about the disadvantages of residing close to a lake not in good condition, some criteria were again provided in the question for selection like, congestion, informality, parking, garbage, no greenery, poor administration, property price. The majority of respondents (46%) expressed issues related to garbage with raising questions on the functioning of the Swachh Bharat Abhiyan[6] and its exclusion in cleaning the lakes. It further hints the need for cleanliness. 18% expressed issues of congestion and lack

[6] It is a national level Clean India Campaign.

of greenery; 5-6% expressed issues with the informal settlements as a reason for an unclean neighborhood. Few expressed concerns of poor administration pertaining to the above and the property prices affected. *When asked about* willingness to contribute towards the improvement/development of lakes, more than half the respondents (53%) expressed willingness to contribute they realized that improvements in the condition of the lake will directly improve their living and environmental conditions; whereas 40% do not want to contribute and 7% responded as they don't know or aren't sure. This represents people are willing to contribute for the improvement but as they are trapped in a social dilemma of who will start and how to start, they are waiting for an initiative from the government or private sector to take up the lake development where they may support instead of taking up the lake cleaning initiatives by themselves. There is an implicit assumption among the people that the natural resources like the lakes are the government property and therefore they are blamed for not cleaning or not taking responsibility. This shows that the idea of governance is limited to the governance by the government.

When asked about how they intend to contribute, the majority of the respondents (43%) showed interest in one-time contribution, 21% didn't know how to contribute or through which means, 13-15% mentioned about contributing through some kind of yearly service charge/tax; and 8% mentioned of one-time service charge as convenient. This shows that people are willing to contribute, however, their perception of contributing is limited to short time like some annual fee or onetime fee. They were unable to comprehend a regular contribution from their side. This also reflects that it is likely that some respondents were just saying to get over with the survey or with the trouble of engagement in the governance process since we have too many kinds of taxes and we pay tax on almost everything which makes it difficult for common citizens to comprehend. *When asked about* how they value good environment, most respondents (88%) expressed importance of good environment, whereas only 4% responded as do not know, and 8% responded as good environment doesn't matter. The latter two responses are from those living in the informal settlements near the lake edge. Majority response shows that the people are conscious about the importance of good environment linking it to the quality of life. Therefore, people are willing to contribute to a healthy environment, however, they do not know how they can contribute to making better built environment and some even are skeptical of getting their hands dirty, a metaphor used for declining to engage.

When asked about the idea of good environment, majority respondents (54%) defined it as cleanliness hinting the unhygienic conditions in the area. For 12%, it is less congestion, for 9-10% it is place with more greenery & waterbodies, for 6-7% it is an organized place and for 2% a recreational space. *When asked about* if called for participation in the lake development process, how will they participate, among the criteria provided for selection like, work, monetary, time and none/busy, 52% showed interest to do physical work, 25% were not willing to participate in any way as they are busy or uninterested, 11-12% may participate through giving time, and 11-12% agreed to provide funds.

5. Discussion

Though there is still abundance of lakes and ponds (Mishra, 1993) many of which are now part of the urban areas, there has been a systematic deterioration of urban lakes in India. The case of Thaltej Lakes is just one example of systematic degradation among the many still existing lakes and ponds in the country. To avert this situation, understanding the local community becomes crucial because the value (Pearce and Moran, 1994) ascribed by them is catered by the government (sometimes private) through certain governance processes (Sanjaliwala and Bhargava, 2021). This social engineering exercise helped understanding the typical social dilemmas that exist in the society which hinders the lake (any common/ natural resource) governance. Sustainability of urban lakes is the overarching concern and a path to address that goes through governance of lakes in integrated manner. The social dilemma pattern in the perception, preference and participation of the urban community in the shared resource, like urban lakes, management is typically concerning in the Indian cities. The above three theories are just a representation of the state of urban community which are holding the key to poor governance in the society. These social dilemmas put the community in a social trap (a situation of playing helplessness) where people continue to fulfil their immediate demands & desires and, in the process, exploit the resources more, which in longer run is the reason for diminishing and deteriorating resources, the urban lakes is just one among the many shared resources that can be looked at to understand the poor state of any resource (Bhargava and Ast, 2020). Importantly, we realize that we need to find how we can avert the social dilemma situation to make the urban community take the responsibility of the urban lakes and thereby shift the lake management by the government towards a collective lake governance. What is of special concern is their perception of having lakes is very anthropocentric and limited to recreation and real estate benefits. Should we wish to conserve them and sustain them for future water needs, the urban community need to first accept the presence of the lakes as a vital water ecosystem for other flora & fauna to survive in the cities. Because if the dilemma continues only for the incentives, it will lead to the worst possible outcome for themselves and for the social-ecological sustainability (Daly and Farley, 2004), which is being noticed in the new lake developments (Bhargava, 2021).

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Chapter 6. The Practice of Managing Water Resources

The last chapter explores how managers and stakeholders are applying Integrated Lake Basin Management (ILBM); citizen activities and environmental education; lake history and culture; lake basin heartware; sustainable use of freshwater resources; countermeasures and technologies for the sustainable use of ecosystem services; biodiversity and biological resources; monitoring based on scientific knowledge; institutional management systems and policies; or any other topic that helps achieve governance and sustainability of lakes and their watersheds.

Active faulting and lake formation in the Himalaya-Tibet orogenic belt

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Abstract

The tectonic convergence between the lithospheric plates of India and Eurasia has created several basins and lakes throughout the dimensions of the orogen. Previous studies on these lakes have mainly focused on issues like management, restoration, biodiversity, sedimentation, etc. However, the relationship between the active tectonic convergence and the origin of lakes and basins has not been fully explored in the past. Therefore, our contribution shows the critical importance of knowing the tectonic causes of how lakes and basins have formed during the tectonic convergence and why it is crucial to study it. We have used the 30m shutter radar topography to make the various geomorphic features such as topographic ridges, basins, water bodies, faults, folds, etc. The geological and structural maps are used and correlated with our geomorphic maps to map the relative ages of lakes and basins and determine the cause of their formation. The results show that lakes and basins have formed in various ways that involve faults, folds, and non-tectonically causes, e.g., glacial melting. Therefore, we have classified the basins and lakes based on their genesis, which could help us

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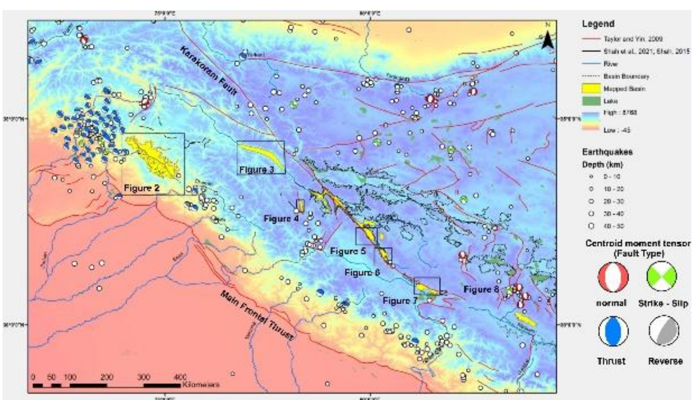
understand the formation of lakes and the role of active tectonics in shaping their growth, development, and depositional setting.

Keywords: *Himalaya, active tectonics, faults, folds*

1. Introduction

Basins usually form during tectonic interaction between two or more plates, and the vast scale of oceanic basins in the world is a clear manifestation of this process over the geological past. Although plate divergence is one of the primary reasons for the formation of basins on the Earth, several lakes and basins also form during the typical life cycle of a convergent tectonic belt [1-3]. This process, however, has not caught the attention of researchers who study lakes because most of the previous studies on lakes have mainly focused on issues like management, restoration, biodiversity, sedimentation, etc. Previous studies suggest that some of the geologically significant examples of lakes had tectonic related drainage impoundment as the leading cause of lake formation [4], which has altered the sedimentation pattern through time and space in some of the studied lake basins [5,6]. However, the details on the role of active tectonic faults in the formation of lakes and basins are still incomplete [4]

Figure 1. *30m shutter radar topographic image is at the background onto which the faults, earthquake CMT mechanism (shown as beach balls), rivers, and lakes are shown. The rectangular windows are regions that are studied in detail. More details and citations are provided in the text.*



Therefore, this work highlights the formation of lakes and basins in the Himalayas, particularly the northwestern portions, and relates it to the active tectonic convergence between the lithospheric plates of India and Eurasia (Figure 1). It shows the importance of tectonic control on the formation of lakes and basins; the motivation is to fully explore the various scientific reasons for their formation, evolution, and growth during a typical orogenic cycle. Our work shows that mapping and understanding the various factors that form lakes is fundamental. We demonstrate that tectonics is the backbone of such processes in the Himalaya-Tibet orogenic belt.

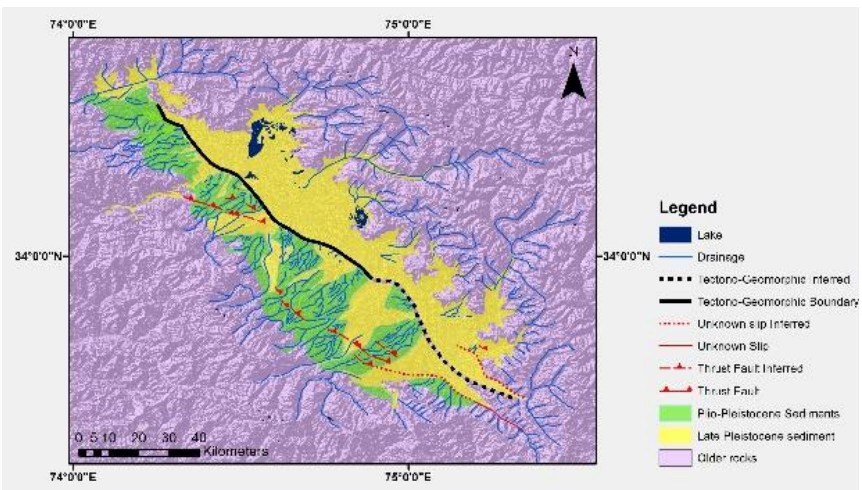
2. Methodology

Geomorphological mapping of lakes and basins was done on the 30m shutter radar imagery, which is obtained from: https://earthdata.nasa.gov/. The mapping of geomorphic features such as ridges and drainage networks was carried out in the Global Mapper 17, where we used the "find ridge line" and "watershed" tools for the same. Subsequently, the extracted ridge lines were combined with hillshade images and river networks in ArcGIS 10.3. The triangular facets were also mapped to delineate the active faults, which were combined with the previously mapped active faults such as [7-14]. The active faults were then processed in the ArcGIS tool to understand the link between the basins and lakes clearly. Seismological information such as earthquake type, depth, strike, dip, and rake are obtained from the United States Geological Survey (USGS) online portal, which is available at https://earthquake.usgs.gov/earthquakes/map/. The earthquake centroid moment tensor (CMT) mechanisms are processed in ArcGIS and plotted on the hillshade imagery to differentiate the three basic types of faults: thrust, normal, and strike-slip. Finally, the earthquake CMT mechanisms, drainage network, and lakes were plotted on the shutter radar imagery to interpret and correlate the tectonic faults with lakes. The CMT data are obtained from the GeoMap App, an open-source tool that covers earthquake events from January 1976 to January 2020. The drainage and lakes were also obtained from the same source. The 3D orientation of raster images was performed in ArcScene.

3. Results and interpretations

Several basins and lakes are shown (Figure 1) to highlight their possible origins during India and Eurasia's tectonic convergence. We have divided the study area into several windows to demonstrate the tectonic reasons that have caused the formation of the highlighted lakes, basins, and other associated geomorphic features. We started with the relatively well studied Kashmir basin, a piggyback basin that was a vast lake in the geological past as suggested by the geochemistry of lake sediments. The lake has dried up, but a few remnants of it are still preserved in the tectonically drowned region of the Kashmir basin [14], which includes the famous Dul Lake in Srinagar and the Wular Lake in Sopore (Figure 2).

Figure 2. *30m shutter radar topographic image is at the background. The active faults, fluvial drainage network, Tectono-Geomorphic Boundary, lakes, and the geological map, are overlayed on the image. More details and citations are provided in the text. The location is shown in Fig. 1.*



This basin sits on the major Himalayan thrust faults and follows their strike, which further reinforces the interpretation that it was formed during the thrusting associated with the ongoing tectonic collision of India and Eurasia. North of the Kashmir basin, a few small lakes are mostly related to glacial melting and are mostly too small to be observed on the 30m satellite images. Similarly, the Leh basin (Figure 3) is also filled with a variety of sediments that broadly indicate lake origin during the tectonic convergence.

This basin fits a pull-apart setting associated with an oblique fault named as Dras fault zone, and it is oriented parallel to the strike of the fault. We have also observed several basins and lakes located between the Kashmir and the Leh basins mostly related to faulting, with some prominent examples related to north-south trending normal faults (Figure 4). The basin was formed by ~E-W rifting and was filled with water to form the lake, which is still observable with orientation parallel to the fault zone. The fault marks the western termination of the basin and the hanging wall region is occupied by the lake, which is suggestive of tectonic origin.

Further east, we show many basins located at the Karakoram fault zone (Figure 5), which is a dextral strike-slip fault. The tectonic geomorphological investigations suggest that the fault is dipping east, and has a component of normal dip-slip, which is reflected from the geomorphology where a prominent downthrown displacement of the hanging wall region

Figure 3. *30m shutter radar topographic image is at the background. The active faults, fluvial drainage network, and tectonic geomorphological mapping is superimposed on the image. More details and citations are provided in the text. The location is shown in Fig. 1.*

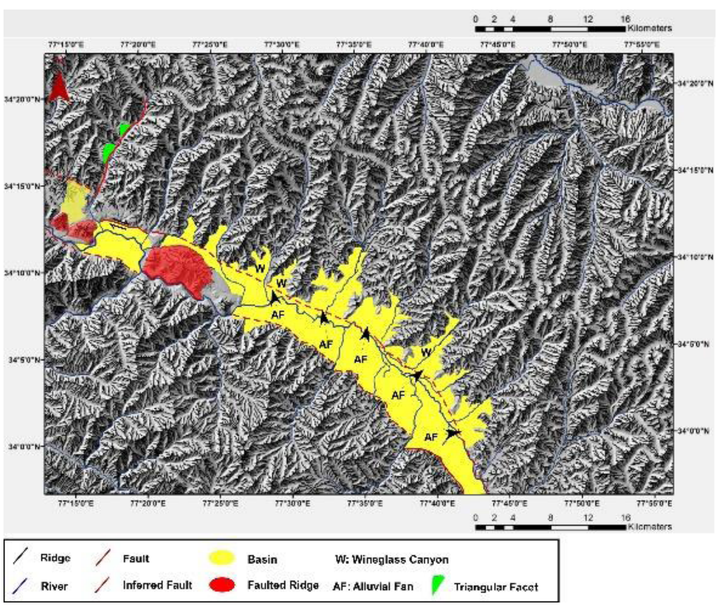
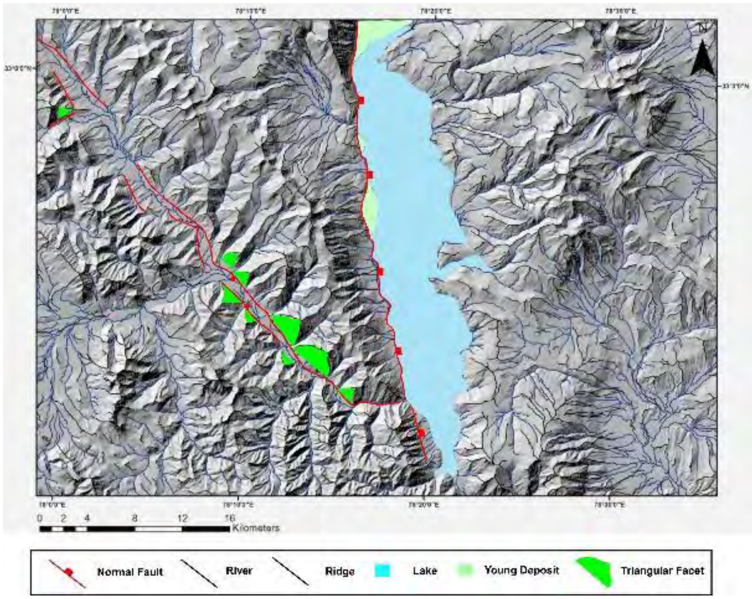


Figure 4. *30m shutter radar topographic image is at the background. The active faults, fluvial drainage network, lake, and the tectonic geomorphological mapping are overlayed on the image. More details and citations are provided in the text. The location is shown in Fig. 1.*



is observable in the east of the fault zone. The basins fit a pull-apart tectonic interpretation, which has created diamond shapes and ~fault parallel ellipsoidal basins and lakes along the fault's strike.

This structural configuration fits a pull-apart structural setting where the expected orientations of normal and strike-slip faults are shown in Figures 5 and 6.

The basin and lake development is consistent with the ~NW-SE strike of the fault zone. Once the fault's strike changes to ~E-W, the basins and lakes also change their orientation, which again reflects the tectonic origin during the development of the fault zones. It is because now the direction of the normal faults is dominant ~E-W, where the basins and lakes have formed (Figure 6).

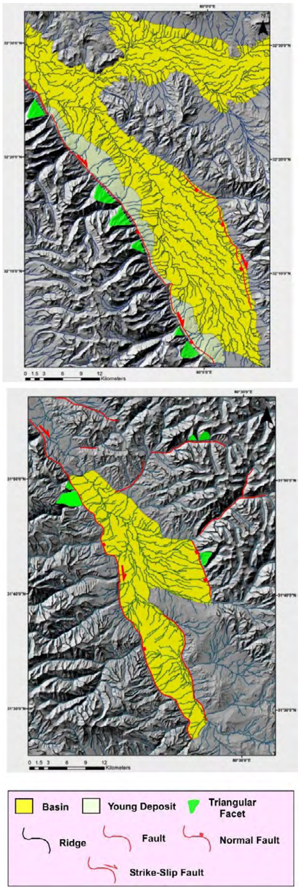


Figure 5. *30m shutter radar topographic image is at the background. The active faults, fluvial drainage network, basins, and the tectonic geomorphological mapping are overlayed on the image. The basins are mostly pull-apart type and are located parallel to the strike of the Karakorum fault zone. More details and citations are provided in the text. The location is shown in Fig. 1.*

4. Discussion and conclusion

The results presented above suggest that ongoing active tectonic convergence between the lithospheric plates of India and Eurasia has created a network of basins and lakes, which roughly follow the strike of the active fault zones.

It confirms that active tectonics is controlling the formation, development and growth of basins and lakes, and such a relationship has not been studied in the past to the best of our knowledge [15-17]. The correlation between tectonics and the formation of lakes and basins fits the northwards indentation and underthrusting of India below Tibet. It also explains the abrupt termination of basins/lakes, their geometries, and their dimensions,

Figure 6. *The 30m shutter radar topography shows the southeastern portion of the Karakorum fault (KF) zone where a basin is located parallel to the strike of the fault, and we have interpreted it as a pull-apart basin where the normal faults are parallel to the fault zone. Several NE-SW trending faults are also shown, which are orthogonal to the trend of the KF.*

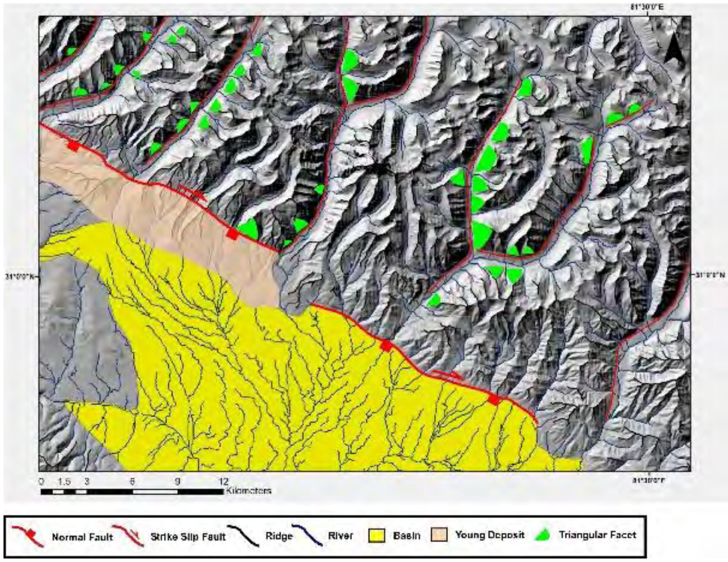


Figure 7. *30m shutter radar topographic image is on the background. The active faults, fluvial drainage network, lake, and the earthquake CMT mechanisms (shown as beachballs) are overlayed on the image. The tectonic domains are mapped and corelated with the location of basins and lakes. More details and citations are provided in the text.*

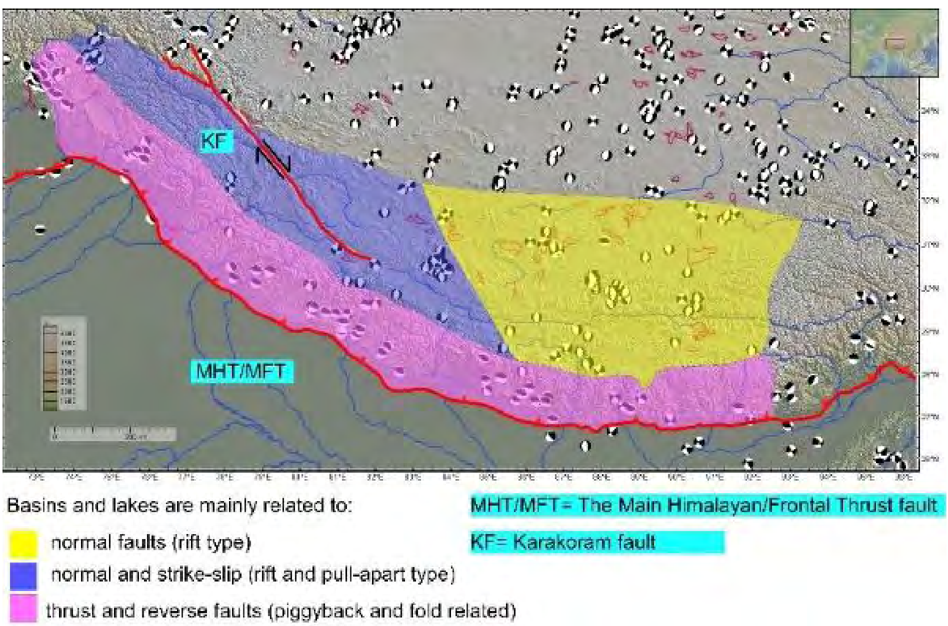
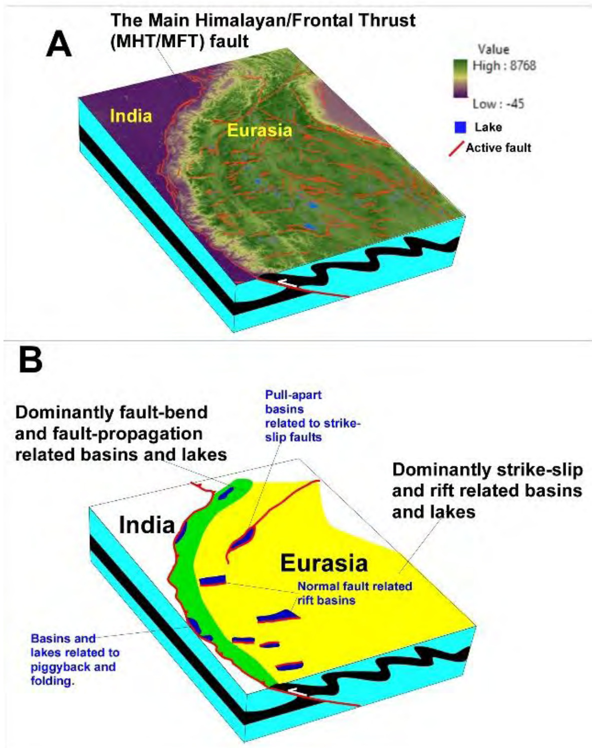


Figure 8. *30m shutter radar topographic image is on the background (A). The active faults, fluvial drainage network, lakes are overlayed on the image. The subsurface structures are shown and corelated with the tectonic convergence between India and Eurasia. The subsurface extension of structure is not scaled and is used as a simple sketch map. The illustration shown below (B) suggests the major type of basins and lakes and their association with the tectonic convergence. More details are provided in the text.*



which have always remained unanswered questions in the past [17,18]. The structural configuration, orientation, and position of lakes and basins is striking and fits the regional convergence between the two plates in a collision. The plate convergence is oblique in the western portions of the orogen, which is also suggested by the structural setting, where the diamond-shaped basins and lakes have formed parallel to the regional strike-slip faults in the hinterland regions. Thus, the regions where the tectonic convergence is oblique show a variety of piggyback and pull-apart basins with limited normal fault related basins. And regions where the tectonic convergence is more normal the basins and lakes are dominated by piggyback basins in the frontal portions and rift basins in the interior portions of the orogen (Figure 8).

