Topics of limnological research in Mexico

Coordinator
Alfredo Pérez Morales

Universidad de Colima

Topics of limnological research in Mexico

Coordinator
Alfredo Pérez Morales

Universidad de Colima

Topics of Limnological Research in Mexico

Avenida Universidad 333
C.P 28040, Colima, Colima, México
Dirección General de Publicaciones
Telephone numbers: 312 316 1081 and 312 316 1000, extension: 35004
Email: publicaciones@ucol.mx
www.ucol.mx

ISBN electrónico: 978-968-9733-13-3
DOI: 10.53897/LI.2025.0032.UCOL
5E.1.1/317000/308/2024 Edición de publicación no periódica

Cover and interior photographs: Juan Franco Rodríguez

Certified Publishing Process with ISO since 2005
Double blind ruling and editing are registered in the PRED Electronic Publishing System

Registration: LI-020-24
Received: September 2024
Dictamination: November 2024
Published: December 2025

This book is dedicated to
Dr. Singaraju Sri Subrahmanya Sarma,
in gratitude for all his teachings in the world of limnology.

Index

Temporal Characterization of Water Quality of Rivers in Contrasting Zones of Two Watersheds in Veracruz, Mexico

José Antolín Aké-Castillo[1]
Miriam Guadalupe Ramos-Escobedo[2]
Eduardo Aranda-Delgado[2,3]

[1] Instituto de Ciencias Marinas y Pesquerías, Universidad Veracruzana.
Calle Hidalgo 617, Col. Río Jamapa, C. P. 94290, Boca del Río, Veracruz, México. aake@uv.mx

[2] Global Water Watch - México, Xalapeños Ilustres 137 int 13,
Col. Centro, C. P. 91000, Xalapa-Enríquez, Veracruz, México.

[3] Grupo de monitoreo Amigos del Pixquiac. Loma Escondida No. 71,
La Pitaya-Zoncuantla, C.P. 91517, Coatepec, Veracruz, México.

Abstract

Water quality is influenced by natural conditions and anthropogenic impacts along the zones of a watershed, being the human impact the most important factor due to pollution. In the state of Veracruz, Mexico, there are two important rivers that reach the Gulf of Mexico: La Antigua and Jamapa-Cotaxtla. In these rivers, there are people that have long term water quality monitoring activities, hence, the information generated can be used to understand the functioning of rivers in different zones of a watershed: Headwater at the highlands and floodplain at the lowlands. The objective of this work is to compare the water quality of both zones using information of physical, chemical, and microbiological parameters measured during the year of 2018 by community monitoring programs. We used a principal component analysis for detecting the most variable parameters and non-parametric analyses to detect significant differences for each measured parameter between the two zones. Also, we classified water quality according to different scales for different parameters. The results showed significant differences of water quality between the two zones of the watersheds, the highland river had the best quality. However, concentration of *Escheria coli* indicated pollution in both watersheds. We concluded that temperature, alkalinity, hardness, pH, and turbidity were traits of each region of the watersheds that respond to climatic seasons. The oxygen was severely depleted in the river at the lowland region of the Jamapa-Cotaxtla river most likely due to organic pollution, fecal contamination is constantly quite a problem affecting water quality in both zones of the watersheds.

Keywords

Escherichia, floodplain, headwaters, monitoring.

Introduction

Water quality is influenced by natural conditions and anthropogenic impacts along the regions of the watershed, being this last factor an emerging problem worldwide that deteriorates water quality for human use as well as ecosystems (Obiluno et al., 2013; Islam et al., 2021). Water flows from higher ground to rivers or creeks that finally reach lowlands and arrives to reservoirs, lakes, or the sea, changing the physical and chemical characteristics of the water through its way. Commonly, streams at the headwaters in a watershed are considered to have "good water quality" while streams at floodplains are negatively impacted by the pollutants that water has gathered while flowing downhill. For the understanding of the function of a watershed, this can be divided into three zones: headwater (source), transition (transfer or middle), and floodplain (depositional) (Nepal et al., 2014; Tang et al., 2020), where natural condition and anthropogenic activities interact and define the water quality.

Different traits of the water can be used as an indicator of water quality, they must be defined by physical, chemical, and microbiological parameters (Chidiac et al., 2023). These traits are natural properties of the water depending of the nature of the soil, altitude and vegetation, and they can be altered by the influence of anthropogenic activities that can modify oxygen concentration, transparency of water, temperature, pH, and microbiological biota by supplying, fertilizers, pesticides, and wastewater, being the latter the most usual negative impact worldwide (Tang et al., 2020). Evaluation of those mentioned parameters is necessary to preserve the natural properties of water. So, monitoring water quality is an issue that must be addressed by governments to face the worldwide water crisis.

The state of Veracruz has two important watersheds with rivers that flow to the Gulf of México, passing through the most important cities: The city of Xalapa in the upstream region in Antigüa wathershed; and the city of Boca del Rio in the downstream region of Jamapa-Cotaxtla watershed. In these two watersheds, two water quality monitoring initiatives have been established with the approach of Community Participatory Monitoring (Deutsch et al., 2009) using the protocols of the Global Water Watch Program from Auburn University, promoted by Global Water Watch Mexico (GWW, 2023). The data from these water quality monitoring initiatives can be used for understanding the differences and functioning of different zones within the watersheds (Ramos-Escobedo et al., 2019).

This work aims to determine and compare the temporal and spatial natural variation, as well as the anthropogenic impacts of the water quality traits of rivers at distinct zones: (headwater and floodplain) in two watersheds.

Material and Methods

Study Sites

Headwater Zone: The study site is the Pixquiac River, located at 1,460 m altitude close to the locality of Mariano Escobedo at the highlands of the La Antigua watershed, whose main drainage is the La Antigua river with a watershed area of 3,443.9 km^2. Several tributaries come from the Cofre de Perote montain (2,416 m) one of them is the Pixquiac river, that arises at the East of Cofre del Perote and supplies water to the Tillereo River that finally enters the La Antigua River (DOF, 2012). The Pixquiac River drains an area dominated by primary and secondary mountain cloud forest, with some agricultural lands and urban settlements. Mariano Escobedo is a locality with a small population (530 inhabitants) and close to the urban zones of Coatepec (55,720 inhabitants) and Xalapa (443,063 inhabitants) (INEGI, 2024).

Floodplain Zone: The study site was located close to the urban zone of Boca del Rio and Medellin de Bravo in the lowerland of the Jamapa-Cotaxtla watershed (<50 m altitude). This watershed of 3,995.4 km^2, is defined by two rivers originated at the highlands of the highest mountain in Mexico: Pico de Orizaba (5,636 m) (DOF, 2008). The Cotaxtla River joins the Jampa River in the lower part of the watershed, this part of the river maintains the name of Jamapa while flowing through the floodplains of the state of Veracruz to the Gulf of Mexico, entering in the extended metropolitan area of Boca del Rio, Veracruz and receiving a strong urban influence. This watershed has a vegetation coverage highly fragmented by human activity, mainly agricultural and urbanization, with a negative impact in support services of the ecosystem (Ortíz-Lozano, 2013). Particularly, the floodplain zone is a deposition zone with an urbanization that displaced the primary vegetation. The study sites are in an urban zone with small remnants of vegetation close to localities of Puente Moreno (34,913 inhabitants), Playa de Vacas (791 inhabitants) and the urban zone of Boca del Río (144,550 inhabitants) (INEGI, 2024).

