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Ecological condition in an altitude gradient of the Margaritas River, Chiapas, Mexico.

Condición ecológica en un gradiente altitudinal del Río Margaritas, Chiapas, México.

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ABSTRACT

The ecological condition is a parameter that allows us to diagnose the structure and functionality of rivers. The Margaritas River basin, located in the municipality of Pijijiapan, Chiapas, Mexico, is an important source of water recharge and supply. In order to evaluate the ecological condition present at three altitudinal gradients of the Margaritas River, a visual evaluation of the physical habitat was performed following Barbour's protocol and some physical-chemical parameters were determined (depth, dissolved oxygen, electrical conductivity, temperature, salinity and hydrogen potential). Ammonium, nitrite, nitrate and phosphate ions were also measured at the three study sites. Three replicates were carried out and an analysis of variance and comparison of means by Tukey-kramer ($p \geq 0.05$) was applied. The results showed a suboptimal (Margaritas 1 and 2 sites) and marginal (Río Ramón site) habitat condition. Physicochemical parameters presented significant differences for site-specific electrical conductivity ($F_{2,6} = 68.77$ $p \leq 0.0001$), electrical conductivity at 25 ºC ($F_{2,6} = 59.67$ $p = 0.0001$) and water temperature ($F_{2,6} = 160.66$, $p \leq 0.0001$), where the highest values correspond to site Margaritas 2. The amount of nitrates (6.83 ± 0.55 mg/L) and nitrites (3.67 ± 1.15 mg/L) at site Margaritas 2 were the highest values obtained. Finally, phosphate ions presented their highest values at the Río Ramón site (0.12 ± 0.05 mg/L). The results obtained provide a current perspective on the state and condition of the Margaritas River, and it is necessary to implement appropriate management strategies for each study area.

KEY WORDS: Water quality, river ecosystem, river assessment, aquatic systems, river vulnerability.

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RESUMEN

La condición ecológica es un parámetro que permite diagnosticar la estructura y funcionalidad de los ríos. La cuenca del Río Margaritas, localizada en el municipio de Pijijiapan, Chiapas, México es una fuente importante de recarga y provisión hídrica. Con el objetivo de evaluar la condición ecológica presente en un gradiente altitudinal del Río Margaritas, se realizó la evaluación visual del hábitat físico a través del protocolo de Barbour y se determinaron los parámetros fisicoquímicos (profundidad, oxígeno disuelto, conductividad eléctrica, temperatura, salinidad y potencial de Hidrógeno). También se cuantificaron los iones de amonio, nitritos, nitratos y fosfatos en tres sitios de estudio. Se realizaron tres repeticiones y se aplicó un análisis de varianza y comparación de medias por Tukey-kramer ($p \geq 0.05$). Los resultados mostraron una condición de hábitat sub óptima (sitios Margaritas 1 y 2) y marginal (sitio Río Ramón). Los parámetros fisicoquímicos presentaron diferencias significativas para la conductividad eléctrica específica en el sitio ($F_{2,6} = 68.77$ $p \leq 0.0001$), conductividad eléctrica a 25 ºC ($F_{2,6} = 59.67$ $p = 0.0001$) y temperatura del agua ($F_{2,6} = 160.66$, $p \leq 0.0001$), donde los valores más altos fueron los del sitio Margaritas 2. La concentración de nitratos (6.83 ± 0.55 mg/L) y nitritos (3.67 ± 1.15 mg/L) obtenidos en el sitio Margaritas 2 fueron los valores más altos. Finalmente, los iones de fosfato presentaron los valores más altos en el sitio Río Ramón (0.12 ± 0.05 mg/L). Los resultados obtenidos brindan una perspectiva actual sobre el estado y condición del Río Margaritas, siendo necesario implementar estrategias de gestión propicias para cada zona de estudio.

PALABRAS CLAVE: Water quality, river ecosystem, river assessment, aquatic systems, river vulnerability.