Therefore, our mapping suggests that the frontal portions of the orogen are dominated by fold and thrust belt related basins, which are mainly represented by piggyback and synclinal basins (Figure 8). The interior portion of the basins is dominated by normal and strike-slip fault-related basins and lakes. The thrust and reverse faults have created several piggyback basins in the frontal part of the orogen, while the interior portions are dominated by pull-apart and rift basins associated with strike-slip and normal faults. It is also reflected in the earthquake centroid moment tensor mechanisms where active deformation domains are mapped [19] and fit the structural setting of the basins and lakes that we mapped here. Therefore, our work shows that active tectonic deformation is mainly compensated by the formation of piggyback basins in the frontal portions of the India-Eurasia collisional orogen and is associated with NE dipping thrust and reverse faults. The hinterland areas are dominated by a combination of strike-slip and normal faults where the structural setting of basins and lakes fit pull-apart and rift tectonics.

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Effect of industrialization on the water around Ambarnath area, India

Gangotri Nirbhavane[1], Kshama Khobragade[2]

Abstract

Ambarnath Chikloli-Morivali industrial zone selected for study purpose. This zone comes under important MIDC area of Thane district. This area is having urban sprawl surrounded by many slum areas. Residential as well as slum area around industrial zone of Ambarnath area was selected for study purpose.

It is important to analyze the ground water to provide the baseline data for future study. Such data is very useful for the local people to avoid further problems related to their health and environment. By doing survey in various areas, sampling stations were selected. Manmade activities and environmental conditions around these areas were also taken into consideration, then 6 representative stations from the Ambarnath area were selected and analyzed for physicochemical-parameter.

Results show that some parameters are present within the acceptable limit of BIS and WHO; they are not affected by the anthropogenic activity till today. Some parameters were present above the limit given by WHO, BIS and CPCB which is an indication of a degraded quality of water due to

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manmade activities. Such contaminated sites are an area of concern. If these sources are not properly maintained in today's time, they will get more contaminated in the nearby future. There is need of a proper treatment and management of available resources.

Keywords: *Groundwater, industrial waste, anthropogenic activities*

1. Introduction

People's life and livelihoods depend on water. Demand for clean water increases continuously with world population growth. People in several areas of the world do not have fresh, potable water essential to their survival. Low-cost water supplies are needed for prosperity and security [1].

Population on earth has been increasing at an alarming rate, which demands safe drinking water. Groundwater is a major source of water all over the world. The physical and chemical properties of groundwater make it a reliable source throughout the world. Groundwater plays variety of roles in day-to-day life, which makes it an important resource for human beings.

It has been estimated that India, Nepal, Bangladesh, Pakistan and China use over 300 billion m^3 of ground water annually, mostly in agriculture. India is the largest user of ground water. Presently about 65% of the irrigation and about 90% of the domestic and industrial water requirements are met through private ground water resources. Use of ground water is becoming unsustainable day-by-day. The fall in ground water level and deterioration in quality gives rise to drinking water shortages. [2]

Industries play a very important role in the economy of our country. With rapid industrialization, pressure on available resources also increases. Man is not only using natural resources, but he is also discharging different types of solid, liquid waste material into the same resources, degrading day-by-day the quality of this vital resources.

The quality of water is a function of physical, chemical and biological parameters, and could be subjective since it depends on a particular intended use and it is influenced by natural and anthropogenic effect. [3]

There are 4 major industrial estates named as M.I.D.C. Dombivli Phase

I & II & M.I.D.C. Ambarnath, M.I.D.C. Badlapur, M.I.D.C. Saravali [4] present in Thane district of Maharashtra. Ambarnath Chikloli-Morivali industrial zone is about 2 kms. away from the Ambarnath railway station on the central railway line. Kalyan is the nearest major junction on this line. Ambarnath is 60 kms. away from Mumbai and 6 kms. away from Kalyan.

Latitudinal and Longitudinal extent of Ambarnath city is 19^0 7'30"North to19^0 14'30" North and 73^0 9'30" East to 73^0 14'30" East. It is present in Konkan belt of Maharashtra, having 3,799.78 hectare area. It is 63 feet from MSL (Mean Sea Level). Humidity is observed from 45% to 87% during the month of August. The annual rainfall received by the Ambarnath town is within 500 mm, during June to July period.

Ambarnath area is one of the fast-growing townships in Thane District of Maharashtra. Rapid industrialization has taken place in this town, since last 2-3 decades. With industrialization urbanization has also increased. Along with it, population of this town too has increased, which further led to growth of residential as well as slum areas around the industrial zone. With the growing population and industrialization, domestic solid waste, sewage from residential areas and effluent from industrial area also increased. Around industrial area many slum areas settled within the last few decades. These slum areas are having lack of sanitation facilities, inadequate solid waste management facilities, and poor drainage system problems. Such problems may cause contamination of the surrounding area. Therefore, an attempt has been made to find out the groundwater quality around Ambarnath industrial zone to check the effect of industrialization and urbanization on surrounding area.

It is important to analyze the ground water to provide the baseline data for future study. Such data is very useful for the local people to avoid further problems related to their health and environment. By doing survey in various areas, sampling stations were selected. Manmade activities and environmental conditions around these areas were also taken into consideration, then 6 representative stations from the Ambarnath area were selected and analyzed for physicochemical-parameter.

2. Methodology

6 sampling sites were selected for study purpose from Ambarnath area & analyzed for physico-chemical parameter for 1 year.

A detail study was carried out during January 2013 to January 2014. Water samples were collected from 6 stations in the first week of every month, consecutively for 1 year. The samples were analyzed for the various physico-chemical parameters. Obtained results were compared with the WHO and BIS standards. Seasonal variation is shown in tabular form. The collected samples were analyzed in laboratory for different physical and chemical parameters as per the standard methods of American Public Health Association (APHA), 1985 and the methods given by Trivedi and Goel, 1986. [5] [6]

Table 1. *Sampling stations with spot number.*

Sr. No.	Sampling stations	Spot No.
1	Kansai Gaon Open Well (Ganesh chowk)	S-1
2	Kansai Hand Pump	S-2
3	Bhimnagar Area, Open Well	S-3
4	Vadavali Bore Well	S-4
5	Bhendipada (Old) Bore Well	S-5
6	Samarth Service Centre Bore Well	S-6

3. Results

Table no. 2.1 to table No. 2.8-Obtained results

Temperature. During the study period, it was found that the temperature of groundwater was higher in summer and lesser during winter season. Moderate temperature was found during monsoon seasons. Temperature of groundwater ranges from 22.8°C to 26.7°C, as all the samples were collected during morning time up from 8 a.m. to 10 a.m. During the year 2013-14, maximum temperature was found as 26.7°C. at Station no. S1 i.e.,

Table 2.1. *Seasonal variation in Temperature in (0C) of the groundwater from the study area during 2013-14.*

S.N.	2013-14		
	Summer	Monsoon	Winter
1	26.75 ±0.83	24.25± 0.44	23±1.8
2	27 ±1.23	23.88±0.22	22.8±1.3
3	26.25 ±0.83	24±1.00	23±1.8
4	25.75 ±1.3	24.25±1.09	23.08±1.7
5	26.38 ±1.09	23.75±0.27	22.9±1.4
6	25.8 ±1.3	24.38±0.66	23.08±1.7

Table 2.2. *Seasonal variation in Electrical Conductivity in (μS/cm) of the groundwater from the study area during 2013-14.*

S.N.	2013-14		
	Summer	Monsoon	Winter
1	310.5±10.6	367.8±15.21	391±7.85
2	326.5±10.93	358.3±16.2	351.5±23.4
3	741.3±10.8	765±9.3	797.3±8.5
4	403.5±7.93	424.3±8.08	407.8±10.7
5	327±11.9	327.8±13.6	373.5±6.54
6	271.8±12.2	298.3±11.8	291.3±19.08

Table 2.3. *Seasonal variation in Turbidity in (mg/l) of the groundwater from the study area during 2013-14.*

©	2013-14		
	Summer	Monsoon	Winter
1	15±0.0	17±0.70	14.3±1.5
2	8.8±0.43	10.5±1.12	9.5±1.12
3	8.3±0.43	11.5±1.12	8.8±0.83
4	7.8±0.43	12.5±1.66	10±1.23
5	6.5±0.5	10.8±1.3	8.5±1.12
6	8.25±0.43	11.3±1.93	9.5±1.12

Table 2.4. *Seasonal variation in Total Dissolved Solids in (mg/l) of the groundwater from the study area during 2013-14.*

S.N.	2013-14		
	Summer	Monsoon	Winter
1	166.3±5.31	166.5±5.72	160±1.41
2	149.5±6.06	149.8±5.12	147±1.22
3	353.8±4.38	350.8±5.36	349.3±2.77
4	158.8±5.97	159.3±4.02	155.8±2.68
5	168±5.83	169.5±4.97	164.5±0.50
6	151.8±7.50	152±5.61	142±1.87

Table 2.5. *Seasonal variation in Total Solids in (mg/l) of the groundwater from the study area during 2013-14.*

S.N.	2013-14		
	Summer	Monsoon	Winter
1	174.25±8.95	176.8±6.98	172.5±1.80
2	163±6.52	161.8±4.97	158.3±1.30
3	363.5±5.17	362.3±5.21	362.8±4.26
4	170.25±6.72	170.5±4.72	168.3±3.49
5	181±5.61	180.5±5.32	177±1.22
6	160.5±8.08	162.5±5.59	152.5±1.12

Tableno 2.6. *Seasonal variation in Total Suspended Solids in (mg/l) of the groundwater from the study area during 2013-14.*

S.N.	2013-14		
	Summer	Monsoon	Winter
1	10±8.95	10.25±6.98	12.5±1.80
2	13.5±6.52	12±4.97	11.25±1.30
3	9.75±5.17	11.5±5.21	13.5±4.26
4	11.5±6.72	11.25±4.72	12.5±3.49
5	13±5.61	11±5.32	12.5±1.22
6	8.75±8.08	10.5±5.59	10.5±1.12

Table 2.7. *Seasonal variation in pH of the groundwater from the study area during 2013-14.*

S.N.	2013-14		
	Summer	Monsoon	Winter
1	6.98 ±0.04	7.06±0.09	7.53±0.08
2	7.82±0.16	7.73±0.17	7.9±0.06
3	7.51±0.16	7.61±0.08	7.85±0.05
4	7.65±0.095	7.9±0.05	7.91±0.06
5	7.5±0.16	7.64±0.13	7.91±0.04
6	7.36±0.02	7.44±0.04	7.48±0.03

Table 2.8. *Seasonal variation for Total Alkalinity in (mg/l) of the groundwater from the study area during 2013-14.*

S.N.	2013-14		
	Summer	Monsoon	Winter
1	233±3.32	207±3.00	220±2.83
2	167± 3.61	154.5±2.96	164.5±3.84
3	182±5.10	156.5±6.06	168.5±7.92
4	188±7.87	163±3.00	178±3.74
5	179.5±2.96	162±2.83	175.5±2.18
6	207.5±4.77	190±2.45	200±1.41

Kansai Gaon Open Well (Ganesh chowk) during summer season. There is no specific Spatial and temporal variation pattern found for temperature.

Table 3. *Water Quality Standards.*

		BIS(**IS 10500 : 2012)**		WHO
Sr.No.	Parameter	Acceptable limit	Permissible limit	
1	Electrical conductivity (µS/cm)		300	-
2	Turbidity (NTU)	1	5	5
3	TDS (mg/l)	500	2000	-
4	TS (mg/l)	-	-	-
5	TSS (mg/l)	-	-	-
6	pH	6.5-8.5	No Relaxation	6.5-8.5
7	Total Alkalinity(mg/l)	200	600	200

Electrical Conductivity. During the entire study period maximum Electrical Conductivity was found at Station No. S3 i.e., at Bhimnagar Area Open Well (797.3 µS/cm) in the winter season of 2013. The present investigation shows resemblance with the observation of Bharti et al., 2011; in study of Bore well water quality in Nagpur region [7].

The major reason for difference in electrical conductivity is anthropogenic activities prevailing in this region, and lithological composition of the area. It was observed that electrical conductivity values increases in some samples with the increasing amount of sulphate, chloride, bicarbonate and hardness as $CaCO_3$ [8].

Turbidity. It was observed that the turbidity of the groundwater sample increases during monsoon compared to summer and winter season. At some sampling stations, turbidity was slightly above the permissible limit given by BIS and WHO, i.e. 5 NTU, which may be due to the presence of suspended and colloidal matter such as clays, silt and fibrous particles present in water. It was observed that open wells water shows more turbidity compared to bore well water for all seasons. For all seasons, open well water shows value more than 10 NTU. In Open well area groundwater samples turbidity always found beyond the permissible limit given by BIS, which may be due to rainfall water and soil particles dispersed into the open well, during rainy season; and in the rest of the season, contamination of water by different particles mixed into open well, this may be the possible reason for turbidity.

Turbidity is a sign of water contamination, it causes because of source close to the drainage channel, ditches or manure grounds, cesspool. In such areas, there are chances of having pathogenic organisms to be enclosed in the turbidity causing particles, which has probability to cause health hazards. [9]

Total dissolved solids. In the study area, concentration of dissolved solids was found more in monsoon season. Site-wise variations were found more for TDS compared to seasonal variation. TDS was also found more in case of open well, compared to bore well. TDS value was found more in case of open well. This may be due to an effect of sewage or drainage line, which affects the nearby aquifer. All groundwater samples were found within the permissible limits of BIS i.e., 500 mg/l, for TDS. Maximum TDS observed at sampling station 3.i.e. Bhimnagar area, open well.

Total suspended solids. Total suspended solids concentration less than 20 mg/l was considered to be clean by most of the people, water having TSS concentration between 40-80 mg/l shows cloudy appearance, while concentration of more than 150 mg/l appears unclean. [10] Specific standards for Total Solids have not been set.

pH. lowest pH was found at Station No. 1, Kansai Gaon Open Well (6.98) during summer season of the year 2013. Bhendipada (Old) Bore Well showed highest pH during winter season. The possible reason behind this may be, due to disposal of solid waste near to hand pump area, which may lead to seepage in nearby hand pump area, which may cause the increase in pH value of hand pump area water. All groundwater samples were found between the acceptable limit of BIS and WHO i.e. 6.5 to 8.5 for pH.

In general, lower the value of pH, higher is the level of corrosion. Increase in the amount of organic carbon, total carbonate by the use of sewage leads to decrease in pH level. It is positively correlated with electrical conductance and total Alkalinity. [11]

Total alkalinity. Total alkalinity in study area varied from 154.5 mg/l (S2) to 233 mg/l (S1) for the year 2013-2014. Alkalinity in water is a sign of natural salts present in water. Minerals which dissolve in water from soil, cause alkalinity. Water alkalinity and hardness are functions of the geology of the area and the percolation of rain and surface water along with the dissolved carbon dioxide of the atmosphere. Rain water is naturally acidic, which tends to dissolve some minerals more easily [12]

4. Conclusions

No specific spatial and temporal variation pattern had been found for temperature parameter.

All groundwater samples were found within the permissible limits of BIS for total dissolved solids, alkalinity.

TDS were found more in case of open well, compared to bore well. Site wise variations were found more in case of TDS compared to seasonal variation. E.C. and TDS were found highly correlated with each other and correlation coefficient matrix also supports this interpretation. It was observed that open well water shows more turbidity compared to bore well water for all season, and they were always found beyond the permissible limit given by BIS and WHO. [13]

All open well samples indicate water pollution problem. It was found that open wells are extremely polluted by sewage water and up to certain extent they are also polluted by industrial effluent seepage.

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Harare water security: water supply issues and opportunities. The role and the politics of the Lake Chivero, Zimbabwe wetlands

C.H.D. Magadza and P. Tendaupenyu

Abstract

Harare, formerly Salisbury, was founded in 1890. It is the capitol City of Zimbabwe. It is located in a sub humid tropical ecozone, at 17.900S and 30.800E. The water supply to Harare comes from the Manyame River and its tributaries. Salisbury, now Harare, was established on a marshy area and the original water supply was from a small stream running along what is now Julies Nyerere Avenue. A series of reservoirs were constructed beginning with Cleveland dam (910 ML) in 1913 culminating in Lake Manyame (490 ML) in 1975. The main water supply reservoir of Harare City is Lake Chivero (250 ML) constructed in 1952.

Watershed surface area is 2 227 km^2. Mean precipitation ranges from 750 mm to 900 mm per year. Mean maximum and mean minimum temperatures of 10.6°C 29.9°C. Precipitation confined from November to March. Dry season river flow is supported by seepage from wetlands.

Harare City sits on the wetland headwaters of its water supply. For over eighty years the Harare water supply was secured by prohibiting development on wetlands. The city area is 98,300 ha, of which 21,750 ha (22%) are wetlands. The population of Harare is 2,123,132, and growing at 0.78%.

Records of the Manyame Rive flow into lake Chivero indicate a decreasing annual flow. On the other hand, development pressure on wetlands is resulting in loss of wetland. Although since 1939 the government has discour-

aged or outlawed developments on wetlands, wetlands loss in urban areas is occurring at significant rates, largely due to the government's reluctance to enforce the various legal instruments that exists to protect wetlands for fear of losing political support.

Apart from urban Harare there are six satellite settlements that depend on their water supply from Lake Chivero. Sediment studies on Lake Chivero show that by 2017 the reservoir has lost 20% water storage due to siltation. Thus, water supply security of Harare and satellite settlement is being compromised each year. Many suburbs now go without municipal water supply for extended, periods, forcing them to relay on underground water. Consequently, water table in the suburban Harare have decreased by up to 20 metres.

Concurrently, the Municipality's capacity for waste treatment has deteriorated, resulting in discharge of inadequately treated sewage into Lake Chivero. The fine mud sediments now store sufficient phosphorus to sustain hypereutrophic state for several years after rehabilitation of the sewage works.

Keywords: *Wetlands, water supply security, hyporrhea*

1. Introduction

Lake Chivero features

- Lake Chivero 30°46' E to 30°52' E and 17°52' S to 17°56' S
- Year established 1952
- Surface area of 26.32 km^2
- Full capacity of 250×10^6 m^3; 15.7 km long
- Current mean depth is 9 m (maximum= 27.43 m)
- Watershed area is 2,227 km^2 ranging in altitude between 1,300m and 1,500 m.
- Mean precipitation ranges from 750 mm to 900 mm per year.
- Mean maximum and mean minimum temperatures are 10.6°C and 29.9°C

- The climate is subtropical seasonal, with precipitation confined from November to March.
- Dry season flow is maintained by seepage from riparian wetlands.

2. Harare wetlands: a diminishing resource

Wetlands cover 3% of the area (11,717.4 km^2) of Zimbabwe (2021). Of the available wetlands a meagre 21% are stable while 18% are severely degraded and 61% moderately degraded (Republic of Zimbabwe, 2021)

Figure 1. *The hyporrhea: the underground water stirage. (Photo C.H.D. Magadaz)*

Harare City covers 98,300 ha., 21,750 of this area is wetlands, 22%. Every year the wetlands area diminishes due to conversion to "development". The discussion that follows evaluates the impact of "development" on the water supply safety of Harare City and its satellite urban communities.

2.1 Wetland services

2.1.1 Water provisioning

Figure 1 shows a shallow excavation on a wetland. The far ground shows a green grassland with no signs of water. It is this underground water, technically called the *hyporrhea* that seeps onto the stream banks and support the stream flow. When the capacity of the wetlands to store this water is destroyed by "development" the stream ceases to flow in the dry season.

Figure 2 shows the Nyatsime stream. This stream is a tributary of the Manyame River.

The picture was taken in March, at end of the wet season, when it should be flowing. Instead, there are isolated pools along the stream bed. The greenery shows the stream is flanked by a riparian wetland.

However, on the left side of the view the wetland has been cultivated for crop production. It has thus lost the sponginess of a wetland and so no longer stores water for the dry season to sustain stream flow.

Figure 2. *The hyporrhea; the invisible. (Photo C.H D Magadza)*

3. Standardised Manyame River run off

Standardised normal deviates of Manyame River. Note that in the 24 years between 1954 and 1978 there were 10 years of above average and 14 below average flows. In the 23 years between 1978 and 2001 there were only four years of above average and 17 years of below average.

The figure shows a piecewise regression of precipitation and river flow. The break point is 900 mm precipitation. Above this value, river flow reflects the amount of precipitation in the watershed. The model accounts for 62% of the variance in river flow when river flow as above the break point.

Below the break point the river flow response to precipitation is less predictable, with precipitation accounting for only 32% of river flow. Low rainfall seasons are accompanied by high solar radiation, increasing evaporation in the watershed. Wetlands degradation reduces the dry season stream flow contribution from wetlands. A combination of wetlands degradation and climate change is likely to reduce hydrological income of Lake Chivero.