Sampling Design

Sampling stations were selected following criteria established by Global Water Watch (GWW) protocols (Deutsch et al., 2009). Minimum 2 sites along the river, one located upstream a suspected pollution source (in this case human settlement) and one downstream from that.

Headwater Zone: Antigua watershed, three sampling stations: 1) Vado de las Monjas (VM) before a human settlement, 2) Seis de Enero (SE), and 3) Mariano Escobedo (ME), after the population of La Pitaya and Mariano Escobedo were stablished at river Pixquiac. The sites were sampled each month from January to December 2018 (except June) (Fig. 1).

Floodplain zone: Jamapa-Cotaxtla watershed, four sampling stations along the Jamapa River: 1) Arroyo Moreno (AM) an important stream that flows to Jamapa River, 2) Playa de Vacas (PV), before the joining of Arroyo Moreno and the population of Boca del Río, 3) Puente (P) in the joining of Arroyo Moreno and Jamapa, and 4) Jamapa (J), close to the mouth of the river in the Gulf of Mexico. The sites were sampled from January to December 2018 (Fig. 1).

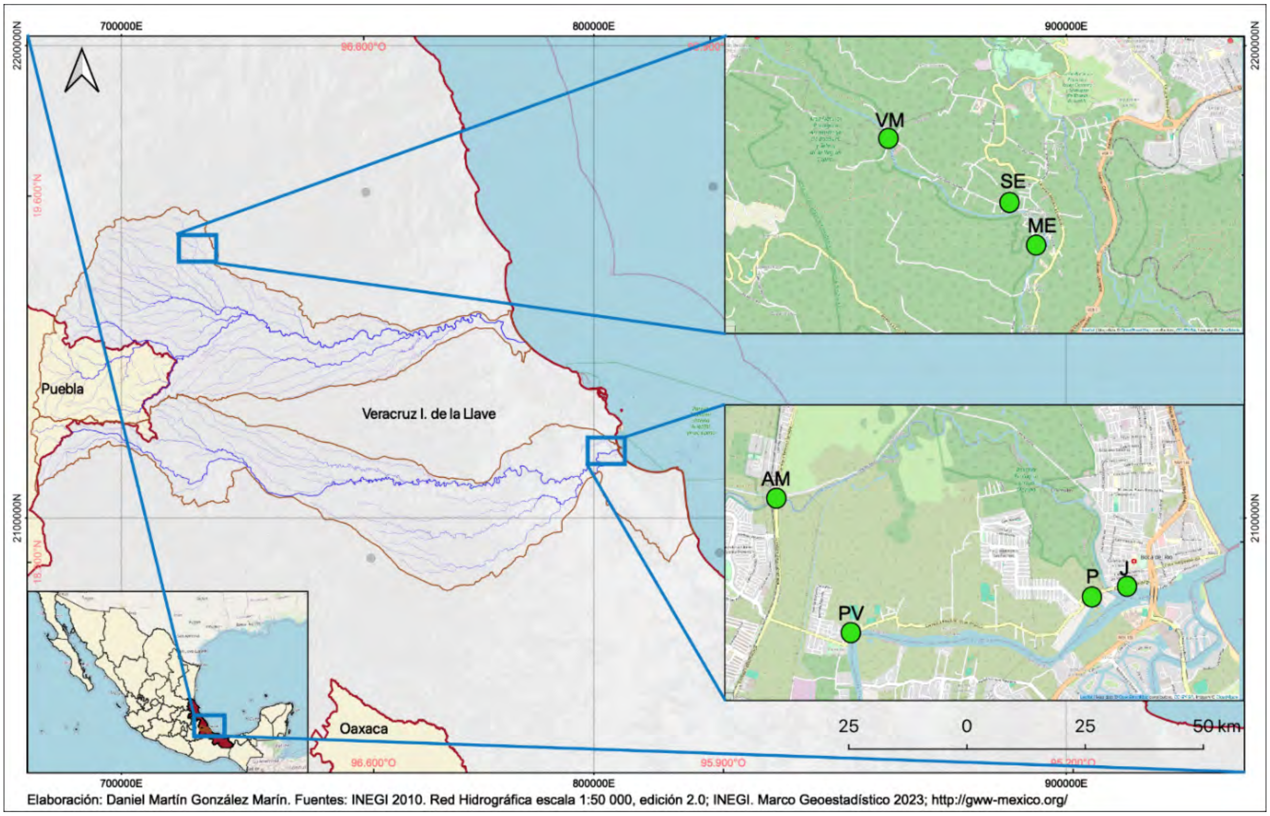


Figure 1. Sampling Site Locations (Green Circles). Headwaters Zone: Vado de Monjas (VM), Seis de Enero (SE) and Mariano Escobedo (ME); Floodplain Zone: Arroyo Moreno (AM), Playa de Vacas (PV), Puente (P) and Jamapa (J).

Water Quality

Water quality was determined using the protocols and techniques considered in the data quality and quality assurance Plan of the Global Water Watch Program at Auburn University.

For the physicochemical analysis, we use the Alabama Water Watch Kit by LaMotte (Temperature, hardness, alkalinity, pH, dissolved oxygen, and tubidity; code 9844-02 LaMotte ©). All variables were measured *in situ*. Temperature was measured with an alcohol thermometer (±0.5°C); pH measurements are based on comparing scale colors (±0.5) using indicator solution in a scale from 3 to 10.5; Hardness follows the titration method with EDTA (0-200 mg/l); Alkalinity follows the titration method with sulfuric acid (0-200 mg/l); Oxygen measured is based on the Winkler method, and turbidity is based on transparency using a standard drop method (5-200 JTU). Determination of these physicochemical parameters were done once by sample, except for dissolved oxygen which were done using two replicates (Deutsch et al., 2009). For the Antigua watershed, June was missing.

The microbiological analyses were conducted using the Coliscam Easygel method by Micrology Labs, which consist of media with inhibitors that only allow the growth of coliforms and a sugar linked to a dye that make it possible to differentiate *Escherichia coli* from other coliforms (Colony Forming Units CFU/100 ml). The cultures were done using three replicates by sample indicated by GWW protocol (Deutsch et al., 2009). For the Antigua watershed, data for January, November and December were not available.

Statistical Analyses

Principal Component Analysis was performed using all data to identify any temporal and spatial clusters in physical, chemical, and microbiological data (Jolliffe & Cadima, 2016). All data were transformed (log2 (x+1)) prior to the analyses (Zar, 2010). Components 1 and 2 (maximum variance explained) were selected according to eigenvalues and plotted to visualize clusters.

To detect significant differences between watwershed zones in each parameter, Mann-Whitney U tests were used (data failed homogeneity of variances). Two approaches were used for explaining differences: annual mean values, and monthly mean values between regions. All analyses were performed using the software Statistica ver. 7 (Statsoft, Inc. ©).