Introduction

River ecosystems provide humans with ecosystem services, such as drinking water, food, and recreational activities (Ullah *et al.,* 2018). Changes in land use and some landscape patterns significantly influence the management of river ecosystems and are reflected in water quality, structure, and functionality (Malacarne *et al.,* 2016; Rossi *et al.,* 2018; Liu *et al.,* 2022). River ecosystems have been used by humans as a source of resources and as a pathway for waste disposal, which historically originated a gradual degradation (Alonso & Camargo, 2005). For example, in Mexico, the occupation of the deltaic plain formed by the Mezcalapa-Grijalva-Usumacinta rivers dates back 3500 years with the presence of the Olmec culture and the impact of deforestation, as well as the modification of these rivers, has affected the morphodynamics of deltaic system (Sandoval-Rivera *et al.,* 2022).

Ecosystems deterioration was accentuated after the Industrial Revolution, due to the increased production of waste materials, the introduction of new pollutants, and the increase in population in cities, which in turn generated more waste (Oscoz *et al.,* 2006; De los Santos *et al.,* 2022). Indeed, deterioration is such that currently, these ecosystems constitute one of the most degraded worldwide (Reid et al., 2019, Albert et al., 2021).

In recent years, climate change and human disturbances such as dam construction and deforestation have caused severe impacts on the ecological environment of large river basins, significantly altering the structure and functionality of the ecosystems, and enhancing vulnerability (Varis *et al.,* 2012; Pan *et al.,* 2022). Currently, worldwide and particularly in Mexico, there are several causes of water quality alteration and the degradation of biological communities. These include organic matter pollution, nutrient enrichment, elimination or degradation of riparian forests (Escalona-Domenech *et al.,* 2022), rectification and channelization of rivers (Tovilla, 2005), channel regulation, increase of inorganic and persistent organic pollutants, and mining activities (Zhou *et al.,* 2019; De los Santos *et al.,* 2022; Golin *et al.,* 2022). These causes have led to significant modifications in the ecological status of rivers in Mexico (Díaz-Pascacio *et al.,* 2018; Ortiz, 2019).

Ecological status is the measure of the quality of the structure and functioning of ecosystems (Ferreira, 2012). Good ecological status becomes visible when the biological communities in an aquatic system are equal or very close to those that can be found in unaltered conditions (Volonté *et al.,* 2015). In a good ecological state, the physicochemical conditions and also the configuration of the environment (hydromorphological conditions) should allow the development of these communities (Martínez *et al.,* 2004; Ferreira, 2012).

Particularly in a river, a worthy ecological status is defined by aspects such as water quality, habitat, aquatic organisms, ecological processes, or hydrology, acting at different scales of interaction (Deegan *et al.,* 2010; Pinto & Maheshwari 2011; Poole *et al.,* 2013). Therefore, the assessment of physicochemical, hydromorphological, and biological quality (based mainly on the composition of aquatic flora, invertebrate fauna, and fish) determines the ecological status of water bodies (Ferreira, 2012). Specifically, physicochemical parameters provide adequate information on the nature of the physical properties and chemical species of water, allowing an assessment of its quality for different types of use, unlike other biological methods (Samboni *et al.,* 2007).

The study of the ecological condition of rivers in Chiapas, Mexico is of singular importance due to the extensive process of land cover and land use change that the watersheds of the state are undergoing (Tovilla, 2005). These processes cause an increase in sediments that are naturally carried by the rivers downstream, and reach the coastal lagoons (where most of the coastal rivers flow), and cause siltation problems in the lagoons (Carbajal-Evaristo *et al.,* 2015).

The Margaritas River basin in southeastern Chiapas is an important source of recharge and water supply that supplies coastal lagoons and low-lying communities (Tovilla, 2005). Some authors have found a very close relationship between the ecological condition of the habitat and abiotic factors assessed in the river (habitat quality, water temperature, pH) and nutrient concentrations such as phosphorus and nitrogen (Stevenson, 2014; Charles *et al.,* 2019; Tang, 2020).

Thirty-seven percent of the extension of the Margaritas watershed is formed by induced grasslands in which livestock activity predominates, which has led to a decrease in the ecological condition of the banks and the fragmentation of riparian vegetation (Escalona-Domenech *et al.,* 2022). For this reason, it is of utmost importance to make a diagnosis of the current state and condition of this river ecosystem. From this perspective, this study aimed to evaluate the ecological condition present in an altitudinal gradient of the Margaritas River, based on the physicochemical parameters of the water and the evaluation of the physical aquatic habitat.