Figure 3. *Standardised Manyame River runoff.*

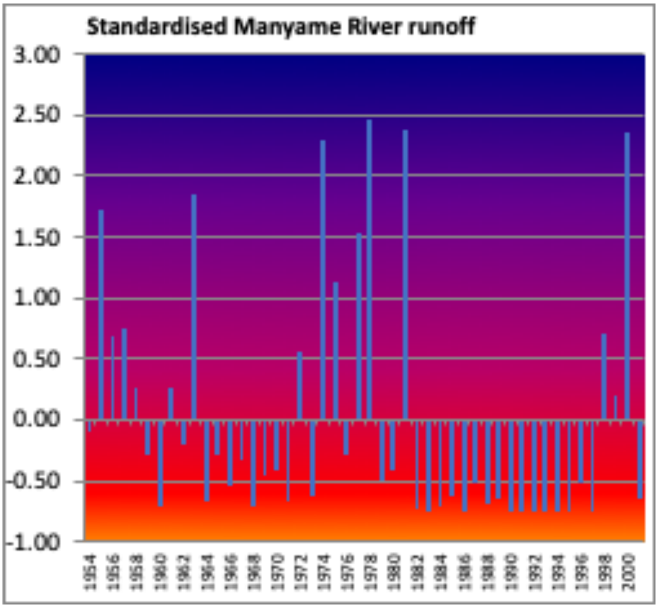


Figure 4. *Relationship between precipitation and river flow in Manyame watershed. (Magadza 2018)*

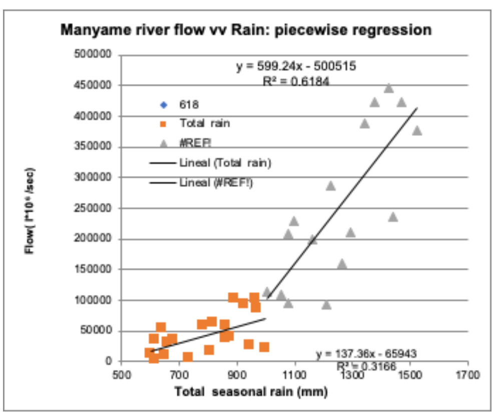


Figure 5A. *Ratio of sewage carrying inflows to the Manyame River mainstream inflows.*

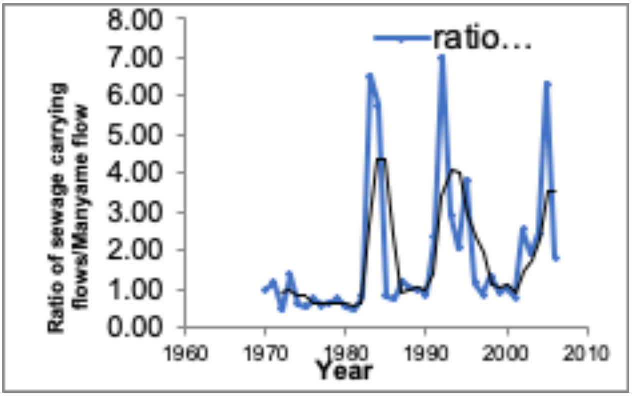
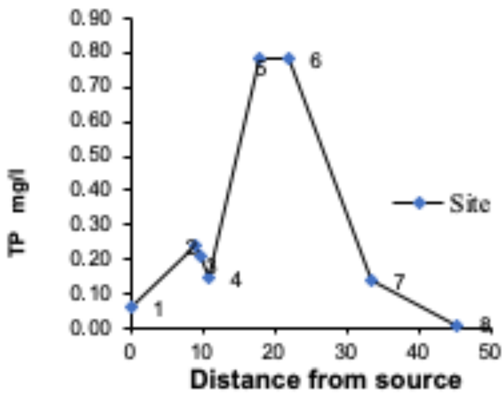


Figure 5B. *Purification of the Gwebi River from sewage pollution. (Mabhumbo 2015)*



3.1 Water purification

Figure 5A shows the variation of the ratio of Lake Chivero inflow from streams contaminated with sewage. Note that the moving average of sewage carrying inflows has increased from below 1 from 1980 to more than 1 subsequently. In drought years the sewage carrying streams inflows can peak to more than five times the Manyame River watershed run off.

Figure 5B shows the capacity of the Gwebi River wetlands to process the sewage effluent discharged into it and purify the river water by reducing the phosphorus load of the stream. In a distance of 12 km the river reduces the phosphorus load by a factor of 45. This would incur an operation cost of U$28,000.

Protection of reservoirs from siltation

The figure above shows potential silt runoff that would silt up stream and their receiving reservoirs. The left panel shows how wetland grasses intercept suspended mater and prevent siltation. The conversion of Harare wetlands into crop fields destroys the wetlands' capacity to protect streams and reservoirs from siltation.

Figure 6. *The picture shows potential source of silt from unsurfaced road and the interception of the suspended solids during rainfall by wetland vegetation.*

In the communal areas, livestock is the peoples' savings bank. Each household tries to have as many as they can. However, the grazing resources are not under the control of the communities so, there are no protocols for managing the grazing pasture. Here cattle are seen grazing on a wetland. Thirty years earlier they would not have been able to access this wetland because the wetland would have been waterlogged. However repeated hoof pressure has compacted the marshland and turned it into a dry area. which cannot support a hyporrhea. Consequently, the dry season stream flow is reduced.

Figure 6. *Change in Cotswold Hill wetland "wetland status as they are converted to housing estates development". Views from Google Earth.*

Mombe mombe everywhere

4. Threats to water supply security: Wetland's degradation.

4.1 Wetlands draining

An attempt to drain a wetland for development of a shopping mall, medical centre and residential facilities. The wetland covers an area of 500 ha. Downstream to the wetland are residential properties that would be flooded during a heavy rain season. The Environmental Management Act prohibits such "development".

5. Consequences of wetlands destruction: Siltation

5.1 Reservoir siltation

The picture above shows cattle grazing a dam in a communal land. Chief Nyamabishi dam was constructed in 1958. By 1978 it was heavily silted. Now it is completely full.

Figure 5. *Wetland destruction for development. (Photo C.H.D. Magadza)*

Development Constructions

Figure 7. *Google pictures above show changes in wetland status as they are converted to housing estates.*

2010

2021

Figure 8. *Picture shows cattle grazing on a completely silted dam. (Poto C.H.D Magadza)*

Cattle grazing on Nyamabishi, Chihota, built 1958: by 1976 it had almost silted up and is now completely silted. (Photo C.H.D. Magadza 2017)

At a larger scale Figures 9 y 10 show the results of wetlands degradation in the Lake Chivero watershed. Figure 9 shows the depth of sediments in the lakes.

The map shows the distribution of sediments in Lake Chivero according to depth of sediments.

Note that in many places the sediments are as much as 11m deep!

The sediment distribution follows the original river channel. Areas of up to 11m sediment depth occur over the greater length of the lake.

From 1986 to 2014 the cumulative percentage growth of sediment depth was 257.7%.

The land use changes were correlated with both human population growth and sediments accumulation in the lake (ρ =0.07, p = 0.03). Tendaupenyu et al., 2017.

By 2017 Lake Chivero had lost 20% of its water storage capacity, i.e., 49,126,170.34 m^3 (18%) in 65 years, most of it in the last 30 years.

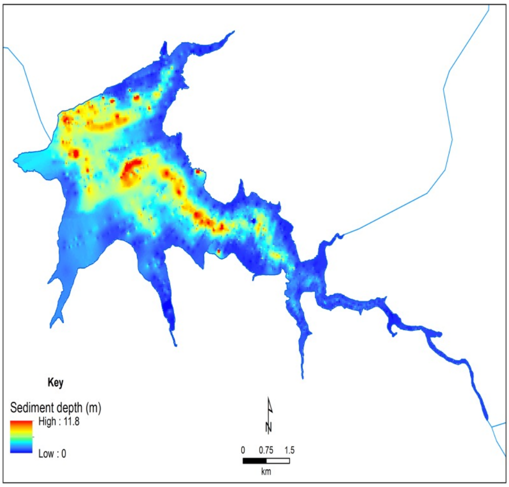


Figure 9. *Sediment depth in Lake Chivero.*

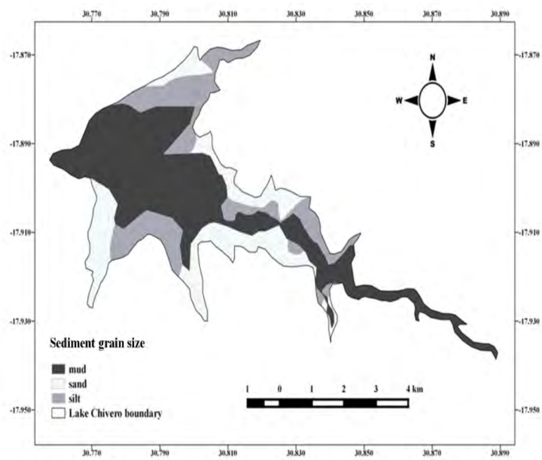


Figure 10. *Sediment texture (grain size) distribution in Lake Chivero.*

From 1986 to 2014 the cumulative percentage growth of sediment depth was 257.7%. The land use changes were correlated with both human population growth and sediments accumulation in the lake (ρ =0.07, p = 0.03). Tendaupenyu et al., 2017.

Figure 10 shows the sediments grain size distribution. Rivers transport suspended solids of different types, and grain sizes. When flow diminishes, the heavy particles are deposited first and earlier. The very fine sediments settle last and take longer to settle the fine particle complex with dissolved substances, such a phosphorus, heavy metals and organic substances.

The map shows the distribution of sediment sizes in Lake Chivero. The black area shows the distribution of fine particles that complex with water dissolved chemicals, such as phosphorus. The map thus indicates extent of nutrients storage in the sediments. Under suitable conditions these can be released into the water column and sustain eutrophic conditions.

- By 2017 Lake Chivero had lost 20% of its water storage capacity, i.e., 49,126,170.34 m^3 (18%) in 65 years, most of it in the last 30 years.
- Mean sediment depth is 4m with a maximum of 11m.
- 1953 bathymetry map indicated maximum and mean water depths of 32.2 m and 11.27 m respectively.
- In 2014 the estimates for maximum and mean depths were 24.5 m and of 8.3m respectively.
- This situation makes any measure to restore and repair the damage to the lake very expensive.

6. Policy conflicts

6.1 Environmental Management Act. Chapter20 :27

The following are the provisions of the Environmental Management Act (Government of Zimbabwe):

- "Wetland" means any area of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, and includes riparian land adjacent to the wetland.
- No person shall, except in accordance with the express written authorisation of the Agency, given in consultation with the Board and the Minister responsible for water resources
  - (a) reclaim or drain any wetland;

- (b) disturb any wetland by drilling or tunnelling in a manner that has or is likely to have an adverse impact on any wetland or adversely affect any animal or plant life therein;
- (c) introduce any exotic animal or plant species into the wetland.

- Any person who contravenes subsection (2) shall incur a fine not exceeding level eight or imprisonment not exceeding two years or to both such fine and such imprisonment.
- **If any other law is in conflict or inconsistent with this Act, this Act shall prevail.**
- However, the Act is supreme it gives discretionary powers to the Minister in the case of objections to the proposed development.
- Any developer who wishes to develop on wetlands must produce an environmental impact assessment (EIA) which is prepare by developer's contractor. The developer normally expects a favourable report, else he finds another environmental expert. The Environmental agency levies a percentage of the total development cost to the developer.
- If the Environmental Agency approves of the EIA, then development can proceed, even though project would be in a wetland.

7. Conclusion

Jared Diamond coined the word "Ecocide" to describe a process of ecological damage that ultimately leads to a community process that becomes an essential component of the natural ecological infrastructure on which social development is anchored. Harare is built on the headwaters of its water supply. This consist of a network of wetlands that feed the streams. In this discussion we have sown how wetlands in Harare, and indeed in the country as a whole, are being degraded by agriculture, construction development and poor livestock management in the watershed as a whole.

The results of this ecological degradation are siltation of water storage facilities, and in the city's main supply reservoir a storage capacity loss of significant economic importance. Many Harare suburbs now do not have reliable municipal water supply, relying on boreholes. We also show that over and above this ecocide is the over arching climate change impacts that have reduced precipitation in the area.

An important observation is that the country has a strong environmental management law, but its applicatin leaves the Harare wetland vulnerable.

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In search of sustainable management of the Valle de Bravo dam, Mexico

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Abstract

The effect of overlapping tourism uses and water supply in the Valle de Bravo reservoir (VBR) is analyzed with a multidisciplinary approach, and it is examined whether local economic growth can be based on sustainable tourism (ST), which locals promote with the water authority. To do this, the effects of management measures on the natural history of the reservoir and its basin were analyzed, and the results were compared with the Sustainable Development Objectives (SDOs) and their Goals. Nine SDOs and 25 Goals were underestimated, which mainly affects the environment and intergenerational equity. In this case, reality compromises the possibility of achieving sustainability in the short term due to the eutrophication of the reservoir. Eight measures are proposed to achieve sustainability, highlighting the modification of Goal 1 of SDO 8, since here is shown that a growth of more than 7% of GDP may not be possible without threatening the natural resources of developing countries.

Keywords: *Reservoir management, water supply, tourism, eutrophication, sustainable development goals*

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1. Introduction

The 2030 Agenda seeks to conserve resources for future generations, but it is necessary to focus and align the SDOs with the surrounding reality so that they acquire potential as influential and transformative norms (Hajer et al., 2015). The Bruntland Report warned more than 30 years ago about the deterioration of receiving bodies and coastal areas caused by drainage, but eutrophication keeps deteriorating fisheries, the supply of drinking water, navigation and the landscape without respecting deadlines or volumes, and demands control and restoration measures with economic and environmental costs (Holden et al., 2014; ONU, 2021). Poor planning or organization of tourism degrades, reduces and destroys the resources that sustain its own economy, requiring a systemic approach to understand the complexity of the tourism/environment system and its interrelationships, in order to align the SDOs to conserve the entire ecosystem and meet with human rights (Hashemkhani et al., 2015). To achieve this, it is useful to group the SDOs into categories and dimensions, as shown in Table 1. For example, basic human needs, a 1st dimension (SDOs 1 to 8), must always be above the preservation of intrinsic value of nature, a 2nd dimension (SDOs 13, 14, 15). While in tourism, the safeguarding of long-term ecological sustainability, a 1st dimension (SDOs 6 and 12 to 15), must be above the aspirations to satisfy a better life, a 2nd dimension (SDOs 8 to 10) (Holden et al., 2014).

Table 1. *Dimensions and objectives of Sustainable Development and Tourism and its Categorization (C) (Holden et al., 2014)**

Topic/author/year	Dimensions	SDO	C
SD Bruntland et al., 1987*	Satisfy basic human needs	1, 2, 3, 4, 5, 6, 7, 8	1[a]
	Ensuring long-term ecological sustainablity	6, 12, 13, 14, 15	
	Promote intragenerational equity	9, 10, 11, 12, 16	
	Promote intergenerational equity	9, 10, 11, 12, 16, 17	
STS Hoyer 2000*	Preserve intrinsic value of nature	13, 14, 15	2[a]
	Satisfy aspirations for a better life	8, 9, 10	
	Promote environmental protection	9, 11, 12	
	Promote citizen participation	4, 5, 10, 16	

Thus, economic growth is a potential means of facilitating the fulfillment of the four 1st dimensions and not a 1st dimension in its own right, contrary to the "triple bottom line" model, which equates environmental, social, and economic components. The eutrophication of the VB reservoir caused a crisis in 2012. In several communiqués from Conagua and a local NGO (CNA 2012; Teorema Ambiental 2012), it is read that tourism faced the closure of navigation due to the excess of cyanobacteria that produce neurotoxic substances in the water, and service providers asked the authority to implement Sustainable Tourism and clean up the reservoir. In Banderas et al. (2019), there is a comprehensive evaluation with technical proposals to restore the reservoir, correcting a partial diagnosis that highlighted the symptoms and underestimated the causes of the problem.

2. Materials and methodology

In the present work, our evaluation is related to the objectives and goals of the SD and the ST, with the objectives, first, of developing a sustainable scheme to support public policies considering the demands of the local population, and second, to extrapolate said scheme at the national level in response to the presidential call to promote the ST as a source of income (PND 2019).

3. Study area

The study area is the Valle de Bravo dam and its drainage basin. The dam experienced a substantial reduction in extractions when passing from the Miguel Alemán Hydroelectric System (MAHS) to the Cutzamala System (CS), which provides 24% of the drinking water consumed by Mexico City (CDMX), which would hardly serve to compensate for something more of the leaks in the service of the city. The reservoir and the runoff basin of its main tributary, the Amanalco River, were characterized, as well as the dam and the climate (Banderas et al., 2019), highlighting the location and density of the main human settlements, noting that the reservoir is relatively deep. The bucket has already lost 21% of its capacity at a rate of about 1.3 hm^3 $year^{-1}$, while the hydraulic balance presents strong contrasts and is recurrently negative, due in part to the climate and in part to the diversion of runoff towards agriculture, livestock and fish farming, which provide fertilizers and erode the soil, polluting the water and silting the bottom. To this is added its tourist attraction, highlighting the population increase of 286% since 1979, and 41% of GDP between 2010 and 2015.

The results of monitoring water quality in the basin revealed the increasing frequency of extremely high values, linked to the increasing human influence on natural gradients, which are lost towards the lowlands as human settlements grow. Furthermore, the human contribution of N and P to the reservoir has grown in the same proportion.

In the limnology of the reservoir, the behavior of the maximum chlorophyll stands out, which went from 53 to 88 mg m^{-3} between 1992 and 2001, while the cyanotoxin-producing algae were dominating in the phytoplankton. In general, biodiversity declined in favor of a few species resistant to eutrophication (Banderas et al., 2019).

The change of use of the reservoir, from electricity generation to a supply source, was decisive in this result, since it lengthened the hydraulic retention time of the reservoir (T), aggravated by two additional factors: 1) the promotion of tourism through land expropriation and its transfer to investors, favoring urban growth especially on the northern, southern and eastern banks of the reservoir, as can be seen in the satellite photographs; and 2) the poor management of the reservoir when extracting water from the epilimnion, which caused the emergence of hypolimnetic water, loaded with the decomposition products of organic matter at the bottom.

4. Results

In the previous evaluation (Banderas et al., 2019), four other actions were detected that enhanced eutrophication, separating the reservoir from SDG 6 Goals 3 to 6, and SDO 15 Goals 1, 4, 9.

At the beginning, the 1st dimension of covering basic human needs (SDO 6 Goal 1, and SDO 7 Goal 1) was fulfilled with the supply to the VM first of energy and then of water, and the benefit for the locals with local tourism (SDO 8 Goals 3, 9). Not so the 1st dimension of safeguarding long-term ecological sustainability (SDO 6 Goals 3, 6, 6b; SDO 12 Goals 2, 4, 5, 8, 12 b; SDO 13 Goals 1, 13b; SDO 15 Goals 1, 2, 4, 5, 8, 9), despite the fact that the studies recurrently revealed the growing contamination in the river and the reservoir. The first warning arose between 1987 and 1993, when the oxycline became anoxic at the bottom of the reservoir, coinciding with the change in P supply mainly to anthropogenic influence. The repulsive eutrophic aspect emerged in 2003-2004. A few years later it entered hypertrophic conditions (Guimarais et al., 2018).

Degradation overcame the resistance mechanisms of the reservoir and gradually decreased the landscape attractiveness and the environmental services of the micro basin, thus forcing navigation to be prohibited, affecting service providers and threatening the drinking water service to the CDMX.

Repellent algal blooms and associated cyanotoxins nullified the preservation of the intrinsic value of nature, intergenerational equity and the aspirations of fulfilling a better life (SDO 11 Goals 4, 6 and 11a, and SDO 12 Goals 2, 4 and 12b).

The intra-generational equity of SDO 10 Goals 2 and 3, and SDO 16 Goal 16b was ignored by paying low prices for the expropriated land to the natives, and high prices for the corridors, favoring urban owners and intermediaries.

5. Discussion

The weak side of VBR's sustainability is economic and environmental. The first by prioritizing the GDP for tourism, since it contributes with 93.7% of the local GDP, which represented 33% of the state GDP in 2015 (USD 600 x 10^6), 41% higher than the GDP of the sector during 2010. This growth of 8.2% per year exceeds the 7% proposed for developing countries, which opposes SDO 8 Goal 1 with SDO 15, Goals 1, 2, 4, 9, and forces the possible cut of the water supply to the VM, contrary to SDO 11 Goals 3 and 11a. The high cost, \$6.15 m^{-3} of transferring drinking water to the CDMX must be added as well as the cost of unsuccessful studies, actions and works by the public and private sectors to prevent environmental impact, ignoring

SDO 6 Goals 4 and 5. In addition, the country is geopolitically related, requiring the formulation of multilateral policies that involve SDO 17 Goals 4 and 14, reciprocally related to SDO 8 Goal 1, in this case opposed to ecosystem conservation.

Environmentally, **T** is more likely to increase due to diversion of water for agriculture, preventing organic matter and agrochemicals from leaving the reservoir. To save nature, tourist services could be made more expensive to reduce the visitors number, but this would only benefit the wealthiest, would require the displacement of many locals and the abandonment of touristic infrastructure, which is incompatible with intra-generational equity.

How much fixed population can the VBR ecosystem support while conserving nature in near-sustainable conditions? On one hand, the one it had before 1990, when anoxia occurred and urban P exceeded that of runoff. That is, a third of the current one (100,000/3 = 33,000), and a proportional GDP of 2.7%. Another estimate assumes that all the runoff from the set of micro-basins ends up in the dam, and taking the volume of the reservoir in 1990, 395 hm^3, the quotient: fixed population/volume of the dam results in 11 m^3 ind^{-1} $year^{-1}$. But the estimated minimum right to water is 36 m^3 ind^{-1} $year^{-1}$, that is, more than three times the water currently available in the system.

But the population must be reduced to another third, since the WHO establishes a consumption of 150 L ind^{-1} d^{-1} and the growing agricultural footprint absorbs runoff in the basin, resulting in 12,045 individuals. For its part, since 1990 tourism has grown from 2.5 to 3 million visitors a year, which requires that **T** be reduced to about 12 months.

Large investors could be replaced by community tourism to increase the number of beneficiaries, but without conserving nature.

CDMX neglected sustainability long ago in the logic of conserving (or increasing) its contribution (23%) to the national GDP, exploiting neighboring basins underestimating SDO 8 Goal 4, and SDO 11 Goal 6. Will VBR repeat this scheme considering its contribution of 33% to state GDP, omitting SDO 8 Goal 9; SDO 12 Goal 12b; SDO 15 Goals 1 and 4; and SDO 17 Goal 19?

6. Conclusions

1. T is a determining factor of the aquatic eco-system quality and its associated resources.

2. Physicochemical and biological indicators must be carefully and seriously considered as early warnings that can guide environmentally friendly management, in accordance with SDO 6 Goals 3 to 6, 6a and 6b.

3. Six ways of operating the SDOs are proposed:

3a. Through an inclusive and supportive educational reform in accordance with SDO 4, Goals 5, 7 and SDO 13 Goal 3.

3b. Issue laws formulated and implemented in a participatory manner in accordance with SDO 10 Goal 3 and SDO 16, Goals 3, 5, 6, 7, 10.

3c. Strengthen coordination between sectoral agencies in water management.

3d. Facilitate the interaction at the top of the water agencies of well-trained and informed specialists in the different areas of knowledge, to achieve an inclusive mutualism, in accordance with SDO 16 Goals 6 and 16b; and prevent generalists with superficial knowledge from maneuvering towards competitive exclusion.

3e. The economy and finances of water must occupy a separate chapter in the Ministry of Economy, and be governed by *sui generis* guidelines for this vital resource, based on nature and not only on the market or on value judgments, in accordance with SDO 10 Goal 4.

3f. Review the compatibility of SDO 8 Goal 1 with the conservation of nature, at least in the tourism sector of developing countries, since a GDP of 7% can threaten resources.