Results

Alkalinity and oxygen are the chemical traits that most heavily influenced the variation of water quality among data of the two zones of the watersheds. In addition, the temperature, the hardness, and microbiological traits also have a strong influence in the variation of water quality considering all data (explaining 64.6 % of total variation). Turbidity and pH do not contribute significantly to explain differences between the two zones studied (Fig. 2).

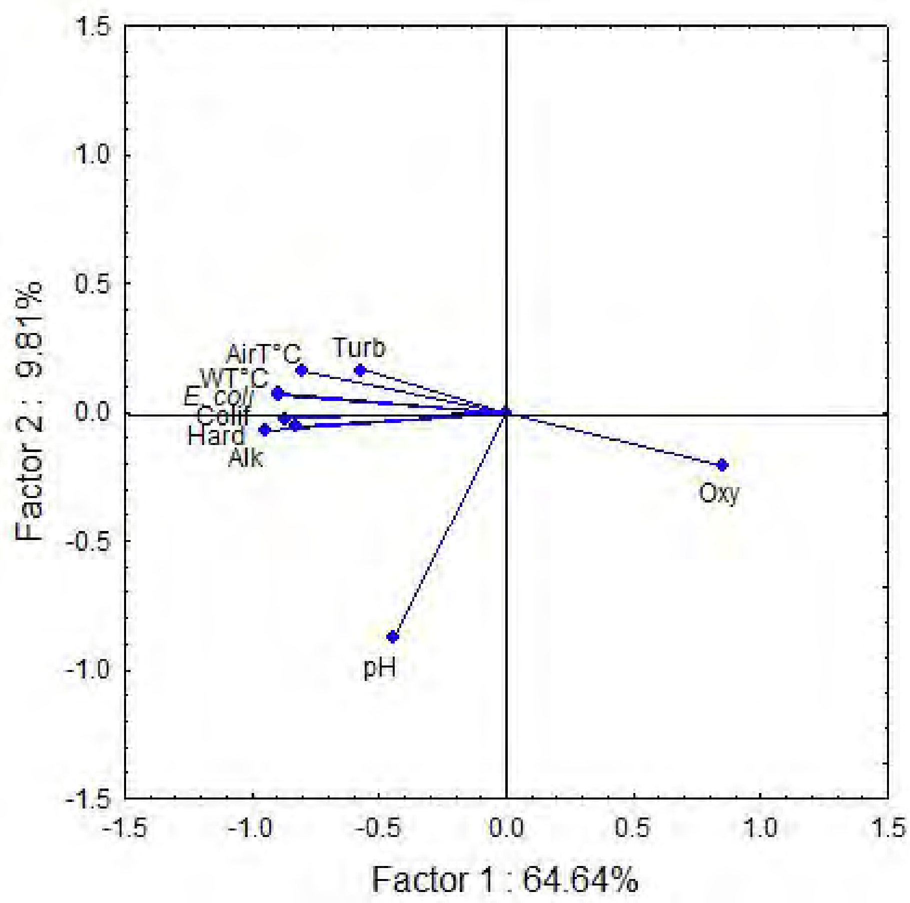


Figure 2. Contribution of Variables in Components 1 and 2 Considering Data Form the Headwaters Zone of the Antigua Watershed and Floodplain Zone of Jamapa-Cotaxtla Watershed.

The plot of data derived from PCA resulted in 3 groups, each with agglomerated data (Fig. 3). The headwater zone formed a compacted group (blue circle in the the plot) well separated from the floodplain zone (left side of the plot) indicating that water quality is different and, in this case, the headwater zone characterized by high concentrations of dissolved oxygen and low values of air and water temperatures, hardness, alkalinity and *E. coli* and coliforms. Only one datum split from the cluster, which had a pH value slightly lower than the rest of this watershed zone.

Floodplain zone was characterized by high values of air and water temperatures, hardness, alkalinity, and *E. coli* and coliforms but very low values of dissolved oxygen concentrations. In addition, pH values have an influence on this zone separating two groups (curved red lines in the plot) with neutral (group in the left-upside of the plot) and slightly basic pH (group in the left-downside of the plot) which corresponds to different stations and different months, so a local influence of seasons acts (salt wedge) directly in the pH.

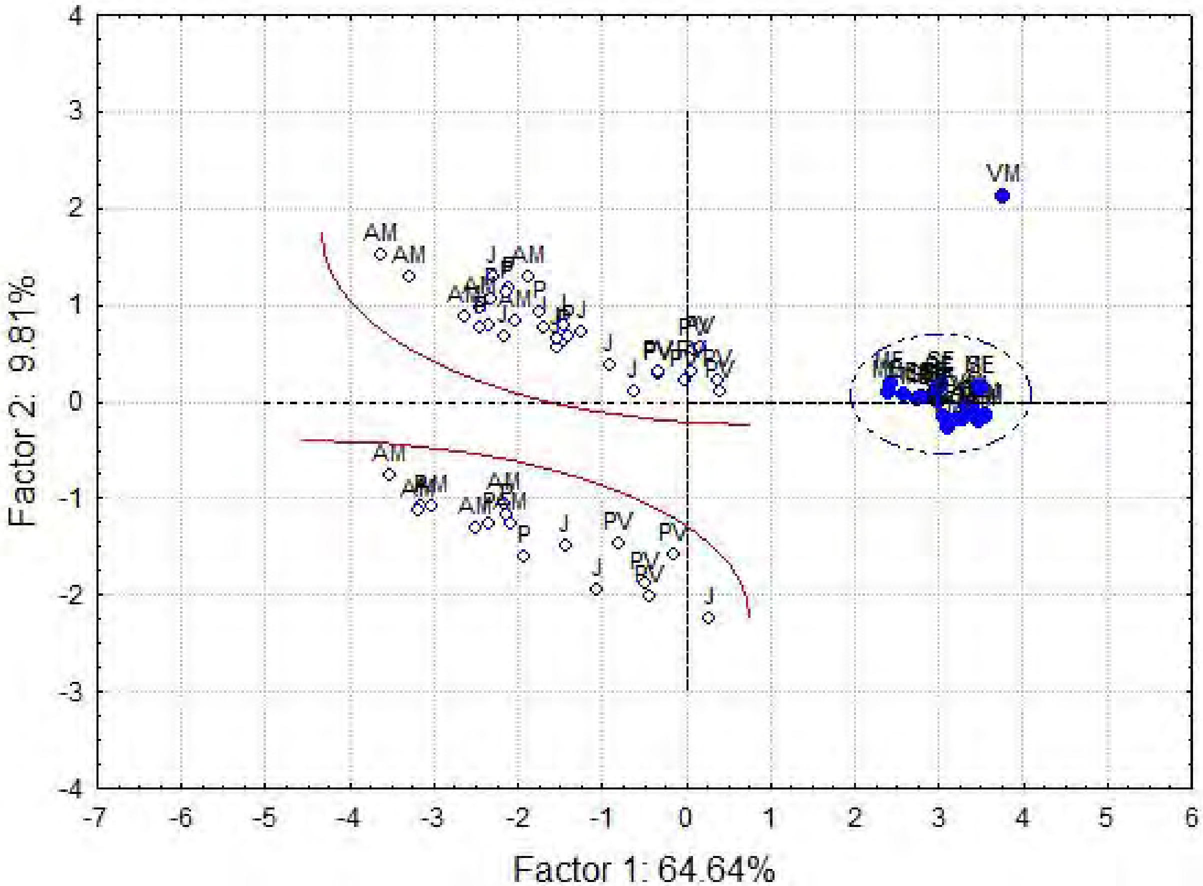


Figure 3. Plot of Data of the Headwaters Zone (Pixquiac: Filled Circles) and Floodplain Zone (Jamapa-Cotaxtla: Empty Circles) Derived from PCA. Vado de las Monjas (VM), Seis de Enero (SE) and Mariano Escobedo (ME), Arroyo Moreno (AM), Playa de Vacas (PV), Puente (P) and Jamapa (J). Note Three Groups: Data in Blue Circle, and Two Groups Separated by Red Arcs.