Material and Methods

Description of the study area

The Margaritas river basin is located within the municipality of Pijijiapan, Chiapas, Mexico, between coordinates 93° 07' 57" and 92° 59' 06" W and 15° 25' 01" and 15° 41' 40" N. The watershed is located within the slope formed by the Sierra Madre de Chiapas and the Pacific Ocean, and is part of the hydrological region No. 23 (RH 23) Costa de Chiapas (CONAGUA, 2009) and its total land area is 19,475.81 ha (Figure 1).

Figure 1. The geographical location of the Margaritas River basin

The Margaritas River basin belongs to the physiographic region of the Pacific Coastal Plains of Chiapas, located in the Central American Cordillera (INEGI, 2002). The predominant climate in the basin is warm humid Am (w), which represents 60.95 % (11,871.25 ha) of the total surface area of the basin, while 39.05 % (7,604.56) has a warm subhumid climate Aw2(w) (in the middle and lower part of the basin) and a semi-warm humid climate ACm(W) (in the upper part of the basin) (INEGI, 2008). An average annual temperature of 27.6 °C and an average precipitation of 2,596 mm are reported for the basin according to data from meteorological station No. 23018 of the Comisión Nacional del Agua (CONAGUA-MEXICO) (Escalona-Domenech *et al.,* 2022), although in the higher areas of the basin it can reach 2,600 mm per year. The flows of this river follow a behavior according to two marked seasons of the year, rainy and dry. The rainy season includes the months from May to October, while the dry season includes the months from November to April. The historical maximum precipitation values occur during the month of September and the minimum in January (Figure 2).

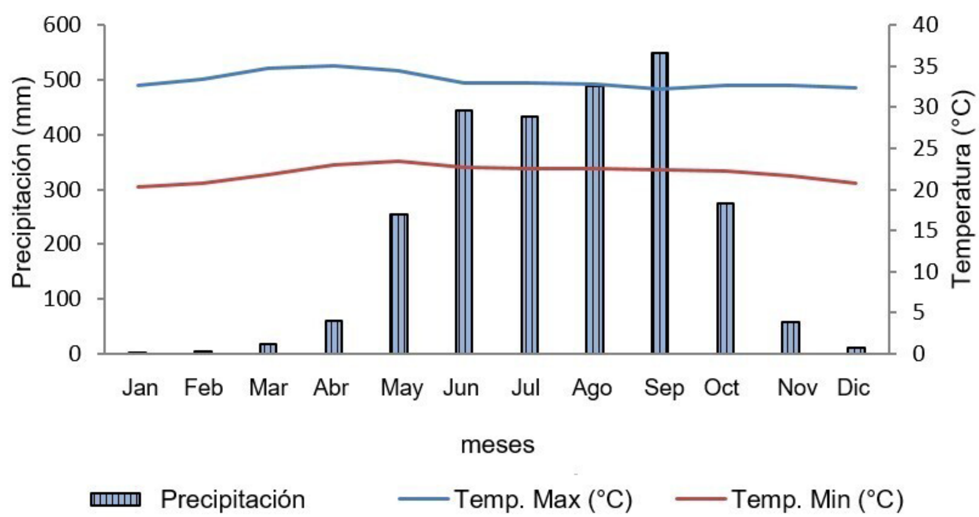

Figure 2. Walter and Lieth climate diagrams of the Margaritas River basin for the period 1951 to 2021.

Throughout the Margaritas River basin, the edaphology is formed by seven soil units, where cambisol, lithosol, and regosol units predominate, representing 37.58, 37.21 and 17.18 % respectively of the total area of the basin (INEGI, 2016).

Location of sampling sites

Three sampling sites, located at different altitudes of the Margaritas River, were located: 1) Margaritas 1 established between coordinates 15°32’14.37” N and 93° 4’50. 12” W at an altitude of 15 masl, 2) Margaritas 2 installed between 15°35’31.97” N and 93°3’23.53” W at 70 masl and 3) Río Ramón demarcated between coordinates 15°39’46.05” N and 93°1’45.39” W at an altitude of 386 masl (Figure 1).

Habitat evaluation

At each sampling site, the visual evaluation of the physical habitat was carried out following the Barbour *et al*. (1999) protocol for wadeable rivers, which consists of ten variables that are assigned a value from 0 to 20 points. With the sum of all the variables, a final score is given, giving the habitat condition a rating of optimal, suboptimal, marginal, and poor (Table 1).