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Infusing ILBM into IWRM Framework towards water sector transformation – a case of Malaysia

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Abstract

Integrated Lake Basin Management (ILBM) initiatives have been undertaken by Malaysia since the mid-2000s. One of the important documents outlining the initiatives is the adoption of the strategic plan for sustainable lake and reservoir development and management that defines the vision and the policy framework. Malaysia is mainstreaming water in the national agenda with the integrated water resources management (IWRM) paradigm as its central policy towards country commitment to achieve the sustainable development goals on water (since 2001). Lake remains as an important component due to being a part of the river system and its strategic contribution as a resource and livelihood. In the context of water as a resource, lakes contribute towards supplying water for domestic and industrial growth as well as agriculture development besides regulating flood and drought. In the context of water as livelihood, lakes contribute as consumptive water uses through alternative water sources from stormwater and off-river storage ponds, and non-consumptive uses, namely hydropower development, freshwater fisheries and recreation and tourism expansion. The 12th Ma-

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laysia plan will accelerate IWRM in a shared prosperity initiative, encompassing three dimensions, namely economic empowerment, environmental sustainability, and social re-engineering. In the environmental sustainability dimension, specific focuses were given on IWRM (which includes ILBM), biodiversity conservation, climate change mitigation and adaptation, and valuing ecosystem services. Long-term programs, include research and development using innovation and industrial revolution technology (IR 4.0) towards the improvement of pollution monitoring, rehabilitation of degraded lakes, stakeholder and community collaboration in governance, and adaption to future climate changes to enhance lake resilience.

Keywords: *Integrated Lake Basin Management, Integrated Water Resource Management, lakes, sustainability, water sector transformation*

1. Introduction

Management of water resources has been the main agenda of Malaysia to ensure security of water for socio-economic development and living beings. Similar to the global environment, the main challenges of the water sector facing Malaysia were population increase and economic development, and climate change. According to Roser et al. (2013), the world population has increased from 984.94 million in 1800 to 7.87 billion in 2021 [1]. Similarly, the population in Malaysia has increase from 287,000 in 1800 to 32.78 million in 2021; the citizen growth rate remained stable at 1.0% [1, 2]. The gross domestic product (GDP) per capita of the world has increased from 457.7 in 1960 to 10,910.0 in 2020 [3]. Similarly, the GDP per capita for Malaysia has improved from 234.9 in 1960 to 10,412.3 in 2020 [3] The increase in population and economic growth cause an increase competition and conflicts for the water use and pollution at various levels and sectors.

Additionally, the impact of climate change on water resources is becoming more apparent; surface temperature in Malaysia is projected to increase to 1.85 – 1.93˚C by the end of the century [4]. The projected average temperature of the planet could be between 1.1 to 5.4°C warmer in 2100 [5]. The extreme events such as long droughts associated with climate changes increase the water resources conflicts. Fragmented management has been the biggest challenge in managing the water sector in Malaysia requiring a holistic, systemic approach namely the Integrated Water Resources Management implementation in the country [6,7]. The Federal Constitution describes that generally, water and other natural resources are under the responsibility of state governments, except for agriculture drainage and irrigation (FedConst 1957, and Water Service Industry Act 2006) [8,9]. Shared rivers between two or more states can be looked at by the Federal Government, if invited by the states involved [6, 7]. At the federal level, the governance of water is also sectoral-based; administration and development are being carried-out by different ministries and their agencies.

The governance of the lake, in particular, is very fragmented with different parts of the lake system being managed or operated by different agencies and authorities. For example, the dam structure is always managed by the federal agencies while the lake catchment or drainage basin is governed by state agencies. In general, natural lakes are mostly managed directly by the state government agencies. Man-made lakes such as reservoirs are being governed by different agencies, depending on their main users; water reservoirs are under the Department of Water Supply, Ministry of Water and Environment, irrigation reservoir under the Ministry of Agriculture and their agencies, flood mitigation reservoirs are under the Drainage and Irrigation Department, Ministry of Water and Environment and hydropower reservoirs are under the private sectors/govt.link agencies. Small urban lakes and ponds are being managed by the local authorities of each state. As the governance is too fragmented, the water quality status of these water bodies is seldom monitored by the agencies.

This paper reviews the process of infusing ILBM into the holistic IWRM framework. The aim was to examine how ILBM is mainstreaming within the national IWRM framework to support water sector transformation in Malaysia.

2. Management framework

2.1 Integrated Water Resource Management (IWRM)

The Integrated Water Resources Management approach was introduced and accepted during the ICWE Dublin and Earth Rio Summit in 1992. IWRM is defined by Global water partnership as "A process which promotes the coordinated development and management of water, land, and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" [10]. The overall framework of IWRM is based upon three thrusts namely management instruments, enabling environment and institutional framework.

Malaysia takes cognizance of the need to manage water sustainably based on the IWRM approach. Table 1 illustrates the key IWRM progress in Malaysia over the last 20 years. The formation of the National Water Resources Council was one of the earliest initiatives taken by Malaysia towards adopting the IWRM. Malaysia adopted the approach when the IWRM concept was included in the Eight Malaysia Plan and Third Outline Perspective Plan in 2001. A national study for the effective implementation of IWRM in Malaysia was undertaken in 2005 followed by the implementation of IWRM Best Management Practices in 2009 [6,7].

One of the major milestones of IWRM implementation is the endorsement of the National Water Resources Policy in 2011 and launched in March 2012. The policy was based on three principles, namely water resources security, water resources sustainability and collaborative governance [11]. This policy document specifically spells out that Integrated management approach to be under undertaken for river, lake and coastal through Integrated River Basin Management (IRBM), Integrated Lake Management (ILM), Integrated Coastal Zone Management (ICZM), Integrated Shoreline Management Plan (ISMP) and Integrated Flood Management (IFM) approaches [11].

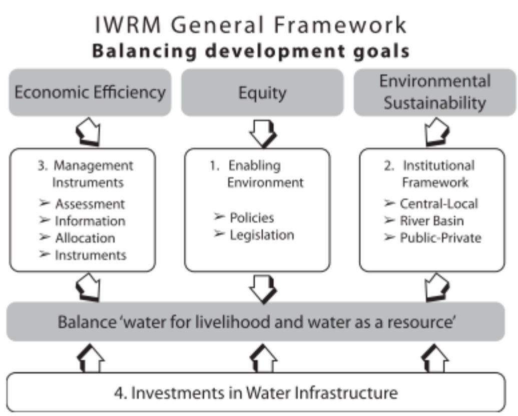
The Academy of Sciences Malaysia (ASM) took the initiative from 2008 to develop a nation-wide IWRM work plan with IWRM as the central thrust [6], in a series of publications. This initiative was summarized in the ASM

Table 1. *Key IWRM progress in Malaysia.*

Period	Initiatives
Before 2000	• Formation of National Water Resources Council
2001 - 2010	• Adoption of IWRM under 3rd outline perspective plan & 8th Malaysia plan • National adoption of IRBM • The establishment of Natural Resources and Environment Ministry • National study for the effective implementation of IWRM in Malaysia • Implementation of IWRM BMP's
2011 - 2021	• Endorsement and launching of National Water Resources Policy • Launched of National Integrated Water Resources Management Plan • Restructuring of MSAN to National Water Council (MAN) • The adoption of WST2040 in 12th Malaysia Plan

2016 publication, the "Transforming the water sector: National Integrated Water Resources Management Plan: strategies and road map" or the NIWRMP. The document introduced the idea for Malaysia to transform its water sector. A total of eleven component plans were structured to the common IWRM framework as shown in Figure 1. The goals of the framework are to balance 'water as a resource' and 'water for livelihood' along the three IWRM thrusts.

Figure 1. *IWRM General framework (source: Abdullah et al., 2016).*



Despite IWRM policy approach being introduced since 2001, the status of IWRM implementation remains low. According to UNEP, the IWRM Status for Malaysia in 2020 scored 63 points, which is medium-high [12].

Malaysia scored low in two areas, namely the management instrument and financing.

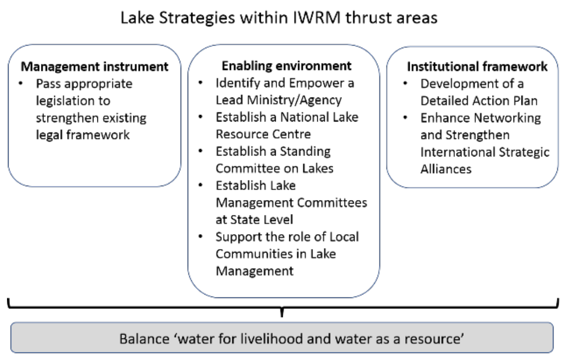
Two of the focused management subsets within the IWRM framework are the IRBM and ILBM. Being the most important freshwater resources, rivers are considered as the source of national economic developments. As such, ASM focused on the application of IWRM at the river basin scale. In fact the "love our river campaign" was probably the earliest initial milestone of IWRM implementation in the country. To date, Malaysia has 189 main river basins, covering 95% of its land mass. 26% are large with drainage areas of more than 1,000 km^2. About 57% of the river basins have a catchment area of less than 500 km^2. IRBM plans are being developed to support IWRM implementation. These plans will aid in the overall governance of each river basin. However, managing river basins also comes with various challenges. The main challenges in managing each river basin, are developing cooperation and collaboration among the agencies, at various Federal, State as well as Local Government levels, to ensure the health of the basin ecosystem [13].

2.2 Integrated Lake Basin Management (ILBM)

Lakes, due to their unique characteristics such as long retention time and complex response dynamic, require special management focus. Integrated Lake Basin Management (ILBM) is an approach that focuses on standing water bodies in lakes, reservoirs and ponds. ILBM approach is also considered a subset to IWRM with the goal to achieve "sustainable management of lakes and reservoirs through gradual, continuous and holistic improvement of basin governance, through sustained efforts for integration of institutional responsibilities, policy directions, stakeholder participation, information, technological possibilities, and funding" [6]. Malaysia has undertaken various initiatives in promoting sustainable management of lakes based on the ILBM approach since 2004. Earlier initiatives have been focusing on identifying issues and status of lakes in particular eutrophication and developing strategies for sustainable development and management in 2009 [14].

The national vision for Malaysian lakes in the strategic plan is "The sustainable use of lakes for their ecosystem services and economic values" while the policy framework identified is "Lakes and reservoirs will be sustained, restored and protected through the adoption of an Integrated Lake Basin Management (ILBM) approach" [14]. Eight strategies were formulated and categorised further in the NIWRMP based on the IWRM framework in Figure 2.

Figure 2. *Lake Strategies within IWRM General framework.*



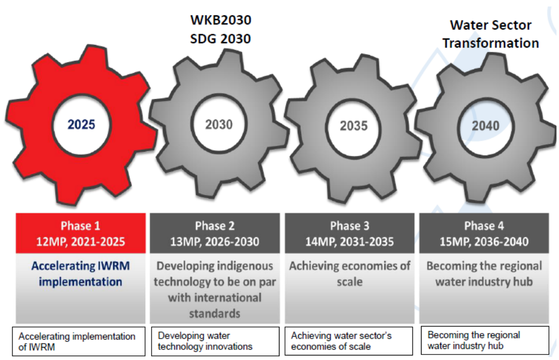
Due to the importance of lakes in providing various services for the nation, National Water Research Institute of Malaysia (NAHRIM) commenced a study in 2020 to update the inventory of water bodies in the country. The most recent inventory of lentic water bodies in Malaysia identified a total of 379 lakes, reservoirs and ponds that provided various services such as water supply and fish products, flood mitigation and hydropower generation [15].

3. Water sector transformation and Twelfth Malaysia Plan

Water sector transformation (WST) is a national agenda by Malaysia to "transform the water sector into a dynamic & vibrant economic sector" which aims to contribute significantly to the national GDP, provide good quality affordable water to the public, and create new job opportunities by facilitating resilient development of science and technology innovation and research [16].

The WST2040 spans over four phases and will be completed within 20 years or within four Malaysia development plans (Figure 3). It has two objectives namely (1) water security and sustainability (2) water as an economic opportunity. The phase 1 of WST2040 (2021-2025) is currently ongoing under the twelfth Malaysia Plan with the goal to accelerate the IWRM implementation. Phase 2 (2026-2030) aims to develop indigenous technology to be on par with international standards while Phase 3 (2031-2035) aims to achieve economies of scale. The last phase or phase 4 (2036-2040) aims to transform Malaysia into a regional water industry hub.

Figure 3. *The four phase of WST2040.*



The Twelfth Malaysia Plan (12-MP) which was launched last year aims to support the transformation of water sector in Malaysia. WST was included as a specific chapter in the Development plan to ensure the budget development allocation is in line with the government planning.

The key issues identified in the 12^{th} MP that led to ineffective water resources management can be divided into five areas, namely people, governance, infrastructure, information and finance (Table 2, EPU 2021).

As such, the strategies mooted in accelerating the adoption of Integrated Water Resources Management (IWRM) will be based on a shared prosperity initiative, encompassing three dimensions, namely economic empowerment, environmental sustainability, and social re-engineering that includes

Table 2. *Key challenges in Malaysia in water resources management (EPU, 2021).*

Scope	Issues
People	• Lack of ownership and ability to protect and conserve water resources • Absence of a clear platform for inclusive local community involvement in water governance.
Governance	• Ineffective governance of water sector due to uncoordinated approaches in managing water resources at all levels and sectors • Poor enforcement and a lack of scope for punitive action.
Infrastructure	• Insufficient and unsustainable water infrastructure to support growth
Information	• Lack of data-driven and science-based decision making due to the absence of a centralised database to integrate water-related data and information on research, development, commercialisation and innovation (R&D&C&I) activities • Limited expertise among water technologists and scientific community
Finance	• Poor financial sustainability of water industry and high dependence on public funding

1) Empowering people as agent of change in transforming the water sector
2) Strengthening governance at all levels
3) Enhancing capability in data-driven decision making
4) Ensuring sustainable financing
5) Developing sustainable infrastructure with cost-effective technology

The goal of the 12-MP and thirteen Malaysia Plan is to ensure Malaysia will achieve its commitment towards Sustainable Development Goals 2030 and Shared Prosperity Vision 2030.

Lakes remain as important components due to being a part of the river system and its strategic contribution as a resource and for livelihood. As a resource, lakes supply water for domestic & industrial growth and agriculture development and regulating flood and drought. For livelihood, lakes function as consumptive water uses such as alternative water sources such as stormwater ponds and off-river storage. Lakes also function as non-consumptive uses such as hydropower development, freshwater fisheries, recreation and tourism expansion.

The lake initiatives and programs identified to support IWRM can be divided into three areas as follows:

3.1 Research and development (R&D)

Development of the R&D ecosystem is critical to enable science-based and data-driven decision making. Despite increasing public financing given for R&D activities over the last few Malaysia development plan, the public R&D development remains sporadic with water-related data and information scattered among different agencies and institutions [16]. Lack of coordination, monitoring and evaluation framework, commercialization, innovation and industrial linkages were reported to have hindered the effectiveness of the public R&D ecosystem in the country [17]. Limited expertise among water technologists and the scientific community were acknowledged as factors that could hamper sustainable management and development of water sector. As such, strengthening capability through research, development, commercialisation and innovation is emphasized under the WST2040 to ensure sound decision-making.

The WST2040 promotes the application of 10-10 Malaysian Science Technology Innovation Ecosystem Framework (MySTIE) which is based on current and leap-frogging technologies as well as the National Water Innovation roadmap (2021-2040). Concerning lakes, the blueprint for Lakes and Reservoir Research and Development was completed in 2015 to support integrated R&D activities. The blueprint specified the need to focus R&D activities at the lake basin or catchment scale. The research studies should be trans-disciplinary or interdisciplinary combining physical and social sciences aspects [18].

Improvement of pollution monitoring is outlined in the NIWRMP and 12-MP to support IWRM implementation. Research should be focusing on the carrying capacity of the water bodies based on total maximum daily load (TMDL) concept for lentic-lotic waters [6,16,18].

Rehabilitation and restoration of degraded lake ecosystems is an important enabling environment to ensure lakes continue to provide their ecosystem services [6]. Studies should be carried out to assess the level of degradation such as storage loss from sedimentation as well as eutrophication and other pollution levels [18].

3.2 Stakeholder and community collaborations in governance

The WST2040 emphases enhancing collaborations among all stakeholders, including the communities, for successful water sector transformation. This includes promoting advocacy, awareness raising and capacity building activities, i.e. public participation in caring for lakes and rivers. Collaboration can include engaging nearby lake communities or developing citizen science on lake monitoring and management. Both integrated management approaches such as IRBM and ILBM are an important program concerning water as a resource [6].

For successful ILBM implementation, the focus requires more than planning. This needs to include monitoring and evaluation. There is a need to review and update governance requirements at Federal, State and Local levels to ensure smooth transfer of management from and at all levels. Lake basins management that aims towards development, or conservation, requires not only plans and programs but also must be supported by appropriate management framework providing for continuous improvement [19]. According to RSCE - Shiga University, and ILEC (2014), sustainable lake basin management is achieved when both planning and governance are geared together [19]. Generally the ILBM emphasis on developing ILBM Platform Process is on continuous improvement in the governance pillars.

Since stakeholder participation is also one of the governance pillars in ILBM approach, implementing ILBM will support IWRM implementation in Malaysia. The overall goal is to create a shared means, agenda and/or place for the affected stakeholders and basin society as a whole to address conflicts [6, 19].

3.3 Adaptation to climate changes to enhance lake resilience

As climate change impact will affect the water sector, adaptation to climate changes is necessary to enhance lake resilience to climate change. WST2040 puts emphasis on promoting evidence-based and integrated approaches for climate change adaptation and disaster risk reduction in development planning and R&D programs such as forecast and projection of climate change on water resources including dams [16].

The WST2040 recommends the construction of new dams to be multi-use or multi-purpose, such as for water supply, power generation, irrigation and flood mitigation under the 12-MP [16]. Additionally the function of flood retention ponds will be expanded for utilisation as raw water storage and/or aquifer recharge [16]. The role of the existing lake will also be enhanced to adapt to the changes in the effects of drought and floods. Development of new dams or man-made lakes such as off-river storage (ORS) is proposed along rivers to reduce the flood issues. This ORS will also function as a water resource alternative to support water for livelihood [16].

Additionally, the development of underground dams is being promoted in WST2040 under the 12-MP to enhance the use of groundwater as an alternative or conjunctive water source. Detailed feasibility studies on such underground dam developments especially in water-stressed areas will need to be undertaken to determine their exact potential, and hazards [16].

Development of nature-based solutions such as constructed wetlands is encouraged to alleviate the extreme events such as floods and droughts as well as addressing water pollution issues in all water resources including rivers and lakes [16].

4. Conclusion

In conclusion, ILBM is an important management mechanism for lentic water resources to support IWRM in Malaysia. IWRM paradigm as its central policy (20-year plan) towards country commitment to achieve the sustainable development goals on water. Enhancing capability in data-driven decision making – i.e. long-term programs, include research and development towards the improvement of monitoring and rehabilitation of lakes, stakeholder and community collaboration in governance, and adaptation to future climate changes.

Acknowledgements

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Lake Fuquene, Colombia: the importance of governance

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Abstract

Lake Fuquene is located in the middle of the Colombian Eastern Mountain Range at 2,600 metres above sea level. It is one of the most important fresh water bodies and the second largest ecosystem above this altitude in the Northern Andes of Colombia. It was a sacred place for the Muiscas (the original inhabitants in the region), of great historic-socioenvironmental importance and crucial for the daily lives and prosperity of the basin's communities. Fuquene is habitat of endemic flora and fauna, supports fish populations and regulates water flow in the basin. This ecosystem provides freshwater to 105,000 rural and 76,000 urban inhabitants, hosts agricultural activities and represents an essential source of food sovereignty for the 17 municipalities within its area of influence. Fuquene had an area of 12,000 hectares, which has been reduced down to only 3,260 due to the development of unsustainable anthropic activities and inadequate management policies. The climate crisis poses a threat to the lake's ability to provide ecosystem services. Strengthening of governance, comprehensive catchment policies, restoration efforts, sustainable activities and wastewater treatment

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are some of the mitigation and adaptation measures that can ensure the health of this significant ecosystem for future generations.

Keywords: *Eutrophication, governance, ecosystem-based and nature-based solutions*

1. Introduction

Lake Fuquene is located on the Colombian Northern Andes (co-ordinates 5°300'N; 73°500'W), within the Ubate River basin (1,752 square kilometres) in a high-altitude tropical region, on a plateau between the Departments (provinces) of Cundinamarca and Boyaca, at an altitude of 2,600 metres above sea level. The lake covers an area of 3,260 hectares, has a volume of 82.5 million cubic metres and mean depth is 2.5 metres (JICA, 2000).

It is one of the most important freshwater bodies and the second largest ecosystem at such altitude in the Northern Andes of Colombia. It forms part of a lake complex made up by the Fuquene, Cucunuba and Palacios lakes, of great historic-socioenvironmental importance and most relevant for the survival and prosperity of the basin's inhabitant. During pre-Colombian times, Lake Fuquene was a sacred place for the Muisca people (original inhabitants in the region), who called it "Fox Goddess Bed". Nowadays, it is still a material part of local people's traditions, but its spiritual meaning has faded away.

Fuquene hosts endangered endemic fauna and flora; it is a key habitat for a large number of migrating bird species; sustains fish populations and regulates water flow in the basin. This is one of the most important ecosystems in Colombia, supplying freshwater to some 105,000 rural and 76,000 urban inhabitants, further to representing an essential source of food independence for all 17 municipalities within its area of influence. Water so supplied is used for human consumption, as well as for agricultural activities (milk production, cattle rising and crops) and water distribution to an irrigation district (Valderrama & Hernández 2007; Asociación de Pescadores Los Fundadores & Fundación Humedales 2011).

Fuquene originally covered an area of 12,000 hectares, which, due to performance of anthropic and unsustainable activities, has reduced down to just 3,260 hectares over the course of the last 200 years (dropped MB, Pinilla-Vargas M, Andrade G, Valderrama-Escallón E, Hernández S. *Lake Fuquene.* Wetland Book 2016). For many years, the lake has been subjected to unsustainable practices and inappropriate management policies. The climate crisis poses a threat against its resilience and its capacity for providing essential services to the ecosystem, hence applicable policies must guarantee mitigation and adaptation actions to potentially reduce the vulnerability of affected communities. Urgent recommendations to guarantee the health of this ecosystem for current future generations include comprehensive ecosystem-based catchment policies, restoration efforts, sustainable agriculture and economic activities, as well as optimal wastewater treatment. In the basin live 180,000 inhabitants. The climate in the region is characterised by almost constant temperature whilst humidity varies between 70% and 79%. Average annual rainfall is 1,030 mm (JICA, 2000). Fuquene belongs to a lake complex formed by the Fuquene, Cucunuba and Palacios lakes, covering an area of 19,194 hectares and comprising 5 sub-basins.

More than 95% of the lake basin has been altered; out of the 29.1 km perimeter, only 2.4 kilometres is not hydraulic modified. The current lake complex used to be a great lake covering more than 1,000 square kilometres. Draining operations and deep transformation of the territory limited water connection between the 3 lakes. By 1934 the wetland complex was no longer connected. As stated above, the original 18,500 hectares are down to only 3,260 hectares after 200 years. The strong and continued human intervention in the lake basin and in the ecosystem has changed its natural conditions. Water quality reflects eutrophic conditions (over enrichment of waters with organic matter and nutrients).

Fuquene represents a local hot spot of freshwater biodiversity, with 307 species. Amongst the species present in the lake, it is worth highlighting catfish, an endemic endangered species, and crayfish as the most troubled exotic species. Out of the 125 bird species found in Fuquene, a high proportion are migratory, 3 endemic and 5 endangered, such as the Apolinar's wren. Fuquene ecosystem services are many and diverse: water source and fishing supply, recreational options, environmental and cultural wealth, habitat for a large number of endemic and migratory species, balancing basin vessels, buffering climate event effects, carbon dioxide and nitrogen fixing reservoir and water and erosion regulator.