The mean values of all variables were significantly different between the watershed zones (Table 1), so water quality is noteworthy different. However, significant differences between zones varied temporarily: water temperature, alkalinity and oxygen concentration were significant different between zones in all months; hardness was significantly different almost in all months except in October; pH was not significantly different in any month and turbidity did not show significant differences most of the time (except from January to March); *E. coli* concentrations have significant differences in February, March, May, August, September, and October as well as total coliforms except in February (Table 1).

In general, the water quality of both watersheds is affected negatively by fecal contamination (indicated by red color in Table 1). However, *E. coli* concentrations are acceptable for contact at headwater zone in some months of the year (indicated in yellow in table 1). Oxygen concentrations indicate good and very good water quality at the headwaters while at the floodplain region, the concentrations showed poor water quality in the river.

Table 1. Mean Values of Physicochemical and Microbiological Variables of the Headwaters Zone (H) of La Antigüa Watershed and Floodplain Zone (F) of Jamapa-Cotaxtla Watershed. (*) Significant Differences Mann-Whitney U Test ($P<0.05$) between Regions. (-) Missing Values. Scale Color Based in Deutsch et al. (2009); (a) Concentration Very Low for Aquatic Life; (b) >200-600/100 mL Limit for Human Contact (Recreational). Sample Number for Each Month H = 3, F = 4. Total Sample Number H = 33 (Except for Coliforms H = 24), F = 48). Number in Parenthesis is Standard Deviation.

Month	Zone	Air °C	Water°C	pH	Hardness CaCO3 mg/l	Alkalinity mg/L	O2 mg/l	Turbidity JTU	E.coli CFU/100 ml	Coliform CFU/100 ml
J	H	20.17* (1.76)	12.67* (0.29)	7.17 (0.29)	20.00* (0)	30.00* (5)	8.17* (0.6)	2.00* (0)	–	–
	F	24.38 (1.11)	24.38 (0.25)	7.25 (0.29)	635.00 (421.78)	285.00 (149.89)	2.83	7.25 (8.62)	70766.67	59850.00 (38075.42)
F	H	22.83 (2.75)	16.00* (1)	7.00 (0)	16.67* (5.77)	25.00* (0)	7.53* (0.06)	2.00* (0)	94.67* (63.22)	3111.11 (346.94)
	F	26.13 (1.25)	26.88 (1.31)	7.38 (0.25)	657.50 (396.67)	237.50 (135.74)	3.63	23.75 (17.97)	49333.33	43950.00 (54980.81)
M	H	22.0* (1)	16.33* (0.58)	6.83 (0.29)	20.00* (0)	26.67* (2.89)	7.17* (0.06)	2.00 (0)	527.78*	3700.00 (180.28)
	F	25.38 (0.48)	28.25 (1.19)	7.00 (0)	745.00 (296.25)	240.00 (150.50)	2.30	16.25 (22.5)	49433.33	37683.33 (34494.72)
A	H	19.17* (1.61)	16.50* (0.05)	7.00 (0)	23.33* (5.77)	25.00* (0)	7.00* (0.26)	4.00 (1.73)	838.67	5572.33 (891.82)
	F	28.13 (1.18)	30.13 (2.02)	7.00 (0)	870.00 (260)	242.50 (135.25)	2.35	21.00 (32.88)	42266.67	26050.00 (35301.43)
MAY	H	21.67* (1.53)	17.67* (1.15)	7.00 (0)	13.33* (5.77)	28.33* (2.89)	6.97* (0.15)	2.00 (0)	444.44* (452.55)	3505.56 (1683.78)
	F	29.13 (2.17)	32.00 (1.68)	7.13 (0.25)	652.50 (401.78)	171.25 (23.23)	2.13	3.50 (1.73)	53033.33	51433.33 (30506.08)
JUN	H	–	–	–	–	–	–	–	–	–
	F	28.63 (1.49)	28.38 (0.75)	7.00 (0)	102.50 (33.04)	112.50 (14.43)	1.26 (2.53)	10.00 (4.08)	114133.33	47516.67 (16834.21)
JUL	H	19.83* (2.25)	17.17* (0.76)	7.00 (0)	20.00* (0)	28.33* (5.77)	6.97* (0.16)	2.00 (0)	1105.78	2511.22 (925.76)
	F	30.38 (1.80)	31.13 (1.88)	7.25 (0.29)	180.00 (74.83)	130.00 (21.60)	1.38 (2.14)	2.00 (0)	100416.67	21383.33 (12837.95)

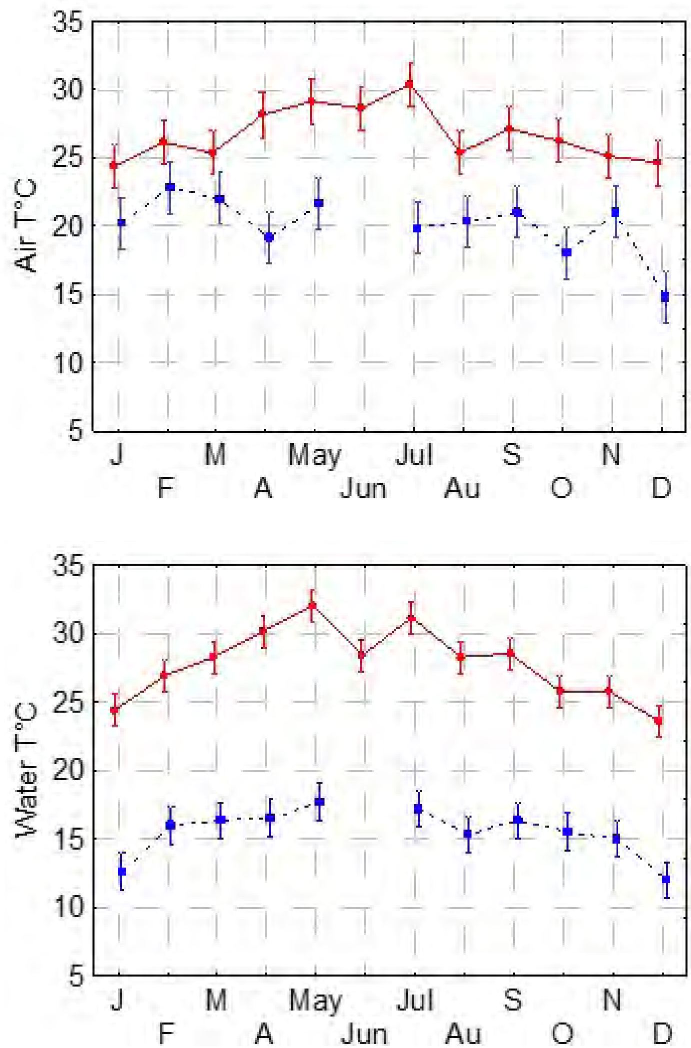
Continued on following page.