The GDP of this area is about USD 2,455. In economic terms, activities performed in the region include agriculture, livestock, mining, handicrafts, tourism and fishing on a smaller scale. The soils are very suitable for livestock farming. In the last 10 years there has been a continuous growth in the number of cattle heads from 120,232 head of cattle in (2001) up to 146,218 (2010), dairy production of 850,000 litres per day, further involving 50% of the population, about 45,005 people. Agriculture only accounts for 5% of the area. Nowadays, many of the traditional crops such as cubio (*Tropæolum tuberosum*), are no longer farmed or are used only for self-consumption. Potato crops are the most relevant, covering about half of the farmed land, followed by tomatoes, maize, peas, and onions. Artisanal fishing in the lake is critical due to the dramatic reduction in natural supply of species. Only 48 of the almost 200 fishermen reported 20 years ago are still fishing in Fuquene. The tertiary sector, mainly represented by tourism and handicraft activity, is a driving force in the region. Handicrafts employ more than 175 people, selling baskets made from natural fibres extracted directly from the shores. Another material of great importance is wool. Tourist activity has become more dynamic in recent years with ecotourism activities and ethnographic and cultural initiatives.

2. Materials and methodology

The materials and methods used for preparation of this document mainly comprise all the information compiled by Fundacion Humedales over the course of 20 years working on Lake Fuquene. Such information has been generated through monitoring processes with participation from the communities, fishers associations, craftspeople, schools and academia. Moreover, we count on a bibliographic review of all accessible information published by the competent environmental authority and the Ministry of the Environment. Also, during said 20 years presence in the region, the Fundación

Humedales team have conducted several surveys, interviews and polls within the communities, whereby socioenvironmental information has been obtained in respect to the condition and evolution of Lake Fuquene.

3. Results and discussion

3.1 Lake Fuquene environmental problematic

Throughout the years, the environmental quality of the Lake Fuquene and ecosystem has seriously degraded due to implementation of State policies intended to dry up wetlands during the 19th and part of the 20th century. Also, performance of unsustainable anthropic activities has altered the components (water, flora and fauna), leading to the reduction of the lake's basin, currently covering 76% less than originally, with water quality further reflecting eutrophic conditions (Valderrama et al. 2013).

The environmental quality of the Ubate – Suarez basin holding the Lake Fuquene has considerably reduced over the course of the last few decades with irreversible impact on biodiversity, water and soil. This has led to the loss of ecosystem functions and services that are fundamental for maintenance of the Fuquene, Cucunuba and Palacios lakes complex and for well-being of the local population. In summarised form, the economic and domestic activities carried out within this basin have caused the following affectations to the ecosystem:

1. The rate of deforestation and therefore the presence of erosion are extremely high. 95% of the original vegetal cover is destroyed, and has been transformed into agricultural land.
2. Poor hydraulic management along with poor decision-making process. Fuquene has been drained since the Spanish conquest and a peripheral canal was built for easier drainage from the lake to the river.
3. Poor water quality. This valley is the largest dairy producer in Colombia. In areas with high cattle concentration, such as Fuquene, phosphorus levels are high, cow treading adversely affects the seepage rate and macro porosity of the soil, causing lost sediment through surface flow from

cattle pastures and cultivated areas. For its eutrophic conditions, Lake Fuquene has large areas of macrophyte, floating, rooted and exotic species. Upon dying, plants go to the bottom and organic matter decomposes. Such process consumes oxygen, thus limiting phosphorus fixation in the sediment and allowing it to cycle towards the water column. Thus, it becomes available for phytoplankton and plants, promoting greater coverage of surface water, more abundant macrophytes, augmented decomposition and hence increased oxygen consumption and more phosphorus cycling to the water from the sediment. Water quality is also affected by high population rates: there are 11 municipalities pouring their wastewater into Fuquene.

4. Expansion of exotic flora species, such us macrophytes, which were introduced to control the level of nutrients present in the water. Introduction of fish species such as carp (*Cyprinus carpio*), golden mackerel (*Carassius. auratus*) and pelagic crab (*Procambarus clarkii*) for fishing purposes, as well as poorly planned farms for trout (*Oncorhynchus mykiss*) and herbivorous carp (*Ctenopharyngodon idella*).
5. Lost storage capacity for radicular invading aquatic vegetation systems moving the water column.
6. Reduced flow of brooks, creeks and rivers ending in the lakes complex.

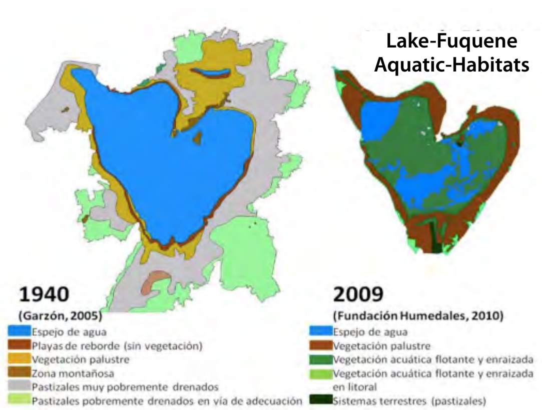
The above has led to a dramatic situation in the Lake:

1. High sedimentation rates, as much as 1 mm per year – doubling the rate in the last 500 years (van der Hammen, 1998).
2. 50% surface water loss
3. Serious storage and regulation problems.
4. Decreasing fish population, impacting food security for the communities. In the last 10 years, successful fishing reduced by 80%, which adversely affected food security for fishermen, 90% of whom ultimately abandoned fishing (Asociación de Pescadores los Fundadores & Fundación Humedales 2011).
5. Displacement of certain endemic species, which have almost disappeared.

3.2 Fuquene basin management

Lake Fuquene is of great historic importance, from the Muiscas to the present day. This water body has been present and forms part of everyday life for neighbouring communities. It has been used for multiple purposes but, due to mismanagement of the lake and the entire basin, many of the ecosystem services provided by the lake have extremely deteriorated. However, Lake Fuquene is still a highly significant enclave.

Figure 1. *Reflecting pool evolution and aquatic habitats layout changes between 1940 and 2009 at Lake Fuquene (Franco et al., 2011)*



The Fuquene, Cucunuba and Palacio lake complex is considered as:

- Centre of biological diversity and endemism of the most important Andean freshwater biota in Northern South America.
- Belonging to the High Andean complex of freshwater eco regions in Latin America.
- Important bird area (so declared in 2004)
- A strategic site for preservation and sustainable use of natural resources with an ecosystemic management approach, integrating biological and social components. For purposes of safekeeping the natural and cultural heritage of this area of interest, and bearing in mind the great impact of the alarming situation of the Fuquene basin ecosystem, the

Regional Environmental Authority Corporación Autónoma Regional de Cundinamarca (CAR) declared it Protected Regional Area classified as Regional Integrated Management District (DRMI), forming part of the Colombian National Protected Areas System (SINAP) with the fundamental purpose to preserve water resources and habitats of associated biodiversity, thus securing provision of environmental services and supply of ecosystemic goods to local and regional communities within the area of influence, upon defining a specific environmental management plan. Such environmental management plan prioritises hydrological supply, preservation of high Andean forests, protection of habitats and conservation of soils. It included zoning, defining 3 areas:

- protected areas, mainly the Fuquene and Palacio Lake water bodies;
- restoration and recovery areas, mainly rivers and creeks; and
- areas for sustainable use.

3.3 Impact stories

Many impact stories may have taken place in Fuquene, but due to weak governance, few have been implemented and those which ended successfully have been led by civil society.

Since 2000 an intense process of participatory monitoring of biodiversity and its use has been rolled out by Fundacion Humedales, the community and civil organisations. This process comprises training the population on physical-chemical-biological indicators to follow up and control water quality. This participatory process has been transferred to many river basins across the country and is a key tool for conservation and protection of ecosystems and for articulation with the competent authorities.

Another example is implementation, for the first time in Colombia, of nature-based solutions for treatment of domestic wastewater and conformation of civil associations for participatory water management. In 2014, Fundación Humedales started an international co-operation programme for treatment of domestic wastewater through Green Filters. Implementation of 3 green filters attached to the basin, treating domestic wastewater for more than 2,000 people, is preventing entry of about 9.5 tons of nutrients per year into Fuquene. This solution has been replicated in other parts of Colombia.

3.4 Governance

Concerning governance, the Lake Fuquene basin is a varied and complex ecosystem that requires diverse and inclusive management and governance to fulfil conservation objectives, implement ecosystem-based adaptation measures as promoted by Colombian legislation, and take into account the sustainable wellbeing of the communities.

The environmental history of the players present within Fuquene territory is quite long. Since the 1980s, a first group of biologists, ecologists and civil society started to articulate participatory monitoring, environmental education and development, where local community support projects have been rolled out to encourage civil society to participate in the necessary dialogue to achieve an integrated management of natural resources and an effective governance process.

At national level, Lake management is determined by nationwide policies on integrated biodiversity management and climate change, which make special reference to wetland ecosystems and ecosystem-based adaptation. All of them have instruments for citizen participation, which for the time being are characterised by their weakness. This represents the key problem within Lake Fuquene management. Even though the legal scenario for civil participation is robust and well defined, environmental authorities do not apply it evenly, leaving civil society as mere observers of decisions made. This has led to full delegitimisation of such authorities by civil society, difficult dialogue and mistrust on any action taken by the environmental authorities for missing transparency, accessibility and participation on information and during formulation. Hence, governance at Fuquene poses great challenges, mainly due to lack of interest in real articulation from the players. There are no incentives to motivate and favour generation of horizontal links between the environmental authority and civil society. Although the legislation establishes that management plans must be formulated on a participatory basis, such participation is done by inviting civil society to participate in workshops for plan formulation purposes, but it ends up not having the desired impact, given civil participation is often overshadowed by private interests or by political and / or administrative agendas.

4. Conclusion

Fuquene needs a change in policy, focussing on the ecosystem, to include all stakeholders and providing for adaptation strategies to face the threats of climate change. In summary, Fuquene is a very important socio-ecosystem in a very advanced state of deterioration. Strengthening local governance will help to articulate the current players, influence decision-making and contribute to implementation of conservation, recovery and climate change adaptation measures enabling sustainability of the ecosystem and local livelihoods in the basin.

Acknowledgements

To all our Living Lakes Latin America & Caribbean colleagues, for sharing their objectives, knowledge, ideas and projects in order to keep working and co-operating for the health and sustainability of lakes and water bodies all over the world, which is the calling that unites us.

We would like to thank the entire Fundación Humedales team, who, throughout their mission, for more than 20 years have been monitoring and protecting such significant lake for its wealth in species and ecosystem services. And, above all, our greatest gratitude to the communities, fishing associations, craftspeople, NGOs and the entire civil and academic society, whose will, effort and commitment lead their everyday fight for Fuquene to continue being what it has always been: a lake so special that it is considered sacred.

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Lake Zirahuen, Michoacan, Mexico: Advances of lake deterioration

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Abstract

Zirahuen is one of the youngest and clearest lakes in Mexico, it is located in the central area of the State of Michoacán. Its main economic activities are based on tourism, fishing of species such as white fish (*Chirostoma estor copandaro*). It has a high biological importance as it has a high number of fish, birds and amphibians, most of which are native and some are endemic. However, the drainage basin of Lake Zirahuen, like most of the hydrological basins in the state, have suffered from a progressive ecological deterioration due to agricultural exploitation and changes in land use, resulting in a decrease in soil fertility and the water capture potential. Consequently, economic and social deterioration is also a process associated with poverty and social margination. Despite the ecological incompatibility of present land use in the drainage basin, it has a positive water balance. The present document aims to elaborate an environmental diagnostic of the basin of Lake Zirahuen. The study includes sources of different investigations that have taken place in this region to generate compatible environmental policies for the sustain-

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able management and conservation of this valuable Mexican aquatic ecosystem, where scientific research and social participation are of fundamental importance.

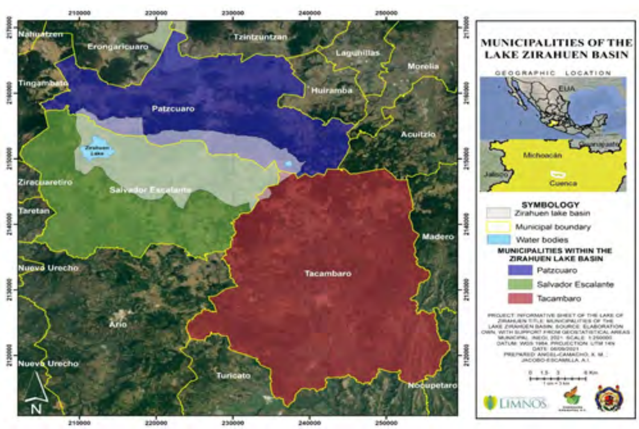
Keywords: *Mexican lake, Lake Zirahuen, water quality, eutrophication, water balance*

1. Introduction

Lake Zirahuen, also known in indian P'urhepecha language as "The mirror of Gods", gets its name from being one of the deepest and transparent lakes in Mexico [1], is located in the north-central part of the State of Michoacan, within the hydrological region of the Balsas basin at an altitude of 2,075 meters above sea level; it is part of the lacustrine system of the State. It is considered as a monomictic, oligotrophic, endorheic lake with a maximum depth of 43 m [2].

The watershed of Lake Zirahuen includes the municipalities of Salvador Escalante, Patzcuaro and Tacambaro, covering 72%, 27% and 1% of the surface, respectively (Figure 1). Most of the population is concentrated in the urban localities and the rest of it is located in rural localities [3].

Figure 1. *Municipalities of the basin of Lake Zirahuen.*



Is one of the youngest lakes in Mexico and it is considered to be one of the most important lakes in Michoacan. Its economical productivity is based on tourism, handicrafts and fishing of different species such as the white fish (*Chirostoma estor copandaro*).

Zirahuen is of great biological importance due to the number and variety of fish, birds and amphibians, most of which are native and some are endemic species. However, the basin of Lake Zirahuen, like most of the basins in Michoacan, has a experienced significant negative impact derived from environmental deterioration and the consequent socioeconomic problems of the region.

As a result of the growth of agricultural activities that take place inside the basin, Lake Zirahuen is under a progressive process of eutrophication. This situation represents increasing concern for the local population due to the possible negative effects on health in rural communities, fishing and recreational activities.

The objective of this document is to generate an up-to-date database about the present status of lake and basin, to analyze the process of degradation in Lake Zirahuen, and to propose a plan for sustainable management.

2. Materials and methodology

A documentary research was carried out using quantitative and qualitative data representative of the last 50 years on the lake and its basin. Simultaneously, field work was carried out to collect environmental, economic and social information, based on the guidelines for the preparation of information sheets on lakes (ILEC) to identify the changes that have occurred over time and carry out a comprehensive diagnosis of the present status of Lake Zirahuen.

2.1 Water balance

The estimation of the water balance was based from data collected by Sistema Meteorológico Nacional (SMN-CNA) and the application of the principle of conservation of masses. This establishes that, for any arbitrary volume, and for any period of time, the difference between input and output will be conditioned by the variation of the volume of stored water.

The water balance was estimated using the following expression:

$$\text{Input} - \text{Output} = \text{Storage Changes}$$

Input	Output
Precipitation	Evaporation
Surface runoff	Perspiration
Infiltration	Surface runoff
	Water export

Equation 1. *Water Balance equation.*

3. Results and discussion

3.1 Climate

According to Köppen's climate classification modified by [4] and the data collected from the meteorological station SMN 00016146 of Zirahuen [5], the climate is Cb(w2) (w)(i´) g, which describes a mild climate with a maximum temperature of 24.8 °C and a minimum of 7.2 °C respectively, it has a total annual precipitation of 1,098.8 mm and a total evaporation of 1,233.5 mm. It has no variations in the annual distribution of temperature; so that the region is an isothermal lake thermal regime. Wind intensity is between 1.38 and 4.16 m/s with an incidence of 70.28% and an average annual speed of 1.8 m/s [6].

3.2 Soils

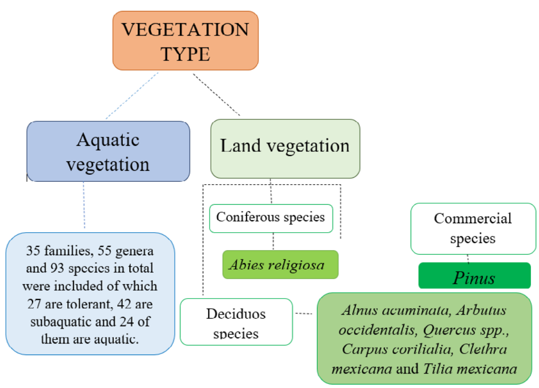
The basin types of soil are Andosol ocric with a surface coverage of 14,228.80 ha, Andosol humic with a surface coverage of 5,894.52 ha and Lithosol with a surface coverage of 5,042.41 ha, whereas Pheozem haplic covers 230.42 ha, Andosol mollic 354.50 ha, Acrisol orthic 209.31 ha, and Luvisol chromic only 125.57 ha. These soils originated recently and have been formed from volcanic ashes and rocks [7].

3.3 Vegetation

Vegetation is composed of pine, pine-oak, oak and mountain cloud forests [8]. At present native vegetation occupies 36.05%, whereas 10.91% by secondary vegetation, the remaining 46.96% of the basin's surface corresponds to seasonal and permanent agriculture where avocado plantations are rapidly increasing.

Due to the ecological and hydrological characteristics in the basin, strict aquatic plants, subaquatic and tolerant plants are found in stratified profile with depth. Although the lake surface in Zirahuen is much smaller than lakes Patzcuaro and Cuitzeo, it has a greater aquatic plants (Figure 2) richness in which the absence of the water lily (*Eichhornia crassipes*) should be highlighted. However, NOM-059-SEMARNAT-2010 includes *Potamogeton amplifolius* as a threatened species, and *Nymphaea odorata* in danger of extinction [2].

Figure 2. *Types of vegetation.*



3.4 Land use

During the last 20 years, the trend of increasing human settlements has caused the decrease in forest coverage. The change in land use from forestry to agriculture, mainly for avocado plantations, tourism and housing has contributed to the decrease in soil fertility and the potential for water capture during the rainy season, as there is no vegetation cover to retain soils, landslides take place, generating a series of sediment loads, which causes floods and siltation, this erosion process promotes the loss in depth of the lake, the increase in turbidity and increase in concentrations of phosphorus, nitrogen and ammonia (Figure 3).

Figure 3. *Land use and vegetation of the Zirahuen's basin.*

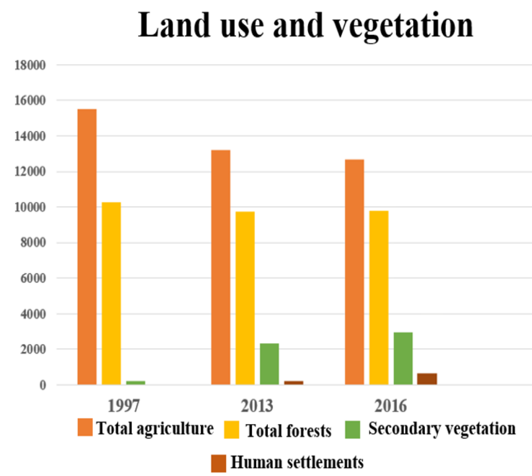
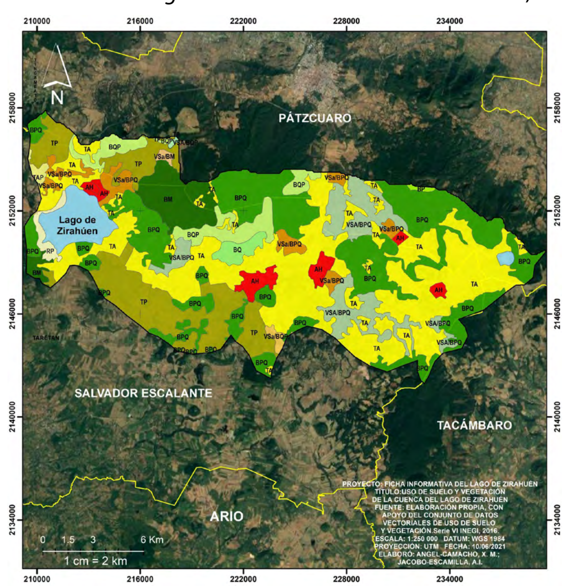


Figure 4. *Land use and vegetation of the basin of Lake Zirahuen, Michoacan.*



Land use of the basin is divided as follows: 46.70% corresponds to agricultural use, 2.43% to human settlements and urban areas, and 3.91% to water bodies; Lake Zirahuen covers 3.6% (Figure 4).

3.5 Lake morphometry

According to most common general parameters [9] the morphological morphometry of Lake Zirahuen is presented in Table 1.

Table 1. *Morphometry of the Zirahuen Lake [7].*

Parameter	Chacon et al. (2010)
Lake surface (A)[km^2]	10.41
Shoreline length (lo) [km]	29.85
Median depth (D_{50}) [m]	20.6
Maximum depth (D max) [m]	43.0
Lake volume (V)[Mm^3]	220.657

3.6 Water quality

Lake Zirahuen vertical thermal stratification in spring, being more evident in summer, with a maximum difference of 6.5°C between the surface and the bottom, due to its deep topography [10].

Table 2. *Water quality [7], [11].*

Parameter	Chacon and Rosas (1998)	Gomez-Tagle et al. (2019)
Electric conductivity (µS/cm)	75.0	255.5
Total suspended solids (mg/L)	2.0	9.55
Total dissolved solids (mg/L)	14.0	163.75
Total Phosphorus (µg/L)	8.7	103.88
Biochemical Oxygen Demand (mg/L)	1.6	8.83
pH	8.1	7.76
Chlorophyll (µg/L)	3.77	24.43
Chemical oxygen demand (mg/L)	2.3	43.44
Ammonium (NH_4)	0.04	0.02

Lake Zirahuen has experienced changes in water quality parameters (Table 2) indicating that there is a process of eutrophication in the lake.

3.7 Water balance

Lake Zirahuen is an endorheic system, with annual precipitation and evapotranspiration of 1,098.8 mm and 1,233.5 mm, respectively [5]. According to the results of water balance equation, the basin has a negative water balance, thus having a water deficit of 10.92% (Table 3), however, the lake has a positive water balance of 51.84% with an annual input of 36,883 Mm^3 and output of 17,762 Mm^3 (Table 4).