Continued from previous page.

AUG	H	20.33* (1.53)	15.33* (0.58)	7.00 (0)	10.00* (0)	36.67* (2.89)	7.07* (0.25)	2.00 (0)	151.89* (56.45)	2879.67 (475.07)
	F	25.38 (0.63)	28.25 (1.32)	7.13 (0.25)	120.0 (24.49)	127.50 (31.75)	1.48	2.00 (0)	101566.67	65016.67 (28313.87)
S	H	21.0* (2.60)	16.33* (0.29)	7.00 (0)	10.00* (0)	25.00* (0)	7.00* (0)	2.00 (0)	294.33*	1177.78 (1333.24)
	F	27.13 (0.25)	28.5 (0.71)	7.13 (0.25)	135.00 (47.96)	153.75 (72.27)	1.83	3.50 (1.73)	94400.00	111950.00 (49124.92)
O	H	18.0* (1)	15.5* (0.5)	7.00 (0)	40.00 (17.32)	30.00* (0)	7.13* (0.06)	2.00 (0)	727.78*	3350.11 (852.06)
	F	26.25 (0.87)	25.7 (1.04)	7.25 (0.29)	105.00 (41.23)	162.50 (49.24)		8.00 (4)	93733.33	145766.67 (95565.89)
N	H	21.00 (3.70)	15.0* (1)	7.00 (0)	16.67* (5.77)	26.67* (2.89)	7.40* (0.1)	2.00 (0)	–	–
	F	25.13 (1.93)	25.75 (0.96)	7.38 (0.25)	252.50 (103.72)	211.25 (94.90)	2.88	2.75 (1.5)	126300.00	151116.67 (97388.74)
D	H	14.83* (0.29)	12.00* (0.5)	7.00 (0)	20.00* (0)	35.00* (0)	8.17* (0.15)	2.00 (0)	–	–
	F	24.63 (2.50)	23.63 (2.02)	7.25 (0.29)	605.00 (457.27)	250.00 (138.74)	3.80	6.00 (4.62)	125350.00	133500.00 (149433.12)
Total	H	20.1* (2.64)	15.5* (1.79)	7.0* (0.13)	19.1* (9.47)	28.8* (4.51)	7.3*	2.2* (0.73)	523.2* (648.75)	3226.0* (1425.35)
	F	26.7 (2.28)	27.8 (2.78)	7.2 (0.24)	421.7 (371.05)	193.6 (103.69)	2.3	8.8 (13.56)	85061.1	74601.4 (73913.29)

Color Scale	Optimal	Very hard	Poor[a]	Acceptable
		hard	Good	Bad[b]
		Moderatelly hard	Very good	
		Soft		
		Moderatelly soft		

Figures 4 and 5 show variation through time of both watershed zones. All variables were always higher in the river at the floodplain than in the headwaters zone, mainly temperature, alkalinity, and hardness (Fig. 4), except the Oxygen concentration (Fig. 5). A temporal change is noticeable in June, the beginning of the rainy season, at the floodplain sites for most of the parameters. Also, in these sites, the hardness and alkalinity respond noteworthy to the dry period (November to May) and the rainy period (June to October) (Fig. 4). Microbiological parameters were higher (>100 times in mean) at the floodplain sites than in the headwaters zone (Fig. 5); no temporary tendency was detected at the floodplain sites. Even when there was an obvious variation at the sites in headwaters, no clear trend was identified in this zone.



Continued on following page.

Continued from previous page.