Table 3. *Water balance Zirahuen basin [5] [12] [13].*

INPUT (Mm3)		
Precipitation (1,098.8mm per year)	300.412	100%
Surface runoff	270.371	90%
Infiltration (10%)	30.041	10%
Input	300.412	100%
OUTPUT (Mm3)		
Evaporation (1,233.5mm per year)	337.2389	100%
Output	337.2389	100%
Water deficit	**-36,83**	-10,92%

Table 4. *Water balance Lake Zirahuen [5] [7] [11].*

INPUT (Mm3)		
Precipitation (1,098.8mm/year)	11.439	31%
La Palma River	17.541	47.56%
Secondary sources	7.903	21.56%
Input	36.883	100%
OUTPUT (Mm3)		
Evaporation (1,233.55mm/year)	12841	12.29%
Extractions	4.921	27.71%
Output	17.762	100%
Positive balance	**19.121**	51.84%

3.8 Fish and fishery

In 1933, the largemouth bass (*Micropterus salmoides*) was introduced to increase fishery productivity and to promote sport fishing [14]. In 1997, five species were reported to be endemic including: *Goodea atripinnis (*Goodeidae*) Alloophorus robustus (*Goodeidae*), Allotoca diazi (*Goodeidae*), Chirostoma attenuatum zirahuen,* this species known as "charal" *(*Atherinidae*),* and *Chirostoma estor copandaro (*Atherinidae*)* this latter is the most commercially valuable species known as "pez blanco". However, in 2013 [15] and 2015 it added the species *Skiffia lermae* (Goodeidae) to the list, as one of the most representative endemic species of the lake. In 2017 [16], two more endemic fish species were identified in Lake Zirahuen: *Allotoca dugesii* and *Allotoca meeki,* both from the *(*Goodeidae*)* family. The rainbow trout (*Oncorhynchus mykiss*) and carps (*Cyprinus carpio*) have been also identified in the lake with no specific date of introduction [17].

Based on the fishing data from the Secretariat of Fisheries, during the period 1984-1996, the fishing productivity of Lake Zirahuen had an average of 12.72 ton/year and in the year 2000 it achieved up to 15.61 ton/year. This estimate includes only the capture of four commercial species: whitefish (1.09 ton/year), charal (3.12 ton/year), carp (8.27 ton/year) and largemouth bass (3.12 ton/year) [18].

3.9 Impact stories

In the basin of Lake Zirahuen one of the main economic activities has been agriculture for the past 2,300 years [19], this activity being one of the latest activities implemented in this zone. From 1998 indian P'urhepecha communities began reforestation actions near the shoreline to strengthen the land and avoid landslides. In the year 2010 funded reforestation and soil preservation projects in the area.

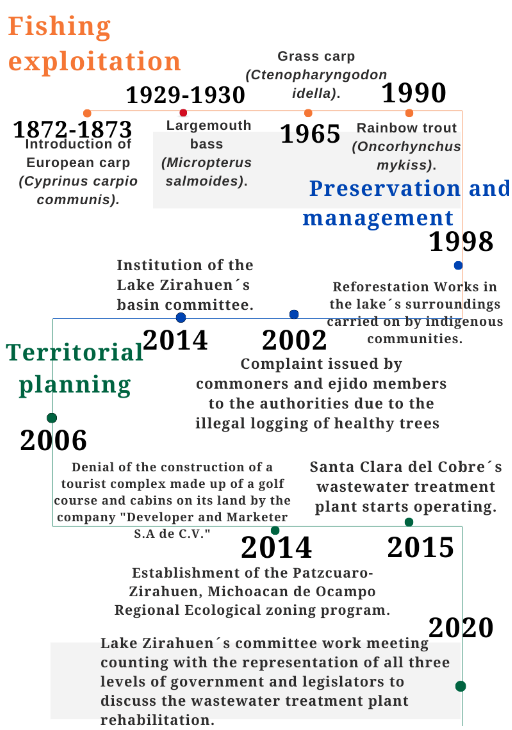
Conflicts have occurred between local communities and private enterprises derived from the increase of touristic infrastructure such as hotels, motor boating, restaurants, and paved roads, thus, members of communities decided to create the organization known as Unión de Comuneros Emiliano

Zapata with the purpose of defending their land and collective benefits of the communities over private interests, one of these projects with touristic purposes was the road surrounding the shoreline of the lake. In 2015 the water treatment plant located in the town of Salvador Escalante started operations according to the municipality and State's Water Authority this facility treats 18% of total sewage that flows through the La Palma or El Silencio stream and into Lake Zirahuen; over time a variety of policies have been implemented with regard to fishing activities, land-use planning, conservation and resource management.

3.10 Governance challenges

According to the results of this study, challenges are contemplated for governance of Lake Zirahuen are as follows (Figure 5):

Figure 5. *Governance challenges.*



4. Conclusion

The effects of ecological deterioration are caused by increasing deforestation, incompatible agriculture practices, erosion, siltation, and untreated sewage discharges, in addition to increasing pollution by artisanal activities and chemical components associated with fertilizers and plaguicides.

The synergic effect of deforestation and intensive agricultural activity, specifically avocado and berry plantations, has generated a severe environmental impact on lake water quality, increasing siltation, turbidity accelerating the process of cultural eutrophication. The water quality of the stream La Palma deteriorates as a primary lake water input.

These processes now are manifested in algae blooms that never were observed before. Recent reports [12] are now evaluating the effects of *Microcystis aeruginosa* and its microcystin products on human health and water consumption risks.

To approach a successful ecological restoration of Lake Zirahuen, a strategic plan is necessary in which social participation is fundamental to regulate the growth of avocado and berry plantations by the destruction of pine forest, to decrease the indiscriminate use of plaguicides, and to insert touristic and urban infrastructure only by rigorous studies on environmental impact.

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Mapping challenges and opportunities in water governance institutions at Escaba Reservoir, Tucuman, Argentina

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Abstract

Lake basins in Latin America face challenges in water resource management and natural resource conservation due to changes in land use, climate variability and governance process deficiencies. In the basins of the Escaba reservoir, Northern Argentina, droughts and floods events, decreased riparian forest quality, and algal blooms have impacted the regulation of ecosystem services and socioeconomic development. To map governance, we consider the pillars of institutions and policies of the Integrated Lake Basin Management (ILBM) framework proposed by the International Lake Environment Committee. First, we propose quantifying the institutional interaction percentage using the spatial boundaries of each institution and a spatial

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overlapping with geographic information systems. We measure institutions at the three levels of public administration (national, provincial and municipal) responsible for managing and administering regional water resources. Second, we compile and spacialize the most frequent water-related socio-environmental problems. Finally, we assess the governance challenges and opportunities for each hierarchical level according to the territorial scope. The results find 21 institutions in the area. The Escaba reservoir zone has the highest percentage of institutional interaction (91.6%) and the highest number of problems at the same point, demonstrating a strong institutional structure; however, community participation in decision-making is needed to reinforce the pillars. Mapping governance using the spatial institution-environmental problem relationships facilitates the visualization of possible management opportunities, identifying the institutional synergies needed to promote the ILBM framework in the basin.

Keywords: *Mapping governance, ILBM, basin lakes, institutions, water policy*

1. Introduction

Governance is the exercise of political, economic and administrative authority in managing a country's affairs at all levels through mechanisms, processes and institutions for citizens to exercise their rights, express their interests and fulfill their obligations [1]. Water governance is the systematic and interdisciplinary process conducted at different orders of government, influencing decision-making on water resource management [2].

Lake and reservoirs governance presents challenges at regional levels, especially in Latin America, which is characterized by weak, underfunded governance mechanisms with confusing accountabilities and inadequate social participation in decision-making [3]. In the Argentine Republic, the water resource governance challenges emerge from the weak horizontal and vertical communication between institutions, and institutions' passivity in administrating water resources particularly impacts the economy and citizenry [4]. Argentine water governance occurs on three main levels: national, provincial and municipal. The nation dictates the laws and regulations for the provinces to guarantee the correct exercise of governance through decentralized bodies, which execute the national laws and enact their own forms of government based on the principles and character of each province. This hierarchical form of organization results in a complex institutional network that communicates vertically (nation-municipality) and horizontally (municipality-municipality and province-province), with interactions that are difficult to measure [5,6].

To achieve proper governance, consensus mechanisms must ensure the participation and communication of all institutions at each hierarchical level; however, quantifying governance quality is difficult due to the numerous relationships and policies. ILEC and RCSE [7] proposed the ILBM (Integrated Lake Basins Management) framework, a comprehensive approach to lake and reservoir management that synthesizes governance into six basic pillars: 1) Institutions, 2) Policy, 3) Participation, 4) Technology, 5) Information, and 6) Financing. When balanced, these pillars represent optimal governance for water bodies. Governance quality can be measured based on the state's bureaucratic procedures, the services and products it provides, or each bureaucratic institution's autonomy capacity [8]. Current governance studies often ignore the spatial dependence of the institutions involved [9], e.g., only mapping environmental conflicts, complicating the visualization and interpretation of their responsibility for the issues [10].

Using a geographic information systems (GIS) environment, this work maps water governance through the spatialization of institutions and socio-enviromental problems to determine the interaction between the institutions involved in managing water resources according to the institutional scope, assessing the governance challenges and opportunities for each hierarchical level exploring participation pillar. The case study covers the basins of the Escaba reservoir in Tucuman province, Argentina, an area that has experienced several floods and droughts events, with severe effects for the population, the environment and the economy due to climate change and the weak management of the reservoir's supply basins and the regulation of outflows.

1.1 Study area

Escaba reservoir is fed by the Singuil and Chavarria rivers, in northern Argentina in Tucuman Province in the department of Juan Bautista Alberdi; it was built in 1940 for irrigation, electricity production, recreation and flood control. It is located 650 m above sea level with an area of 541 hectares and a storage capacity of 138 hm^3 [11]. The reservoir network is designed for irrigation, the Escaba reservoir links to the Batiruana compensating dam, downstream of the Marapa river. This river flows into the Rio Hondo reservoir, which flows into the Mar Chiquita lagoon [12]. Escaba basins are part of the Marapa-San Francisco basin, which extends through the provinces of Catamarca and Tucuman [11].

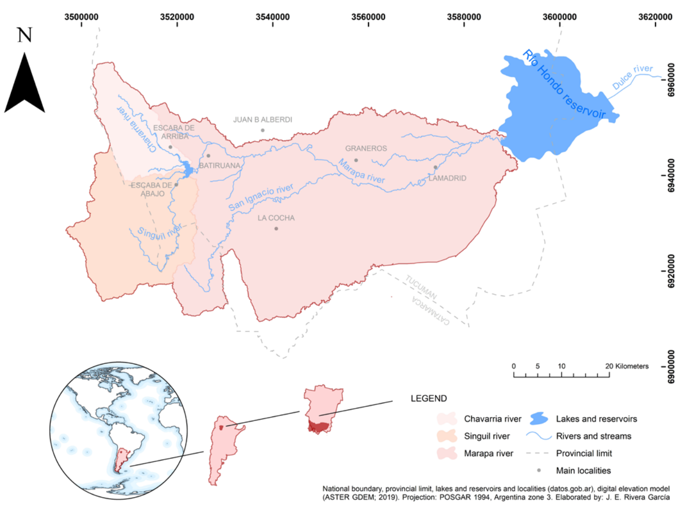
The region presents a very accidental relief, with altitudinal elevations ranging from 599 to 2,849 masl (NASA/ASTER, 2020) and a subtropical monsoon climate with dry winters and rainy summers (average rainfall 1,200 mm; mean annual temperature 17.6 °C) [14]. The climatic and landscape conditions produce a very high water yield, mainly in the mountainous areas of the basins, with rainfall exceeding 800 mm per year, favoring intensive agriculture. Figure 1 depicts the Escaba reservoir supply basins and discharge basin.

2. Material and methodology

2.1 Institutional interaction percentage

The institutional interaction percentage was calculated based on the definition of the territorial scope of the institutions, developed in three steps: Data collection and prioritization, georeferencing, and institutional interaction percentage calculation. First, the institutions managing and administering the water resources were classified according to the three political levels of the Argentine administration (national, provincial and municipal). Second, the institutions were classified based on the political level, creating a buffer zone for each institution defined by its political hierarchy and geographic boundary. Hence, the representative scope of the national institutions contains the whole country, the provincial scope contains the area of the province, here Tucuman, and the municipal scope is defined by the localities that influence water resource management, whose scope was defined as 1 km according to the provincial scale. Finally, the percentage of institutional interaction was defined based on the territorial boundaries overlapping according to the three hierarchical categories, expressed in binary raster file format, where 1 is assigned to the polygon of the national institutions, 10 to the polygon of the provinces, 100 to the local ones, and 0 to the remaining area of the provinces and localities. Thus, by adding the set of scopes for each level, it is possible to count the number of institutions in each hierarchy and measure the degree to which they interact in a given region. The maximum governance was 833 and the minimum was 003, with the unit digits representing the number of national institutions and the tens and hundreds representing the provincial and local institutions, respectively. The average, dividing the number of institutions involved for a given region by the total number of institutions in each hierarchy, represents the percentage of institutional interaction. For example, code 433 indicates a percentage of 83.3 ((4/8)+(3/3)+(3/3))/3, while code 133 indicates a percentage of 70.8 ((1/8)+(3/3)+(3/3))/3.

Figure 1. *Study area. Escaba reservoir basins.*



2.2 Mapping socio-environmental problems and exploring governance quality

The socio-environmental problems were geo-referenced according to the information found in journalistic records, literature reviews and reports in social networks on extreme events. Identifying 11 problems related to poor land management and hydrometeorological phenomena, including floods and droughts, poor soil management practices and infrastructure losses, distributed in the Singuil and Marapa river basins as well as in the reservoir and its periphery (Figure 2).

To explore the governance quality of the institution interaction, we explored the institutions' webpages to extract meeting records, maps, reports, and participation and interaction evidence, such as calls for meetings and records of social media dissemination.

3. Results and discussions

3.1 Percentage of institutional interaction

The institutional interaction results evidence a robust political structure, with 21 institutions (3 national, 3 provincial and 15 local) aiming for the protection and equitable distribution of natural resources. These were subdivided into 8 categories (see Table 1).

Low institutional interaction percentages (33-66%) were found in most of the territory. There is a low institutional interaction percentage for the Marapa basin. The highest interaction percentage, 83.3%-91.6%, is concentrated in the Escaba reservoir zone, evidencing a good intuitional structure. However, a lack of communication between governmental institutions of the same class (horizontal communication) was identified. Also, there is a weak provincial institutional interaction in the upper parts of the Singuil river basin regarding Tucumán and Catamarca. Only one institution is representative: the Sali Dulce basin committee.

Unclear evidence of institution interaction was found. Some institutions' webpages are not updated and present a lack of public data availability. There

Table 1. *Institutions involved in Escaba lake basins water management at the political level.*

LEVEL	CLASS	INSTITUTION
NATIONAL	1	ORSEP
	2	COHIFE
	3	CONICET
PROVINCIAL	1	Hidroeléctrica Tucumán
	2	Recursos hídricos Tucumán
	3	Secretaría de Ambiente de la provincia de Tucumán
LOCAL	1	Comisión de embalse y desembalse del dique Escaba
	2	Ente Autárquico
	3	Junta de regantes
	4	Escuela No° 190 Escaba de Abajo Escuela No° 318 Escaba de Arriba Escuela No° 73 El Corralito
	5	Localidad de Batiruana Localidad de Escaba de Arriba Localidad de Escaba de Abajo Localidad de Villa Escaba
	6	CAP´s Villa Escaba CAP´s Escaba de Abajo
	7	PCMA Escaba
	8	Municipio Escaba

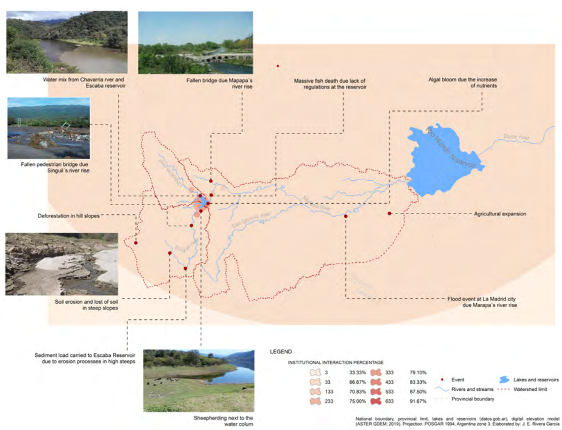
is no record of the participatory pillar, e.g. public calls to meetings or invitations to social actors. Invitations to society were difficult to find, only by informal interviews. Academia institution interaction was found in a flood commission, as the first example of interdisciplinary efforts to promote science-based decisions for flood management.

An impact story concerning actions to improve the natural resources management in lake basins found that the PCMA (2019) promotes bat conservation and biodiversity based on environmental education and protected areas, an example of excelent interaction between the nation, the province, academia and the local population. Another impact story that coincides spatially with a significant institutional interaction percentage is the Batiruana Biological Station, promoted by national agencies (CONICET), private initiatives (Miguel Lillo Foundation and Hidroeléctrica Tucumán) and the town of Batiruana. However, to achieve the station's objectives, collaboration between localities (Batiruana, El Corralito and Villa Escaba) is necessary due to their lack of connection, according to the institutional interaction percentage results (Figure 2). This could be improved by creating regional decentralized organizations that transmit collective needs to higher-level public administration.

Drought-related water management practices affect the regions surrounding the reservoir and the periphery of the rivers in the Singuil and Marapa river basins, highly impacting the local economy. Hydrologic emergencies were declared several times, and the decision-making on water distribution was via one or two institutions; several journal reports were found on this issue (La Gaceta, April 14, 2015). Moreover, the riparian forest quality is poor around the Singuil river, near the reservoir, due to poor animal management by locals. No restoration plans were found.

The problems were heterogeneously spatially distributed. The Escaba reservoir basin supply has 45% of the water-related environmental problems of the reservoir areas. The flood events highly affected the influential Marapa basin, depending on the flow regulation of the Escaba reservoir, mainly Lamadrid City. Moreover, soil erosion and algal blooms were mainly found in zones near the reservoir (Figure 2). Concerning social media messaging on environmental issues, 80% was related to flood impact and economic loss by locals.

Figure 2. *Map of social problems and institutional interaction percentages.*



3.2 Challenges and opportunities

Governance opportunities need to focus on novel interaction, collaboration, and participation strategies.

Developing acceptable solutions, including science-based informed decisions, we identify the main challenges and propose the followed opportunities:

Table 2. *Water governance institutions challenges and opportunities in Escaba reservoir.*

CHALLENGES	OPPORTUNITIES
• Improve institutional interaction and vertical and horizontal communication. • Bi-provincial (Catamarca and Tucuman) interaction to improve reservoir management. • Promote sustainable land management to maintain the local economy in the reservoir's zones. • Increase funding to promote participatory action between institutions • Accelerate actions to improve water governance in the Escaba reservoir basin before new extreme events occur.	• Develop a participatory hydrological management plan. • Promote social participation, involving social actors in water management decisions. • Generate collectives that strengthen local action. • Promote environmental education for knowledge on the environment. • Integrate academia into decision-making processes. • Improve soil management practices at the local scale. • Promote information centralization to create an Escaba basin lake GIS. • Generate an early flood warning system to safeguard local populations.

4. Conclusions

The water management institutional network in the Escaba lake basins is strong, comprising 21 institutions. However, the participatory pillar in the IBLM approach is weak, as evidenced by weak social participation and institutional interaction. Several socio-environmental problems affect the population and natural resources, generating economic losses and promoting social inequity. Collective objectives by the institutions involved in water resource management is needed. Mapping governance considering the spatial scope of the institutions can improve the understanding of the relationship between institutions and socio-environmental problems. This clear visualization can enhance their synergy and improve water governance by identifying each institution's responsibility level. Our proposed method can be used as a proxy to evaluate the IBLM approach, enabling institutions and participatory forums to efficiently present the connections.

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Talayuelas Lagoon, Spain. An example of hidden groundwater-surface water interaction

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Abstract

Talayuelas Lagoon is a Protected Natural Area of 29.66 hectares located within a Site of Community Interest (SCI) in the province of Cuenca (Spain). It is a Micro-Reserve since 2003, in order to protect species and their habitats, within the framework of strategies and policies for the conservation of biodiversity in Europe. Despite the fact that the Management Plan for the SCI area indicates as a fundamental objective the definition of the state of conservation of components of natural heritage, biodiversity, geodiversity and ecological and geological processes, the groundwater component has been completely overlooked. In fact, there are no detailed investigations of the groundwater hydrodynamics in the study area. For this reason, the Instituto Geológico y Minero de España (IGME-CSIC) has addressed the study of the Talayuelas Lagoon within the framework of a research project that includes a number of wetlands. The work carried out has allowed the development of the conceptual model of the wetland, driven by their physical environment factors and components of the hydrological system.

Precipitation and temperature data for the area have been obtained from the nearest meteorological station with complete records. The Thornthwaite

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method and the RENATA computer application (IGME-DPA) have been employed for the estimation of surface runoff and deep infiltration. Finally, in contrast to previous studies, the calculated average water balance (period 2009-2015) has allowed to verify the existence of a significant infiltration component, thus validating the conceptual model.

Keywords: *Water balance, ground water, water framework directive, wetland*

1. Introduction

The Water Framework directive (European Commission, 2000) establishes a framework for the protection of water resources. One of the pillars on which the Directive rests is the sustainable use. This requirement poses a series of new challenges, among which are the effective and sustainable management of aquifers, the need to achieve a good state of all waters, the purification of wastewater and the maintenance of the functionality of ecosystems with respect to soil and groundwater, among others.

Its key principles include prevention of further deterioration and protection and improvement of aquatic and terrestrial ecosystems, as well as terrestrial dependent wetlands. In the Royal Decree for the Regulation of Hydrological Planning (España, 2007), it is stressed that it is compulsory to include in the National Inventory of Wetlands those wet areas included in the register of protected areas of the Water Framework Directive. Terrestrial ecosystems that depend directly on groundwater can affect the status of a groundwater body, so sustainable water management is essential for the achievement of the objective of maintaining their functions and sustainability.

The lagoon (Figures 1 and 2) is located at the eastern end of the province of Cuenca, in the municipality of Talayuelas, inside the region of the "Serranía Baja de Cuenca", next to the border with the Valencian Community. It is a semi-permanent humid zone, at an altitude of about 900 meters.

There are periods when the lagoon is dry, in which the prairies and grassland of the bucket have been used for cattle grazing (Cirujano and Medina, 2014), although these activities have now ceased.

Figure 1. *Talayuelas Lagoon.*

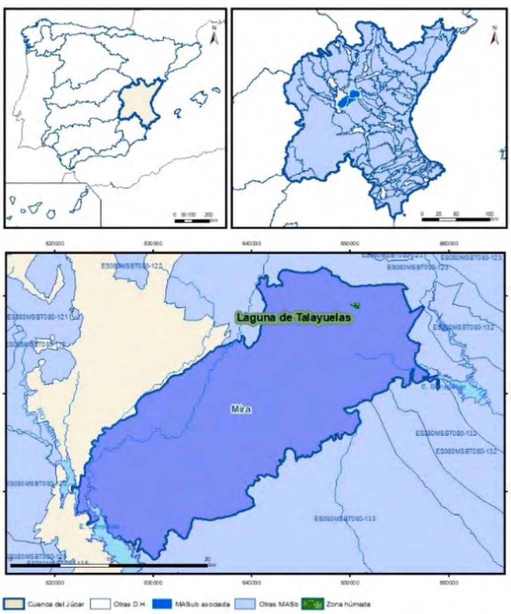


Figure 2. *Location of the Talayuelas Lagoon.*

Physicochemical and nutrient analyses in water and sediments show low levels of inorganic nutrients and medium content in organic matter, respectively (Murueta Figueroa, 2014), which seems to indicate that there has been no significant effect on the Lagoon due to the anthropic impacts suffered prior to its declaration as a micro-reserve.