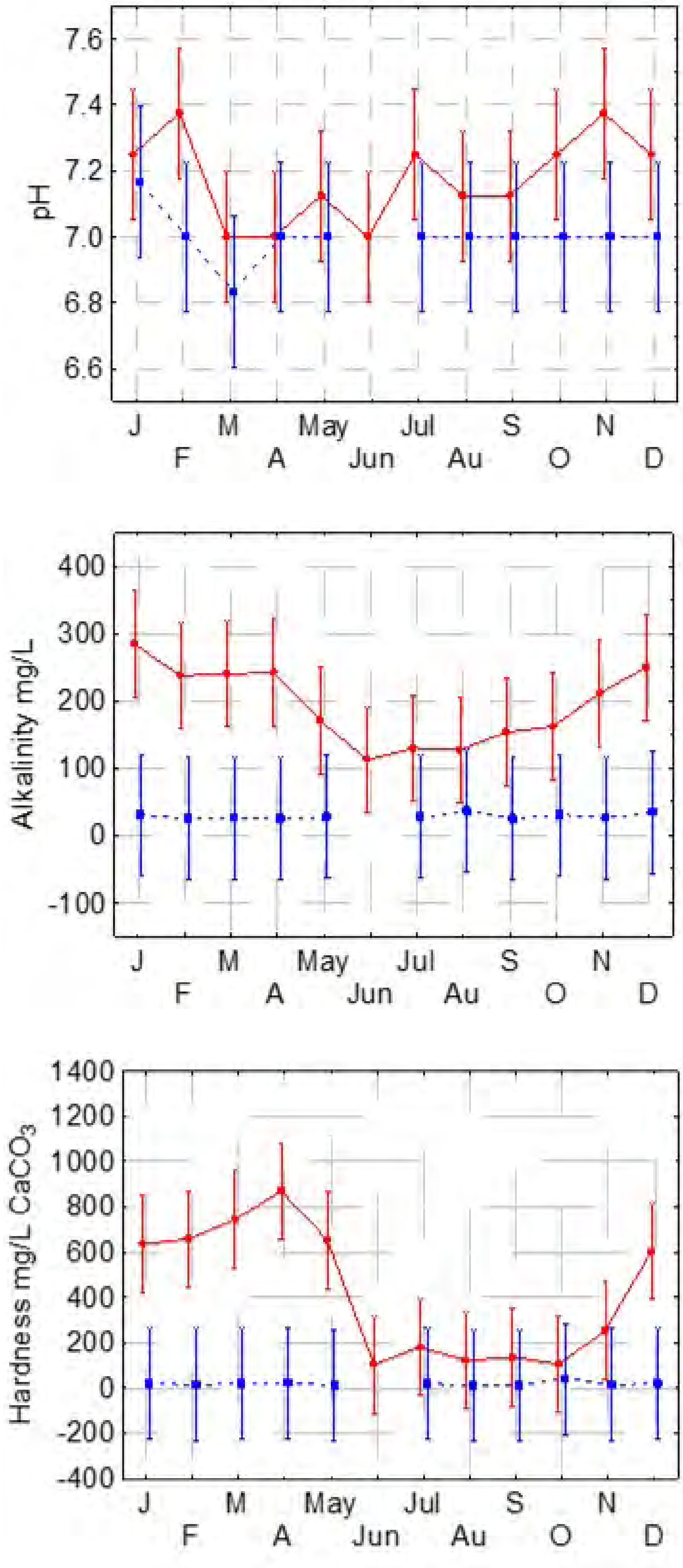
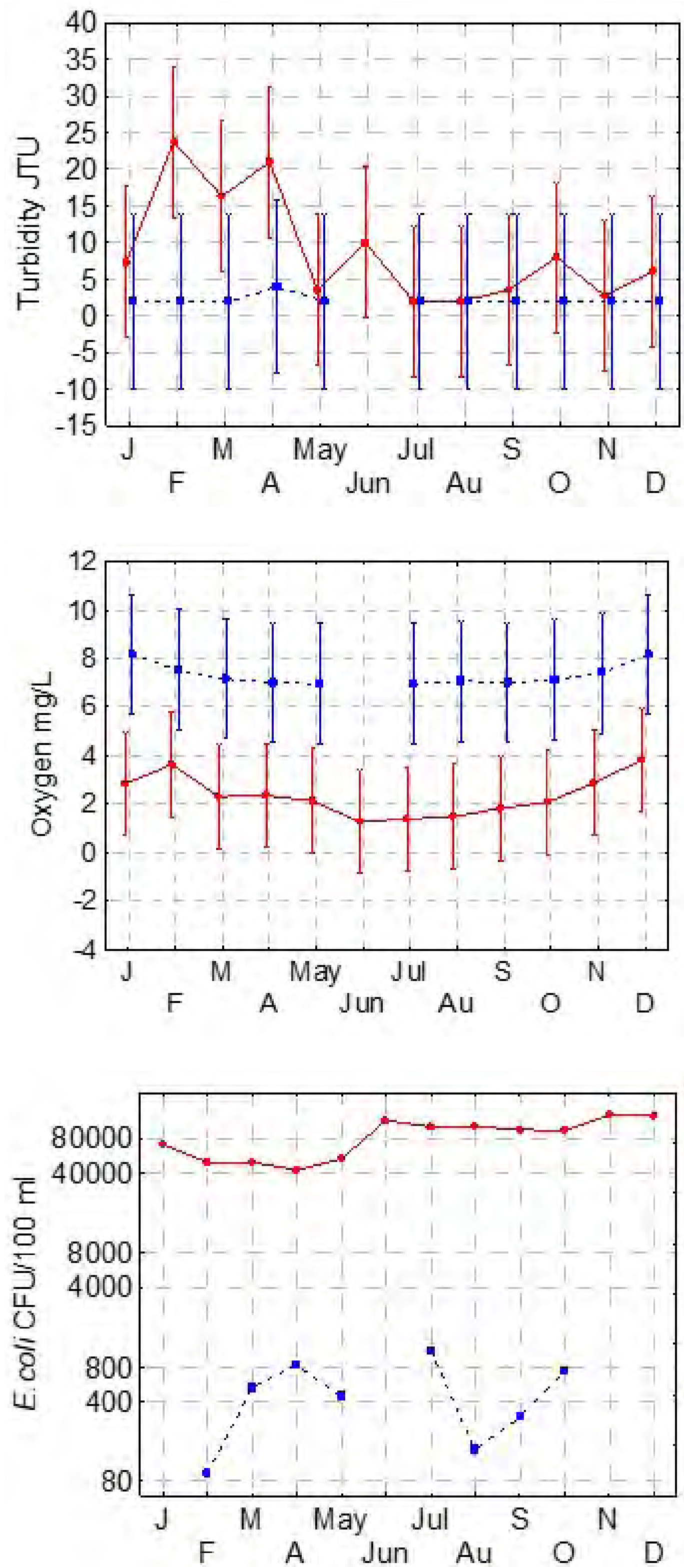


Figure 4. Monthly Mean Values of Air and Water Temperature, pH, Alkalinity, and Hardness. Whiskers Represent 95 % Confident Intervals. Headwaters in Blue Color, Floodplain in Red.



Continued on following page.

Continued from previous page.

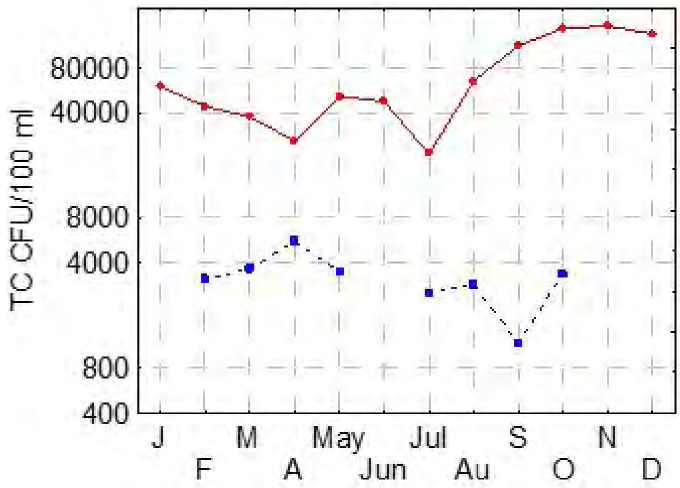


Figure 5. Monthly Mean Values of Turbidity, Oxygen, *Escherichia coli* and Total Coliforms. Whiskers Represent 95 % Confident Intervals. *E. coli* and Total Coliforms Lack Confident Intervals as They Are in Logarithmic Scale.
Headwaters in Blue Color, Floodplain in Red.

Discussion

As expected, floodplain sites had higher values in parameters related to weather and mineralization than headwaters zone. The high values of pH, hardness and alkalinity can be explained by three reasons. First, the geology in the watershed in these zones are extremely different, while in the headwaters igneous volcanic rocks are prevalent (andosol soil type), in the floodplains accumulated clayey sediments (vertisol soil type), mainly from the transference zone, prevail (INEGI, 2023). Second, load of diverse material that dissolves in water and naturally increases minerals concentrations from up to down of the watershed, rises hardness and alkalinity (Shajedul-Islam & Hoque-Majumder, 2020). Third, superficial water quality at floodplain zone is affected by marine influence specifically by the salt wedge and mixing processes that may homogenize water column. At Jamapa River, salt intrusion reaches 5 km along the river in the dry period (Perales-Valdivia et al., 2018), therefore, pH hardness and alkalinity increase in the affected zone as consequence of natural properties of marine water, such as carbonates and other minerals (Boyd et al., 2016). The pH in the different sampled sites of the floodplain is affected by the intrusion of the salt wedge and this is noticeable in the separation of the sites in the PCA analysis. Temporal variations were noticeable in hardness and alkalinity in the floodplain zone while in the headwater zone, it remains almost constant. The beginning of the rainy season in June affects alkalinity and hardness, lowering their values because of the higher supply of freshwater. The Jamapa region has a high capacity of buffering and hard water. In the case of the headwaters zone, the values were within the range considered typical for freshwater: soft water with a good capacity of buffering, and only an atypical value of pH (6.5) was recorded in the Vado de las Monjas site. Turbidity values were higher for the floodplain zone only 3 months when strong winds from the north affect coastal zone (cold mass air coming from North America) and may affect the dynamics of the river by the influence of the sea and resuspending sediments and mixing water column (Perales-Valdivia et al., 2018).