2. Legal framework

In accordance with the provisions of Law 42/2007, of December 13 (España, 2007), on Natural Heritage and Biodiversity, the Ministry of Agriculture, Food and Environment is responsible for proposing places of community importance (SCI). The ministry is also responsible for the declaration of Special Conservation Areas (ZEC, ZEPA) and Special Protected Areas in the case of spaces located in marine areas under national sovereignty or jurisdiction, provided there is no ecological continuity of the marine ecosystem with the terrestrial natural space subject to protection.

Evaluation, approval, authorization or conformity of plans, programs and projects that may affect the Natura 2000 Network is regulated in some Autonomous Communities through the publication of decrees in their corresponding Official Diaries. By Decree 17/2003 of 4 February 2003, the Microreserva "Laguna de Talayuelas" was declared in the municipality of Talayuelas, province of Cuenca (Castilla La Mancha, 2003). In 2015, the Directorate General of Forestry and Natural Areas of the Ministry of Agriculture of the Regional Government of Castile-La Mancha approved the Management Plan of the Site of Community Interest (SCI).

3. Materials and methodology

To characterize the wetland, a study aiming to analyse the natural physical environment in its different aspects (climate, geology, hydrogeology, etc.) has been accomplished.

3.1 Hydrology and geomorphology

The lagoon is located (Figures 2 and 3) in a space formed by the sub-basins of the San Marcos, Magro and Ojos de Moya rivers and several streams, among which the Dehesa or the Hoz streams stand out, all of them tributaries of the Júcar. To the south is Laguna de Abajo, which is normally dry.

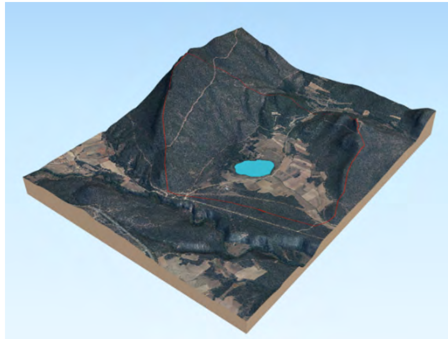


Figure 3. *Talayuelas basin.*

The topographical and geomorphological characteristics show a landscape dominated by relatively large massifs, with mountain ridges (from which various streams flow) and ravines.

3.2 Hydrology and hydrogeology

The materials that constitute the substratum on which the lagoon is settled are composed of detrital materials (clays, sands and gravels) of low thickness (1-2 meter), from the Quaternary, under which there are impervious loamy and clayey materials of the Trias Keuper.

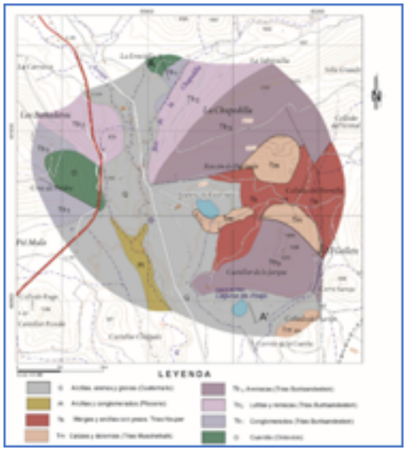
Nevertheless, according to the detailed geological observations carried out, it has been possible to confirm the existence of permeable Muschelkalk carbonates in its southern edge. To the southwest of the lagoon, Tertiary materials outcrop (Figures 4 and 8).

From the hydrogeological point of view, the lagoon is located in the Groundwater Body 080.134 Mira, in the Júcar River Hydrographic Basin, whose total area is about 500 km^2 (Figure 2).

Its Southwest boundary is located in the Contreras Reservoir and the northwest boundary in the Henares riverbed. To the north, it is bordered by the town of Talayuelas and to the southeast; it extends to the towns of Sinarcas and Camporrobles, in Valencia, including the Sierras de Aliaguilla and Mira.

On the other hand, the piezometric level identified in the vertical of the lagoon is located around 770 meters above sea level.

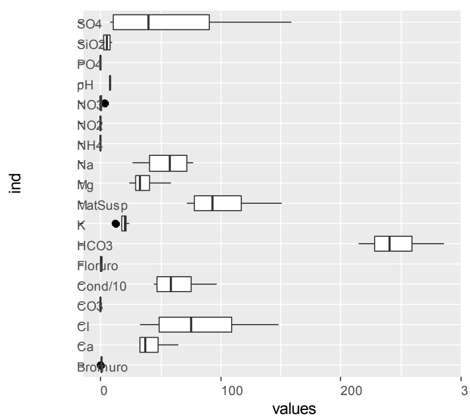
Figure 4. *Geological map of the lagoon environment.*



3.3 Hydrochemical characterization

During the course of several field campaigns, the main physical-chemical characteristics of the water in the lagoons were investigated (Figure 5).

Figure 5. *Boxplots of concentrations in Talayuelas samples.*



Four sampling campaigns have been carried out (05-27-2014, 07-29-2014, 11-19-2014 and 03-11-2015). At the same dates, a sample was taken for analysis in the IGME laboratories at its facilities in Tres Cantos (Madrid).

Figure 6 shows a generalized increase in Na, K, Ca, Mg, sulphates and chlorides concentration in each of the four sampling campaigns carried out. During the same time interval bicarbonates concentration decreases, while conductivity also shows an increasing trend. Data could point to a possible process of enrichment in solutes.

The Piper diagram of Figure 7 also shows the increase in the concentration of sulphate plus chloride during the sampling period, together with the decrease in alkalinity.

However, after a detailed analysis, it was found that low rainfall and high temperatures, with the consequent increase in evaporation, characterize the period.

Figure 6. *Evolution of the relationship among ions.*

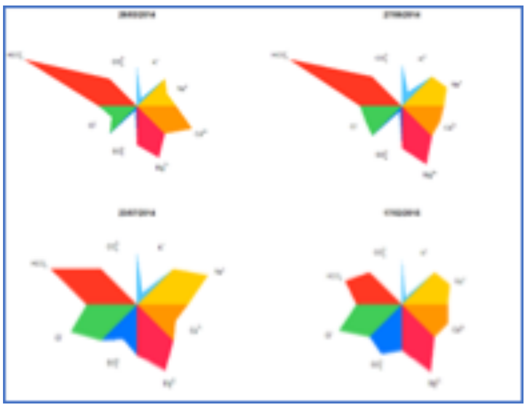
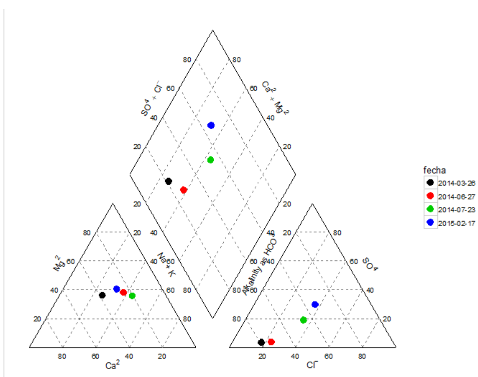


Figure 7. *Piper diagram for water chemistry analysis of samples.*

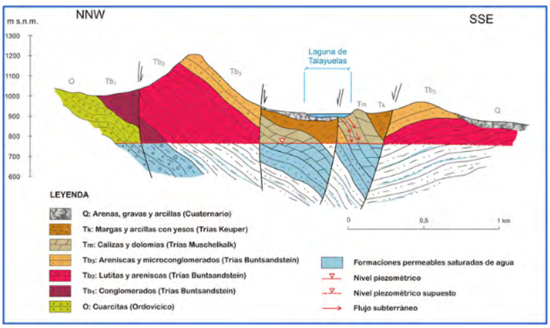


3.4 Conceptual Model

As a result of the work carried out, after analyzing the existing data and the field detail survey, a conceptual model of wetland operation has been developed (Figure 8), which reflects both the factors of the physical environment and its hydrogeological characteristics.

Regarding this, the lagoon only receives water from its catchment basin and the outputs are due to evapotranspiration and deep infiltration through the carbonates of the Muschelkalk formation.

Figure 8. *Conceptual model of hydrological functioning of the Talayuelas Lagoon.*



4. Information processing

The treatment and integration of the spatial data obtained in the different campaigns carried out in the field, from the recording of piezometric levels and from the existing information has been accomplished by means of QGIS (QGIS Development Team, 2016).

On the other hand, the recharge of water to the aquifer has been calculated using the Thornthwaite method (Thornthwaite, 1957), which allows estimating the potential and real evapotranspiration of a site for each month of the year based on a series of basic parameters (fundamentally precipitation and temperature), from which the monthly heat indices are obtained. To this aim, the RENATA computer application (DPA-IGME, 2012) has been used, developed jointly by the Instituto Geológico y Minero de España (IGME-CSIC), the Provincial Council of Alicante and the Aljibe Company.

In order to calculate run-off and infiltration values (based on the geological characteristics of the materials), the sub-basin of the lagoon has been divided into four sectors (Figure 9).

Each of the sectors has been assigned a runoff threshold and a field capacity has been assigned (Table 1) based on experience in the area and hydrogeological criteria.

Finally, the treatment of the climatic series has been carried out using the R programming environment (R Development Core Team, 2011) and its RStudio interface (RStudio Team, 2015).

Figure 9. *Division into sectors of the lagoon basin.*

Table 1. *Sectors considered for the calculation of infiltration.*

Id	Km2 (total 2.63)	% area	RU	Soil type	P0	NC
PL	0.86	33	80	B	22	70
Tm	0.45	17	25	A	90	36
Tk	0.35	13	5	C	14	78
Tb3	0.97	37	25	B	14	78

5. Water balance

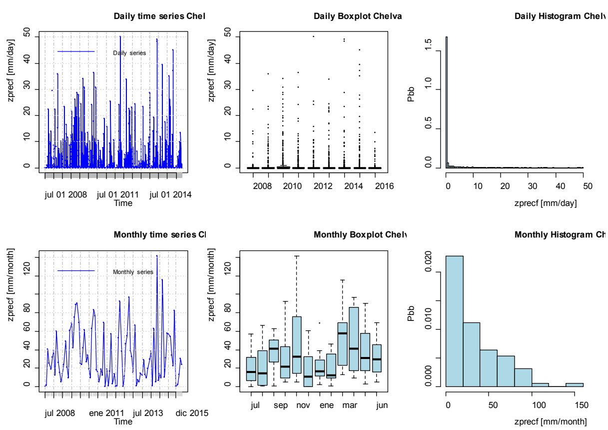
The analysis of the water balance of a system consists of the quantification of the inputs and outputs of water to the said system, of both surface and underground origin (Sánchez, R. and Viñals, M.J., 2012).

The main water inlet in the Talayuelas endorheic basin consists of rainfall, which produces contributions by surface runoff in addition to direct precipitation on the lagoon.

To calculate the balance, the Chelva station has been used. It is the closest station that has complete records of both precipitation and temperature. The Chelva latitude (39.753 decimal degrees) has been used to calculate the heat index using the Thornthwaite method.

Given that Chelva station is located at an altitude of 515 meters and the solera level of the lagoon (Cebriá Romero, 2014) is located at 894.5 meters above sea level, a correction has been introduced in the average temperatures based on the gradient thermal. According to De Crespo and Gutiérrez (2011), the relationship between the mean annual temperature and altitude in the Iberian System, based on temperature records from meteorological stations located in said system, is -6.6 ºC per kilometer. Therefore, taking into account that the difference between the altitude of the Chelva station and the level of the lagoon base is 379 meters, a correction of -2.2 ºC has been introduced in the temperature series.

Figure 10. *Precipitation at Chelva meteorological station.*



The starting point for balance calculation has been the monthly series of precipitation (Figures 10 and 11) and temperature, whose treatment has been carried out in the ClimClass package (Eccel et al., 2015) within the programming environment R.

An algorithm adapted from Thornthwaite and Mather (Thornthwaite, 1957) has calculated potential evapotranspiration, in order to compare the results obtained with RENATA software.

The temperature, on the other hand, presents a very pronounced seasonal variation, with especially high values in the months between June and September, with monthly average temperatures close to 25 ºC during July and August and mean temperatures of around 10 ºC during the months of January and December.

Figures 12 and 13 show the daily and monthly temperature values at the Chelva station for the period between July 2008 and April 2016, as well as the histograms and box plots of daily and monthly time series.

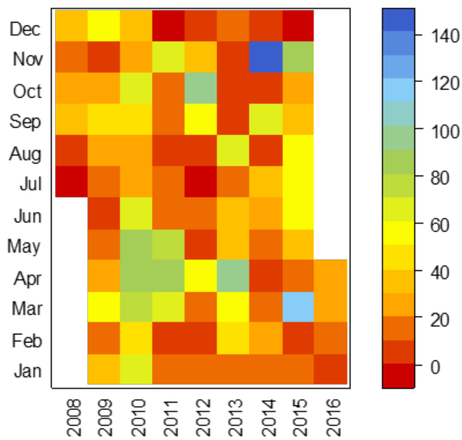


Figure 11. *Distribution of precipitation at Chelva meteorological station.*

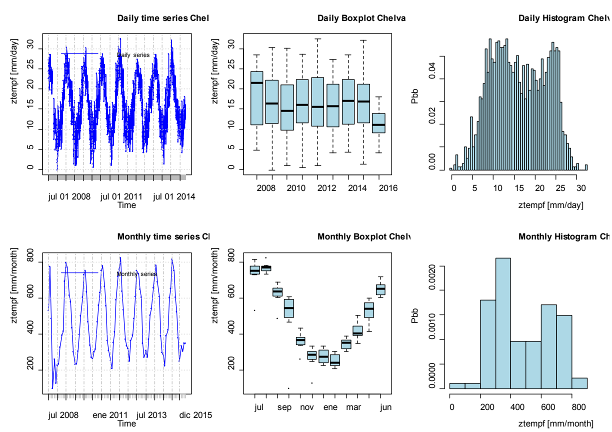


Figure 12. *Temperature at Chelva meteorological station.*

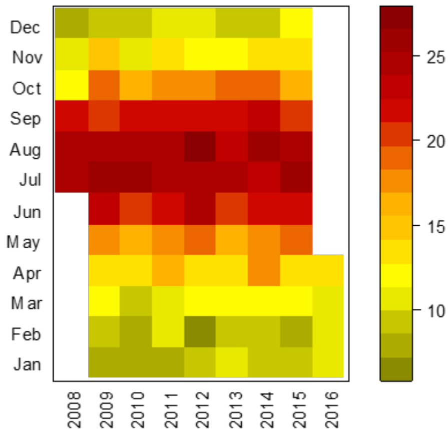


Figure 13. *Distribution of temperature at Chelva meteorological station.*

6. Results and discussion

Despite the variability of rainfall, which causes oscillations in the level of the lagoon (eventually drying up in years of drought), the average water balance by sectors (hm^3) has been calculated by means of RENATA (Tables 2 and 3).

TABLE 2. *Water balance by sector of the Talayuelas basin.*

Sector	P	ETP	ETR	LLU	I	R
PL	0,47	0,85	0,23	0,23	0,18	0,056
Tm	0,15	0,26	0,07	0,07	0,07	0,000
Tk	0,27	0,48	0,03	0,23	0,17	0,064
Tb3	0,20	0,36	0,16	0,04	0,03	0,005
TOTAL	1,09	1,95	0,49	0,57	0,45	0,125

P = Precipitation, ETP = Potential evapotranspiration, ETR = Actual evapotranspiration, LLU = Useful rain, I = Infiltration, R = Runoff

The water surplus has been calculated by applying the Thorntwaite method using the RENATA software.

According to the calculations made, the average balance in the Laguna de Talayuelas is the one that appears in Table 3, assuming that the variations in the level of the lagoon in the long term are not significant.

Taking into account that the total surface of the basin is 2,635 km^2 and the approximate surface of the water mirror is 6 Ha, the surface that can produce surface runoff is 2,575 km^2.

The elaboration of the soil water balance has made it possible to contrast this model, since the entrances to the lagoon are equivalent to 152,500 m^3 per year, coming from the precipitation on the lagoon and the runoff on the basin (excluding the area occupied by the lagoon itself). Given that the existence of an approximately constant level for the water table has been verified, it means that a loss of 102,500 cubic meters per year is taking place due to infiltration into the lagoon.

Table 3. *Average water balance of the lagoon.*

	Inputs		**Outputs**	
	Precipitation	Runoff	Evaporation	Seepage
	27500	125000	50000	102500
		Total	**152,500**	

The evaporation produced in the lagoon is obtained as a product of the reference monthly evapotranspiration by its surface. This produces an average annual evaporation of 50,000 m^3 (0.05 hm^3). The direct precipitation on the lagoon translates into 27,500 m^3.

7. Conclusion

The Talayuelas lagoon is a wetland located in an endorheic basin, apparently without connection to the aquifer. However, detailed geological exploration has confirmed the existence of permeable carbonate materials from the Muschelkalk, south of the lagoon and in direct contact with its water, which is reflected in the conceptual model developed.

Given that the maximum capacity of the lagoon is 2.3 hm^3, for the surface of 9.92 ha, and that for the average surface of the water mirror it is

0.7 hm^3, equivalent to 70,000 m^3, it means that the average annual renewal rate is greater than unity.

The existence of a water relationship between the lake and groundwater implies that an approximate loss of 100,000 cubic meters per year is taking place due to infiltration into the lagoon

There are two facts that support this hypothesis. In the first place, the depth of the piezometric level, located 125 meters below the bottom of the lagoon, and the occurrence of permeable materials, the connection is obvious.

Secondly, the hydrochemical data, which indicate an acceptable quality of the water, which is incompatible with a balance in which the contributions were equal to the output (evaporation), since in this case there would be an increase in the concentration of solutes and therefore a salinization of the water.

As the main recommendation to achieve sustainable management of the ecosystem, it is considered essential to include the management of groundwater resources in management plans. It is also necessary to install piezometric control points upstream and downstream of the lagoon in order to monitor its water resources, both in quality and quantity.

Acknowledgements

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Xochimilco Lake, Mexico. The importance of its preservation: challenges and opportunities

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Abstract

At present-day Xochimilco Lake is the habitat of multiple species, a source of oxygen and natural resources for Mexico City, and an important tourism and cultural center. This work presents a review of the historical, socioeconomic, environmental, and ecological aspects concerning Xochimilco Lake with the purpose of knowing the problematic surrounding the gradual loss of this space and identifying the challenges and opportunities for its rescue and preservation. It was found that the lacustrine area has become a eutrophic wetland, due to diverse land-use practices, urbanization, and the quality of the treated water supplied to the system. It is estimated that 55% of the endemic species are found established in some state of conservation. Among the main challenges and opportunities for political, social, and scientific actors, we find the following: improving the quality of the water through particular strategies, such as the bioremediation of the lacustrine

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system, continuing with the protection of endemic species, preserving the chinampera culture, and incentivizing sustainability in tourism and the use of the resources, with the aid of the circular economy.

Keywords: *Xochimilco Lake, wetland, chinampas, state or status of conservation, circular economy*

1. Introduction

Xochimilco, located in Mexico City, dubbed as the Venice of Mexico, comprises a network of canals, chinampas (floating island gardens), and small lakes, of approximately 203 km [1, 2, 3]. The canals and lagoons, variable in depth, are fed by the treated water of the "Cerro de la Estrella" "San Luis Tlaxialtemalco" water-treatment plants, which supply 1 m^3/s and 0.225 m^3/s, respectively [1, 4]. The lacustrine plane presents altitudes of less than 2,240 meters above sea level (masl) [5]. The climate is temperate–sub-humid, with rainfall during the summer [6]. Annual precipitation ranges between 200 and 900 mm of water, and the mean annual temperature is 15.9 °C [2].

In the region of Lake Xochimilco, interest in conserving the ecosystem and the cultural richness has led to the participation of native peoples, civic organizations, academic institutions, and independent citizens, in carrying out works in diverse aspects such as socioecological studies, the analysis of environmental contamination, the preservation of diverse native endemic and migratory species, conservation of the chinampas, restoration practices, the adaptation of environmental remediation technologies, the uses and applications of the environmental services of the zone, etcetera [1, 4, 7, 8, 9, 10, 11].

In this review, information is gathered on the environmental, cultural, touristic, and socioeconomic importance of Lake Xochimilco. Likewise, one becomes aware of its deterioration and the efforts channeled to conserve it, with the purpose of identifying the current challenges and opportunities in order to contribute to its preservation, because the Lake is of great cultural, environmental, and touristic value in Mexico City.

2. Macrobiodiversity

2.1 Vegetation

Among the plant species found in Xochimilco, 220 are terrestrial and 34 are aquatic; among these, 18 are endemic (see Table 1). The vegetation is mainly composed of native as *Salix bonplandiana* [6], and some bryophytes have been observed, including the following: *Bryum argenteum*; *Fabronia ciliaris*; *Syntrichia pagorum*, and *Tortula pagorum*, which together with the vegetation, co-exist with the following species of fungi: *Xeromphalina* sp.; *Ascobolus michaudii*; *Saccobolus depauperatus*; *Saccobolus truncatus*, and *Ductifera pululahuana* [11, 13]. In the chinampas horticultural crops are produced [10] and, in hot houses, ornamental plants [16]. It is noteworthy that among the reported species, there are 77 terrestrial and 20 aquatic that are considered invasive and that could displace the native species and be, in part, the causes of the extinction of the endemic species; thus, their population should be controlled.

TABLE 1. Endemic plant species in the municipality of Xochimilco. Habitat (Hb): aquatic (Q) or terrestrial (T). Uses: food (f), ornamental (o), medicinal (m), construction or craft (c), biotechnological or environmental importance (i), forage (f) or none (n). Conservation Status (CS): Not Evaluated (NE), Low Concern (LC), Special Protection (SP), Vulnerable (V), Threatened (Th).

Scientific name	Hb	Uses							CS
		f	o	m	c	i	f	n	
Family Amaranthaceae									
Suaeda pulvinata [12]	T	✓							NE
Family Asteraceae									
Cirsium lomatolepis [11, 13]	T							✓	NE
Family Cupressaceae									
Cupressus lusitanica [14]	T				✓				SP
Family Fagaceae									
Quercus deserticola [13]	T				✓				LC
Quercus glabrescens [13]	T							✓	NE
Quercus obtusata [13]	T							✓	NE
Quercus rugosa [13]	T				✓		✓		LC
Family Liliaceae									
Calochortus barbatus [13]	T	✓	✓						NE
Family Loranthaceae									
Cladocolea loniceroides [11, 13, 14	T		✓						NE
Family Malvaceae									
Anoda cristata [11, 13]	T	✓	✓	✓					NE
Family Menyanthaceae									
Nymphoides fallax [2, 11, 13, 14]	Q							✓	V
Family Nymphaeaceae									
Nymphaea gracilis [7, 15]	Q							✓	Th
Nymphaea mexicana [2, 11, 13, 15]	Q	✓	✓						V
Family Pinaceae									
Pinus leiophylla [13]	T			✓					LC
Family Ranunculaceae									
Thalictrum strigillosum [13]	T							✓	NE

2.2 Fauna

There have been reported 47 endemic species in Xochimilco area (see Table 2). Xochimilco Lake, in addition to constituting an important sanctuary for local species, also receives 140 species of migratory birds, which arrive at the park during the winter [16]. This lacustrine system has encountered problems as the invasion of exotic species, for example, carp (*Cyprinus carpio*) and tilapia (*Oreochromis niloticus*), which compete with the native species for food [9, 20]. However, these are only two of the 23 invasive faunistic species that should be monitored in order to maintain the ecological equilibrium of the zone.

3. Microbiodiversity

3.1 Phytoplankton

With the aim of knowing the trophic status of the lacustrine system, diverse studies have been conducted on the flourishing of alga [8, 21, 22, 23, 24, 25]. The diversity of microalgae and cyanobacteria is extensive (see Table 3): at least 53 species are employed for valuable applications. In this field there is the opportunity to study those with potential for the production of metabolites-of-interest in the areas of foods, pharmaceuticals, cosmetics, bioremediation, and bioenergetics, to mention only a few.

3.2 Zooplankton

Among the scarce studies on zooplankton, a wide diversity has been found in Lake Xochimilco (Table 4). Some species, such as *Brachionus angularis*, are of importance for the aquiculture of fish, crustaceans, and amphibians [1]. The majority of these have been employed as indicators of contamination. The presence of *Brachionus plicatilis*, *Brachionus leydigi*, *Brachionus quadridentatus*, and *Alona* sp. (copepod) in the Santa Cruz canal and in Lake Xaltocan is associated with spilled treated water [45, 46].

4. The importance of the lacustrine zone

4.1 Environmental

Among the main ecosystemic services that supply Xochimilco Lake [47], including the recharging of subterranean aquifers, regulation of the local and regional water flow, and the maintenance of biodiversity [16], likewise, the chinampas, which are small islands that are built with lake-bottom sediments, branches, and decomposing vegetation, bordered by willow trees (*S. bonplandiana*) [7, 16], result in a system for watering and in efficient agricultural production [4, 7, 16, 46]. Thanks to the physical and biological processes of Xochimilco Lake, there is flood control, a supply of oxygen, and the regulation of the local climate [48]; thus, the lacustrine zone functions ecologically as a spacious wetland, in the middle of an urban zone, which should be preserved due to its great benefits.

4.2 Cultural

Mexico City was founded on a system comprising five lakes. In the southern zone, today's Xochimilco, the "Mexicas" indigenous peoples devoted themselves to pre-hispanic agriculture; this is how the chinampas were created; those who cultivated these were known as chinamperos, xochimilcas, or chinampatecas [7]. In the Nahuatl language, Xochimilco signifies "in the flower seedbed", and the term chinampas, or chinamitl in Nahuatl, means "hedge close to the reed" [1, 12]. In order to include the chinampera culture on the World Heritage Site List, its originality and its productive system being still robust was of utmost importance [47, 49].

The chinampas serve as a refuge for the axolotl, an emblematic species of the culture of Xochimilco. From the Nahuatl axolotl (*atl,* water, and *xolotl,* monster), the "aquatic monster" was considered by the "Mexicas" as one of the most important of the Aztec gods ("Xolotl"). It was also considered to be an exquisite delicacy and as a basic ingredient of a medicinal tonic [7, 50]. The scientific name for the axolotl (*Ambystoma mexicanum*) was assigned

TABLE 2. Endemic terrestrial (T), aerial (A) and aquatic (Q) fauna in the municipality of Xochimilco. Conservation Status (CS): Not Evaluated (NE), Special Protection (SP), Low Concern (LC), Vulnerable (V), Extinct (Ex), Endangered (E), Threatened (Th).

Scientific name	T	A	Q	CS
INSECTS				
Family Cetoniinae				
Euphoria basalis [13]	✓			NE
ARACHNIDS				
Family Vaejovidae				
Vaejovis granulatus [2, 13]	✓			NE
Vaejovis mexicanus [13]	✓			NE
Family Theraphosidae				
Aphonopelma anitahoffmannae [13]	✓			NE
Family Theridiidae				
Latrodectus mactans [13]	✓			NE
CRUSTACEAN				
Family Cambaridae				
Cambarellus montezumae [7, 15, 17]			✓	Th
FISHES				
Family Atherinopsidae				
Chirostoma jordani [15, 18]			✓	LC
Chirostoma humboldtianum [8, 11, 15]			✓	V
Family Cyprinidae				
Evarra bustamantei [11]			✓	Ex
Family Goodeidae				
Girardinichthys viviparus [7, 15]			✓	E
Goodea atripinnis [18]			✓	LC
Family Poeciliidae				
Xiphophorus variatus [13]			✓	LC
AMPHIBIANS				
Family Ambystomatidae				
Ambystoma mexicanum [2, 7, 11, 15, 17]			✓	E
Family Bufonidae				
Anaxyrus compactilis [13]	✓			LC
Incilius occidentalis [13]	✓			LC
Rhinella horribilis [13]	✓			LC
Family Eleutherodactylidae				
Eleutherodactylus grandis [13]	✓			SP
Eleutherodactylus nitidus [13]	✓			LC
Family Hylidae				
Agalychnis dacnicolor [13]	✓			LC
Hyla eximia [13]				LC
Hyla plicata [13]	✓			Th
Tlalocohyla smithii [13]	✓			LC
Family Plethodontidae				
Aquiloeurycea cephalica [15, 18]	✓			Th
Family Ranidae				
Lithobates montezumae [11, 15]	✓			SP
Lithobates tlaloci [7, 15, 18]	✓			E
REPTILES				
Family Anguidae				
Barisia imbricata [7, 15]	✓			SP
Family Colubridae				
Conopsis lineata [11, 13]	✓			LC
Family Phrynosomatidae				
Sceloporus torquatus [2, 13]	✓			LC
Family Viperidae				
Crotalus triseriatus [2, 13]	✓			LC
BIRDS				
Family Accipitridae				
Buteo jamaicensis [2, 11, 15, 18]		✓		SP
Family Icteridae				
Icterus bullockii [2, 11, 18]		✓		LC
Family Mimidae				
Melanotis caerulescens [11, 19]		✓		LC
Mimus polyglottos [2, 11, 18]		✓		LC
Family Passerellidae				
Aimophila ruficeps [18]		✓		LC
Passerculus sandwichensis [11, 15, 18]		✓		LC
Family Psittacidae				
Amazona finschi [15, 18]		✓		E
Family Rallidae				
Rallus tenuirostris [13, 15]		✓		E
Family Thraupidae				
Sporophila torqueola [11, 18]		✓		LC
Family Turdidae				
Catharus occidentalis [18]		✓		LC
Turdus rufopalliatus [11, 18]		✓		LC
MAMMALS				
Family Cricetidae				
Peromyscus gratus [2, 11, 18]	✓			LC
Family Geomyidae				
Cratogeomys merriami [2]	✓			LC
Family Leporidae				
Romerolagus diazi [2, 15]	✓			E
Sylvilagus cunicularius [2]	✓			LC
Family Procyonidae				
Bassariscus astutus [11, 15, 18]	✓			Th
Family Sciuridae				
Ictidomys mexicanus [2]	✓			LC

TABLE 3. Number of species (spp.) of phytoplankton present in Xochimilco Lake, in the following canals: El Bordo (B), Japón (J), Valle o Isla de las muñecas (V), Apampilco (A), Cuemanco (C), exit to Xochimilco (X), not specified (ns). In the lagoons: San Gregorio Atlapulco (S), Tlilac (T), Acitlalín (L), Huetzalin (Z), not specified (ns). Uses: food (f), health (h), cosmetic (c), pigments (p), biofuels (b), fertilizer or aquaculture (f), water remediation (w), or none (n).

Order	sp	Channel	Lagoons	Uses							
				f	h	c	p	b	f	w	n
Division Bacillariophyta (Diatoms)											
Achnanthales [23, 24]	3	J, ns	ud								✓
Aulacoseirales [1, 23-25]	2	B, J, ns	ud								✓
Bacillariales [8, 23-27]	24	B, J, X, ns	S, L, Z, ns	✓		✓					✓
Cymbellales [23-25]	25	B, J, ns	S								✓
Cocconeidales [23]	2	J	ud								✓
Eunotiales [23, 24]	4	J, ns	ud								✓
Fragilariales [23-25]	18	B, J, ns	S								✓
Licmophorales [21-24]	3	B, J, V, A, C, ns	T								✓
Mastogloiales [24]	2	ns	ud								✓
Melosirales [24]	3	ns	ud								✓
Naviculales [8, 21, 23, 24]	41	B, J, V, A, C, X, ns	S, T, L, Z		✓		✓	✓			✓
Rhabdonematales [24]	1	ns	ud								✓
Rhopalodiales [23, 24]	6	J, ns	S								✓
Surirellales [23, 24, 28]	6	J, ns	ud					✓			✓
Tabella riales [24]	1	ns	ud								✓
Thalassiophysales [23-25, 27, 29]	4	B, J, ns	ud	✓		✓		✓			✓
Thalassiosirales [23-25]	5	B, J, ns	S								✓
Division Charophyta (Charophytes)											
Desmidiales [11, 21, 24, 30]	18	B, J, V, A, C, ns	S, T				✓	✓			✓
Klebsormidiales [24]	1	ns	ud								✓
Division Chlorophyta (Chlorophytes)											
Chaetophorales [24]	1	ns	ud								✓
Chlamydomonadales [21, 24, 25]	19	B, J, V, A, C, ns	S, T	✓	✓					✓	✓
Chlorellales [1, 21, 24, 25, 28, 30, 31]	24	B, J, V, A, C, ns	T	✓	✓	✓	✓	✓	✓	✓	✓
Chlorococcales [24]	1	ns	ud								✓
Chlorodendrales [24]	1	ns	ud								✓
Chlorosarcinales [24]	1	ns	ud								✓
Coleochaetales [24]	1	ns	ud								✓
Ignatiales [24]	1	ns	ud								✓
Oedogoniales [1, 24, 32]	4	ns	ud					✓			✓
Oocystaceae [25]	1	ns	ud								✓
Pyramimonadales [24]	1	ns	ud								✓
Sphaeropleales [1, 21, 24, 25, 31, 32, 33]	60	B, J, V, A, C, ns	S, T	✓			✓	✓	✓	✓	
Tetrasporales [25]	1	ns	ud								✓
Trebouxiales [1, 25, 31, 34, 35]	1	ns	ud					✓		✓	
Ulotrichales [24, 36]	3	ns	ud							✓	✓
Volvocales [24]	1	ns	ud								✓
Zygnematales [1, 32, 35]	2	ns	ud	✓				✓			✓
Division Chromophyta (Chromophytes)											
Synurales [24]	3	ns	ud								✓
Tribonematales [19, 24]	1	ns	ud					✓			
Division Cryptophyte (Cryptophytes)											
Cryptomonadales [25]	1	B	ud								✓
Division Cyanoprokaryota (Cyanobacteria)											
Chroococcales [1, 24, 32]	13	B, J, V, A, C, ns	S, T	✓				✓			✓
Nostocales [21, 24, 37]	8	B, J, V, A, C, ns	S, T		✓						✓
Oscillatoriales [23, 34, 38, 39]	17	ns	S	✓	✓		✓			✓	✓
Synechococcales [21, 24]	14	B, J, V, A, C, ns	S, T								✓
Division Dinophyta (Dinoflagellates)											
Gonyaulacales [22, 24]	2	ns	ns								✓
Gymnodiniales [22, 24, 40, 41]	7	ns	ns		✓		✓				✓
Peridiniales [22, 24, 25, 42]	7	B, ns	S							✓	✓
Prorocentrales [22]	6	ud	ns			✓					✓
Suessiales [24]	1	ns	ud								✓
Division Euglenophyta (Euglenophyta)											
Anisonemida [24]	1	ns	ud								✓
Entosiphonida [24]	1	ns	ud								✓
Euglenales [1, 18, 21, 24, 34, 35, 43, 44]	74	B, J, V, A, C, ns	S, T	✓	✓			✓		✓	✓
Petalomonadida [24]	1	ns	ud								✓

ud: undetermined

TABLE 4. Principal genera of rotifers, and copepods reported in Lake Xochimilco: Cuemanco (C), Santa Cruz (SC) and Xaltocan (X) [1, 45].

Family	Genus	C	SC	X
ROTIFERS				
Asplanchnidae	*Asplanchna* sp.	✓	✓	✓
Brachionidae	*Anuraeopsis* sp.	✓	✓	✓
	Brachionus sp.	✓	✓	✓
	Keratella sp.	✓		
	Plationus sp.	✓	✓	✓
	Platyias sp.	✓	✓	✓
Colurellidae	*Lepadella* sp.		✓	✓
Dicranophoridae	*Dicranophorus* sp.		✓	✓
Epiphanidae	*Epiphanes* sp.	✓	✓	✓
Euchlanidae	*Euchlanis* sp.	✓		
Filinidae	*Filinia* sp.	✓	✓	✓
	Ptygura sp.	✓		
	Sinantherina sp.		✓	✓
	Testudinella sp.	✓		
Gastropodidae	*Ascomorpha* sp.		✓	✓
Lecanidae	*Lecane* sp.	✓	✓	✓
Lepadellidae	*Lepadella* sp.	✓		
	Mytilina sp.	✓		
Lindiidae	*Lindia* sp.		✓	✓
Mytilinidae	*Mytilina* sp.		✓	✓
Notommatidae	*Cephalodella* sp.		✓	✓
Trichocercidae	*Trichocerca* sp.	✓	✓	✓
COPEPODS				
Chydoridae	*Alona* sp.		✓	✓
	Chydorus sp.		✓	✓
Cyclopidae	*Acanthocyclops* sp.		✓	✓
Diaptomidae	*Arctodiaptomus* sp.		✓	✓
Moinidae	*Moina* sp.		✓	✓
Sididae	*Diaphanosoma* sp.		✓	✓

in 1798, by the International Commission on Zoological Nomenclature. On the other hand, since 1994, the *A. mexicanum* received Special Protection status through the Xochimilco Ecological Rescue Plan [51]. The chinampas and the axolotl are identity referents and geosymbols of Xochimilco.

4.3 Touristic

The environmental and cultural riches of Xochimilco are important tourist attractions; visitors are interested in the history and wildlife of the zone [52] and participate in a tour in water-transport vehicles ("trajineras") rowed through the canals, this ride one of the main tourist activities. The tourist activities persist despite the diverse obstacles, such as irregular settlements, the deficient quality of the water, and the land subsidence, the result of the extraction of subterranean water [49, 53]. In addition to controlling the irregular settlements and improving the quality of the treated water, it would be convenient to supply the water of the aquifer at the same rhythm that it is extracted.

4.4 Socioeconomic

In Xochimilco the principal economic activities are agriculture and tourism [12, 16, 53]. Another potential economic option includes the hobby of bird watching; according to ornithological studies, Xochimilco possesses a wealth of birds that reaches 249 species [11, 18]. It is estimated that bird watching generated $329 million USD in Mexico, deriving from 1,183,095 bird watchers, foreigners in the majority [54]. It has been reported that this activity could activate the economy, as long as the quality of water improves [55]; therefore, the condition of this resource is vital for increasing the economic value of Lake Xochimilco.

5. Deterioration

The rhythm of environmental damage in Xochimilco was gradual and subtle until the middle of the XX century. The rate of deterioration increased as the Mexico-City population tripled in size [56]; thus, the greatest affectation to the zone could be caused by urbanization [49, 57]. Despite the prohibitions of land use vs. residential use in protected areas, it is estimated that 25% of the protected wetlands is urbanized, and solely 17% of the chinampas are considered active [56, 57]. The lacustrine deterioration indicators include contamination of the water, water hyacinth plague, and unkempt chinampas [1]. Part of the solution lies in the following aspects: controlling urban sprawl; making the population aware of the care and management of water; providing information to the community on the invasive or exotic species, and promoting the importance of preservation of native and endemic species.

5.1 Loss of species

According to reports, around 55% of the endemic species of Xochimilco are found established under some state of conservation [11, 15, 18] (see Figure 1).

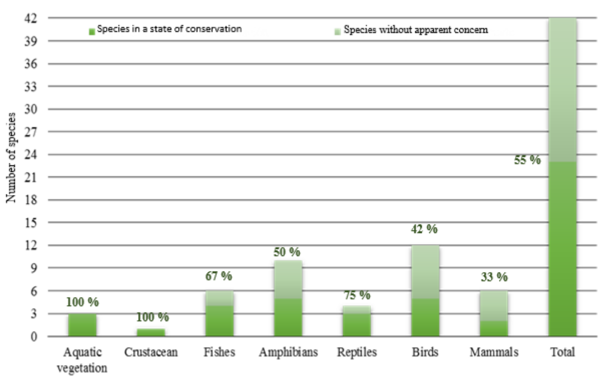

FIGURE 1. Percentage and number of endemic species of Xochimilco that currently are found under some state of conservation (with Special protection , Vulnerable, Near threatened, Threatened, in Danger of extinction, or Extinct).

The disappearance of native fauna appears to be a direct consequence of environmental degradation, mainly affecting the species of amphibians, fish, and mollusks destined for human consumption [58]. The most reported case is that of the axolotl (*A. mexicanum*), which is at present in danger of extinction [7, 59]. Other species with less information with respect to their extinction include the Tlaloc frog (*Lithobates tlaloci*), the Chapultepec splitfin fish (mexclapique) of the Basin of Mexico (*Girardinichthys viviparus*), and the Xochimilca carp (*Evarra bustamantei*), currently extinct. The bird known as the Aztec rail (*Rallus tenuirostris*) [2, 13], and one mammal, volcano rabbit, also known as teporingo (*Romerolagus diazi*) [2, 60] are endemic species that are in danger of extinction. The majority of the species are found limited in terms of the habitat that sustains them. Thus, the preservation of Lake Xochimilco and its well-being is crucial in order to offer these species the hope of survival.

5.2 Contamination

Xochimilco has become a eutrophic wetland, and the current characteristics of the canals and lagoons are due to the seasonal climatic conditions, the diverse land-use management practices (agroecological, touristic, and urban), and the quality of the treated water [17, 23, 61]. It is important to take measures to diminish the contaminants supplied to the aquifer and to invest in removal treatments of these contaminants as well as of pathogens, but always from an environmentally sustainable perspective.

6. Rescue programs

Since 1936, at the national and international level, diverse measures have been implemented with the purpose of halting the deterioration of Xochimilco Lake (Figure 2) [62, 63, 64, 65, 66]. However, despite the efforts of local, federal, and international authorities [67, 68], the lake and its resources appear to continue to be affected by the population growth [55].

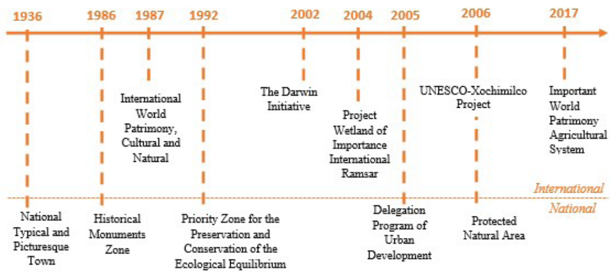

FIGURE 2. Rescue programs and/or international or national recognitions and the year during which they presented.

It would be convenient to involve the population to a greater degree, not only with decision-making, but also in the application of the solutions and initiatives.

7. Discussion

The challenges and tasks are many that should be carried out in the process of preserving Xochimilco Lake; in order to achieve this, the implementation of diverse actions has been proposed [1], and just to mention a few as follows: the construction of dwellings and of sustainable tourist services, which include the design and production of ecological and biodegradable goods, such as the use of Eco-friendly techniques: biodigesters; rainwater collection; solar panels, dry bathrooms, etc. In addition, it is necessary to promote environmental education, for example, workshops could be implemented for composting household organic residues, thus obtaining biofertilizers, promoting the water-care culture, and avoiding the land use and environmental contaminants. Finally, it is necessary to manage external financial support with the aim of executing sustainable regional projects.

The adoption of sustainable practices should include the residents of the zone, of the governmental sector, businesses, and/or acts of restoration that facilitate it [69]. The circular economy would reduce the damaging effects of the linear patterns of production, reducing the harmful effects of linear patterns of production; that is, any primary product should be taken advantage of in such a way that each piece of "waste" would become an asset and no value would be unrecovered [70]. In this manner, sustainability would be achieved in gradual fashion without neglecting the socioeconomic, cultural, and touristic needs.

Xochimilco Lake possesses sufficient resources with which a sustainable circular economy could be implemented. For example, with the end of phytoremediation of the Cuemanco Canal, autochthonous aquatic plants have been employed from the chinampera zone: rooted (*Scirpus americanus*) and floating (*Lemna gibba*) macrophtyes [71]. The water hyacinth (*Eichhornia crassipes*), despite its being a plague, is also used for this purpose. The water resulting from the process of bioremediation could be utilized for watering the chinampas, and the biomass of *E. crassipes* and *L. gibba*, as a bioenergy generator. Similarly, the potential has been evaluated of two species of microalgae, that is, *Chlorella vulgaris* and *Tetradesmus obliquus* (isolated from Lake Xochimilco) and from a cyanobacterium, *Arthrospira maxima*, for removing nutrients from raw residual water and accumulating lipids for the production of biodiesel [72]. Microalgae offer properties that allow them to serve as the raw material for different applications.

8. Conclusion

To preserve the Xochimilco lacustrine area, it is necessary to activate the circular economy in order to drive sustainability in tourism, improve the quality of water and soil, foster the chinampera culture, and implement new programs of the protection and conservation of native and endemic species.

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ABOUT THE ACADEMIC EDITOR

Dr. Sergio Antonio Silva M. Biographical Sketch

Dr. Silva Muñoz is the Provost for Academic Affairs and former Director of International Relations of the University of Guanajuato, Mexico; is a Professor in the Department of Civil and Environmental Engineering, Campus Guanajuato, and a member of the Technical Committee of Civil Engineering Specialists of the Under-Secretariat of Higher Education, Mexico.

He holds a bachelor's degree in Civil Engineering from the University of Guanajuato, a master's and doctoral degree in Engineering from the Tokyo Institute of Technology. Post-graduated from the Building Research Institute of Japan and certified in Water Supply Engineering and Project Management.

Dr. Silva has collaborated in the Department of Environmental Science and Technology at the Tokyo Institute of Technology, the Department of Environmental Engineering for Symbiosis at Soka University in Japan, and Rogue Water in the USA. He has participated in more than seventy water engineering projects for the public and private sectors. In addition, he has published more than forty articles, co-authored two books and a manual, and has given more than sixty lectures in North and Central America, Asia, and Europe.

He has been a special guest of the Japan Society of Civil Engineering, the Malaysian Academy of Sciences, the Japan Institute of Lowland and Marine Research, and the Tokyo Institute of Technology Innovation Center. He has been appointed Chairman of the Board of Directors of the Municipal Planning Institute of Guanajuato, Chairman of the Climate Change Advisory Council of the State of Guanajuato, and President of the College of Civil Engineers of Guanajuato. Since 2008, he collaborates with the International Lake Environment Committee (ILEC), Japan, and was appointed President of the Organizing Committee of the World Lake Conference 2021.

His areas of expertise are: Water Resources Management, Global Water Policies, Strategic Environmental Assessment, and Project Management. He received the 2011Award as the Professional of the Year by the research merit.

18th World Lake Conference,
Sergio Antonio Silva Muñoz (academic
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de Guanajuato and Ediciones Comunicación Científica
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format in PDF, Epub and HTML.

The 18th World Lake Conference, entitled "Governance, Resilience, and Sustainability of Lakes for a Better Society" was held virtually from November 9th to 11th, 2022 at the University of Guanajuato, Mexico. This forum was designed with the primary objective of providing a space where scientists, professionals, students, managers, and practitioners could propose, share, and learn about studies, strategies, and actions which enhance the management of lakes around the world. Different activities were contemplated and scheduled in the organization of this forum, such as conferences, special sessions, technical sessions, and workshops where 194 distinguished investigators and participants shared the results of their research and the knowledge they have gained over the years.

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