Temperature is related to the altitude, so in the headwater zone, air and water temperature was lower than in the floodplain zone. Water temperature in the headwater zone was temperate (cloud forest) while in the floodplain zone, it was warm (coastal plain), and in both regions, a temporal variation was noticeable at the beginning of the dry season (May) with the increment of air and water temperature.

The parameters that showed critical water quality values were dissolved oxygen concentrations and fecal coliforms. While the headwaters zone had optimal concentrations of Oxygen, the floodplain zone was characterized all year by low concentrations that are not optimal for aquatic life. Depletion of oxygen is commonly caused by consumption by high bacterial activity decomposing organic matter (Harremoës, 1982), so this is an indicative of a high load of organic matter (Eriksen et al., 2022).The city of Boca del Río is located in the floodplain and other important localities which use Arroyo Moreno and the Jamapa River as destination of treated wastewater, so a high organic load may be entering the system. In the headwaters zone, dissolved oxygen concentrations were optimal all year long, so support of aquatic life is optimal in this region.

Concentration of *Escherichia coli* was the most important indicator of a negative impact in both zones of the watersheds. Although Pixquiac (headwaters zone) had 2 months with low values of this fecal bacterium, the high values of CFU of *E. coli* indicated an important negative impact most part of the year. Floodplain zone was heavily affected by fecal pollution all year in extremely high concentrations. In both cases, although the method used for estimation of fecal coliform differs from Most Probable Number (MPN), it is sure that these concentrations surpass the maximum permissible limit of concentration allowed for Mexican normativity for residual water to be released in rivers (250-600 MPN/100 ml; SEMARNAT, 2022). The temporal variation was not clear in the headwaters zone, while in the downstream region there is constant strong fecal contamination.

The fecal contamination of water of the rivers and the values observed in the two zone studies may be related to population and the capacity of the treatment systems of wastewater. In the headwater zone, the locality of Mariano Escobedo lacks a treatment plant wastewater operated by the municipality (Conagua, 2024). In the floodplain zone, in the Puente Moreno locality, there is a treatment plant with a capacity of 68 l/s while for Boca del Rio city, only two treatment plants with a total capacity of 380 l/s (Conagua, 2024). According to the information generated between 2014 and 2016, SEMARNAT (2024) estimated that 60 m^3 of residual water is generated by inhabitant in Mexico. This is equivalent to a production of 2 l/s for 1,000 inhabitants, which is a value that represents more than 277,000 l/s and superasses more than 220 times the capacity of the treatment plants established until 2023. So, a high load of organic matter derived from urban wastewater is received by the Jampa River, affecting optimal oxygen concentration for wildlife and incrementing fecal coliforms in the water and other pollutat found in municipal wastewaters.

In developing countries like México, the lack of information and resources to monitor has been acknowledged even in the National Hydric Program 2020-2024 (SEMARNAT, 2020) and this void is specially accentuated at the provinces of the country and rural areas (Hiriart et al., 2010; Jimenez-Cisneros et al., 2010). In general, the governmental monitoring of freshwater bodies in Mexico has not been systematic regarding techniques, criteria to determine water quality which makes assessments and comparisons extremely difficult (Jimenez-Cisneros et al., 2010); these disparities are even more complicated between the criteria used by water and health authorities. These discrepancies and the lack of budget to monitor within the government has resulted in a reduction of the parameters included in the water quality indexes and the frequency of monitoring with the consequent incomplete vision about the quality of the water of most Mexican water bodies (Hiriart et al., 2010). Data of this study show the relevance of community monitoring efforts in contributing to the knowledge of rivers at a local and regional scale. Community data obtained with standardized technique and methodologies contribute to build knowledge in countries like Mexico, where a void of information is the prevalent condition (Flores-Díaz et al., 2018).

Conclusions

Temperature, alkalinity, hardness, pH, and turbidity were traits corresponding to altitude and soil type of each zone of watersheds that respond to climatic seasons. The oxygen concentration was quite different in the two watersheds, indicating a better condition of water quality in the headwaters zone (Antigua watershed) than in the floodplain zone (Jamapa-Cotaxtla watershed), being depleted by organic pollution derived from wastewater. For the two zones the fecal contamination (*E. coli*) was a constant problem throughout the year, and it is indicative of a failed treatment system of wastewater of population close to the rivers.

Acknowledgements

We are grateful to participants in monitoring group: “*Amigos del Pixquiac*” and students at Veracruz University and Technological Institute of Boca del Río during their training period at ICIMAP-UV.

Authors' Contributions

MGRE coordinated the monitoring program. JAAC and EAD collected and analyzed samples. JAAC generated the idea of the analyses of data and wrote the manuscript. MGRE revised the manuscript, interpreted results, and discussed them. JAAC, MGRE and EAD provided feedback to the final manuscript.

References

Boyd, C. E., Tucker, C. S., & Somridhivej, B. (2016). Alkalinity and Hardness: Critical but Elusive Concepts in Aquaculture. *Journal of the World Aquaculture Society*, *47*(1), 6-41. https://doi.org/10.1111/jwas.12241

Comisión Nacional del Agua (Conagua). (2024). *Catálogo de plantas de tratamiento de aguas residuales en operación. Tabla de las plantas de tratamiento de aguas residuales municipales que son manejadas en los sistemas de alcantarillado urbanos y rurales*. https://datos.gob.mx/

Chidiac, S., El Najjar, P., Ouaini, N., El Rayess, Y., & El Azzi, D. (2023). A comprehensive review of water quality indices (WQIs): history, models, attempts and perspectives. *Reviews in Environmental Sciences and Bio/Technology*, *22*, 349-395. https://doi.org/10.1007/s11157-023-09650-7

Deutsch, W. G., Duncan, B. L., Romagnoli, O., & Ruiz-Córdova, S. S. (2009). *Community-Based Water Monitoring.* Spanish version reviewed by Ramos-Escobedo M. G. A Flores-Díaz and E. Aranda-Delgado. *Manual de monitoreo de agua en programas con participación comunitaria*. Centro Internacional de Agricultura y Ambientes Acuáticos, Auburn University.

Diario Oficial de la Federación (DOF). (2008, november 3rd). *Acuerdo por el que se da a conocer el resultado de los estudios de disponibilidad media anual de las aguas superficiales en las cuencas hidrológicas Río Actopan, Río La Antigua, Río Jamapa, Río Cotaxtla, Jamapa-Cotaxtla y Llanuras de Actopan, mismos que forman parte de la porción de la Región Hidrológica denominada Papaloapan A.* Secretaría de Medio Ambiente y Recursos Naturales.

Diario Oficial de la Federación (DOF). (2012, 3 de enero). Acuerdo por el que se dan a conocer los estudios técnicos de aguas nacionales superficiales de la Cuenca Hidrológica Río La Antigua de la Región Hidrológica denominada Papaloapan A. *Diario Oficial de la Federación,* (Segunda Sección).

Eriksen, E., Jacobsen, D., Demars, B. O. L., Brittain, J. E., Søli, G., & Friberg, N. (2022). Effects of pollution-induced changes in oxygen conditions scaling up from individuals to ecosystems in a tropical river network. *Science of the Total Environment, 814*, 151958. https://doi.org/10.1016/j.scitotenv.2021.151958

Flores-Díaz, A., Quevedo-Chacón, A., Páez-Bistrain, R., Ramírez, M. I., & Larrazábal, A. (2018). Community-Based Monitoring in Response to Local Concerns: Creating Usable Knowledge for Water Management in Rural Land. *Water* 2018, *10*, 542. https://doi.org/10.3390/w10050542

Global Water Watch México (GWW). (2023). *Cuidado co-participativo de cuencas a través del monitoreo comunitario de agua*. http://gww-mexico.org/

Harremoës, P. (1982). Immediate and delayed oxygen depletion in rivers. *Water Research*, *16*(7), 1093-1098. https://doi.org/10.1016/0043-1354(82)90124-5

Hiriart, M. M., Espinosa, A. C., López-Vidal, Y., Arredondo-Hernández, R., Díaz-Torres, E., & Equihua-Zamora, C. (2010). Visión integral sobre el Agua y la Salud. In Jiménez Cisneros, B., Torregrosa y Armentia, M. L., Aboites- Aguilar, L. (Eds.) *El agua en México: Cauces y Encauces*. (pp. 291-316). Academia Mexicana de Ciencias. Comisión Nacional del Agua.

Instituto Nacional de Estadística y Geografía (INEGI). (2023). *Carta edafológica*. https://www.inegi.org.mx/temas/edafologia/

Instituto Nacional de Estadística y Geografía (INEGI). (2024). *Censo de población y vivienda 2020*. https://www.inegi.org.mx/programas/ccpv/2020/

Islam, M. M. M., Iqbal, M. S., D'Souza, N., & Islam, M. A. (2021). A review on present and future microbial surface water quality worldwide. *Environmental Nanotechnology, Monitoring and Management, 16*, 100523*.* https://doi.org/10.1016/j.enmm.2021.100523

Jiménez-Cisneros, B., Durán-Álvarez, J. C., & Méndez-Contretas, J. M. (2010). Calidad. In: Jiménez Cisneros, B., Torregrosa y Armentia, M. L., Aboites Aguilar L. (Eds.). *El agua en México: Cauces y Encauces*. (pp. 265-290). Academia Mexicana de Ciencias y Comisión Nacional del Agua.

Jolliffe, I. T., & Cadima, J. (2016). Principal component analysis: a review and recent developments. *Phillosophical Transations Royal Society A*, *374*, 20150202. https://doi.org/10.1098/rsta.2015.0202

Nepal, S., Flügal, W. A., & Shresta, A. B. (2014). Upstream-downstream linkages of hydrological processes in the Himalayan region. *Ecological Processes*, *3*(19). https://doi.org/10.1186/s13717-014-0019-4

Obiluno A. N., Chijioke, C., Igwegbe, W. E., Ibearugbulem, O. I., & Abubakar, Y. F. (2013). Water quality challenges and impact. *International Letters of Natural Sciences*, *4*, 44-53. https://doi.org/10.18052/www.scipress.com/ILNS.4.44

Ortiz-Lozano, J. A. (2013). *Modificación en la provisión de servicios ambientales por efecto del cambio en la heterogeneidad ambiental en la cuenca del Río Jamapa, Veracruz, México.* (Master Thesis) Instituto de Ciencias Marinas y Pesquerías, Universidad Veracruzana.

Perales-Valdivia, H., Sanay-González, R., & Valle-Levinson, A. (2018). Effects of tides, wind and river discharge on the salt intrusion in a microtidal tropical estuary. *Regional Studies in Marine Science*, *24*, 400-410. https://doi.org/10.1016/j.rsma.2018.10.001

Ramos-Escobedo, M. G., Fuentes-Pérez, A., & Ruíz-Cordova, S. S. (2019). Monitoreo comunitario de agua con enfoque de cuenca: experiencias en actividades productivas y de conservación. *Memorias en Extenso Volumen II - I Congreso Latinoamericano y V Congreso Nacional de Manejo de Cuencas Hidrográficas*. Centro Interdisciplinario de Investigaciones y Estudios sobre Medio Ambiente y Desarrollo, IPN Fundación Gonzalo Río Arronte I.A.P. Red Mexicana de Cuencas.

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). (2020, 30 de diciembre). Decreto por el que se aprueba el Programa Nacional Hídrico 2020-2024. *Diario Oficial de la Federación*.

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). (2022, 11 de marzo). Norma Oficial Mexicana NOM-001-SEMARNAT-2021, Que establece los límites permisibles de contaminantes en las descargas de aguas residuales en cuerpos receptores propiedad de la nación. *Diario Oficial de la Federación*.

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). (2024). *Sistema Nacional de Información Ambiental y Recursos Naturales. Informe del medio ambiente.* https://apps1.semarnat.gob.mx:8443/dgeia/informe18/tema/cap6.html

Shajedul-Islam, Md., & Hoque-Majumder, S. M. M. (2020). Alkalinity and Hardness of Natural Waters in Chittagong City of Bangladesh. *International Journal of Science and Business, 4*(1), 137-150. https://doi.org/10.5281/zenodo.3606945

Tang, Y., Leon, A. S., Kavvas, M. L. (2020). Impact of Size and Location of Wetlands on Watershed-Scale Flood Control. *Water Resources Management*, *3*,1693-1707. https://doi.org/10.1007/s11269-020-02518-3

Zar, J. H. (2010). *Biostatistical Analysis*. Prentice Hall.

Topics of Limnological Research in Mexico, coordinated by Alfredo Pérez Morales, was published in Dirección General de Publicaciones of the Universidad de Colima, avenida Universidad 333, Colima, Colima, México, www.ucol.mx. The edition was completed in December 2025. The Arial family was used for typesetting. Non Periodical Editorial Program: Eréndira Cortés Ventura. Cover Design: Adriana Minerva Vázquez Chávez. English Proofreader: Yul Ceballos. Interior Design: José Luis Ramírez Moreno and Leticia Bermúdez Aceves.

This book takes a significant step in showcasing the relevance of limnology to our survival. Freshwater habitats, though they cover less than 1 % of the Earth's surface, are home to a substantial portion of the world's biodiversity—at least 10 % of all known species. Freshwater habitats and the biodiversity they support are under threat. Moreover, our survival depends on access to high-quality freshwater. This book not only highlights the beauty of limnology and the scientific methods used to study it, but it also draws attention to the major causes of biodiversity loss in freshwater ecosystems. It shows all readers what it means to deal with inland waters as a scientist interested in understanding ecosystems and protecting them.

ISBN: 978-968-9733-13-3

9 789689 733133

UNIVERSIDAD DE COLIMA