Table 1. Variables for the evaluation of the condition of the habitat and its score

Parameter		Condition			
		Optimal	Suboptimal	Marginal	Poor
Channel alteration		20-16	15-11	10-6	5-0
Channel status		20-16	15-11	10-6	5-0
Covering of edges by sediments		20-16	15-11	10-6	5-0
Bank stability	Right	10-9	8-6	5-3	2-0
	Left	10-9	8-6	5-3	2-0
Speed and depth regimes		20-16	15-11	10-6	5-0
Substrate for epifauna		20-16	15-11	10-6	5-0
Rapids frecuencies		20-16	15-11	10-6	5-0
Width of the riparian zone of the bank	Right	10-9	8-6	5-3	2-0
	Left	10-9	8-6	5-3	2-0
Sediment deposition		20-16	15-11	10-6	5-0
Vegetal protection of the bank	Right	10-9	8-6	5-3	2-0
	Left	10-9	8-6	5-3	2-0
Total		(200-166)	(156-113)	(100-60)	(47-0)

Bibliographical source: Barbour *et al.* (1999)

Hydrology and physicochemical water parameters

At each site, the parameters of depth (Prof), dissolved oxygen (O_d), electrical conductivity (EC), temperature (T), and salinity (Sal) were determined directly in the field in triplicate using a YSI model 85 portable multiparameter equipment. Hydrogen potential (pH) was measured with an eco-Test pH sensor model pH2. In addition, ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and phosphate (PO_4^-) concentrations were determined using a Hach portable Case equipment model DR/890.

Statistical analysis

A completely randomized design was applied. The sample size included a total of three replicates for each experimental analysis performed (n ≥ 3). For the analysis of the results of each of the variables evaluated in the study sites, an analysis of variance and comparison of means by Tukey-Kramer ($p \geq 0.05$) was applied using jmp pro 15 software (Statistical Analysis System [SAS], 2020).

Resultados

Physical habitat

In the three sites evaluated, ratings were obtained corresponding to two of the states for habitat conditions mentioned by Barbour *et al*. (1999), which were: marginal and suboptimal. Sites Margaritas 1 and Margaritas 2 showed the highest score corresponding to a suboptimal habitat condition (Table 2).

Table 2. Values obtained in the evaluation of the physical aquatic habitat

Site	Altitude msnm	Coordinates	Score	Qualification
Margaritas 1	56	15°32’14.37”N, 93°4’50.12”O	141	Sub-optime
Margaritas 2	68	15°35’31.97”N, 93°3’23.53”O	143	Sub-optime
Ramón river	386	15°39’46.05”N 93°1’45.39”O	92	Marginal

The variables that most influenced this rating were those related to bank protection and riparian vegetation width (Table 3). The variable that showed the least variation among sites was channel alteration (Figure 3).

Table 3. Values were obtained for each variable by sites of the physical aquatic habitat evaluation according to Barbour *et al*. (1999)

Variable	Ramón river	Margaritas 1	Margaritas 2
Bottom substrate for epifauna	10	14	13
Embedment (covering of edges by sediments)	8	12	15
Speed/depth regime	10	13	20
Sediment deposition	10	12	10
State of the flow in the channel	14	19	14
Alteration of the channel	16	19	16
Rapids frequencies	14	20	15
Margin stability (right margin)	2	9	9
Margin stability (left margin)	2	10	9
Margin protection (right margin)	2	2	6
Margin protection (left margin)	2	5	6
Riparian vegetation width (right margin)	1	2	5
Riparian vegetation width (left margin)	1	4	5
Total	92	141	143

Physical-chemical parameters

The results obtained from the measurement of physicochemical parameters of the waters of the Margaritas River, taking into account each of the replicates, are shown in Table 4.O_d (%) = dissolved oxygen in percent, O_d (mg/L) = dissolved oxygen in milligrams per liter, EC 1 (μS/cm) = site specific electrical conductivity expressed in micro siemens/centimeters, EC 2 (μS/cm) = electrical conductivity at 25°C expressed in micro siemens/centimeters, Sal (ppm) = salinity in parts per thousand, T (°C) = emperature in degrees centigrade, pH = Hydrogen potential.

The mean values obtained for each parameter evaluated are shown graphically in Figure 4, while the mean comparison test and ANOVA applied to each parameter are shown in Table 5.

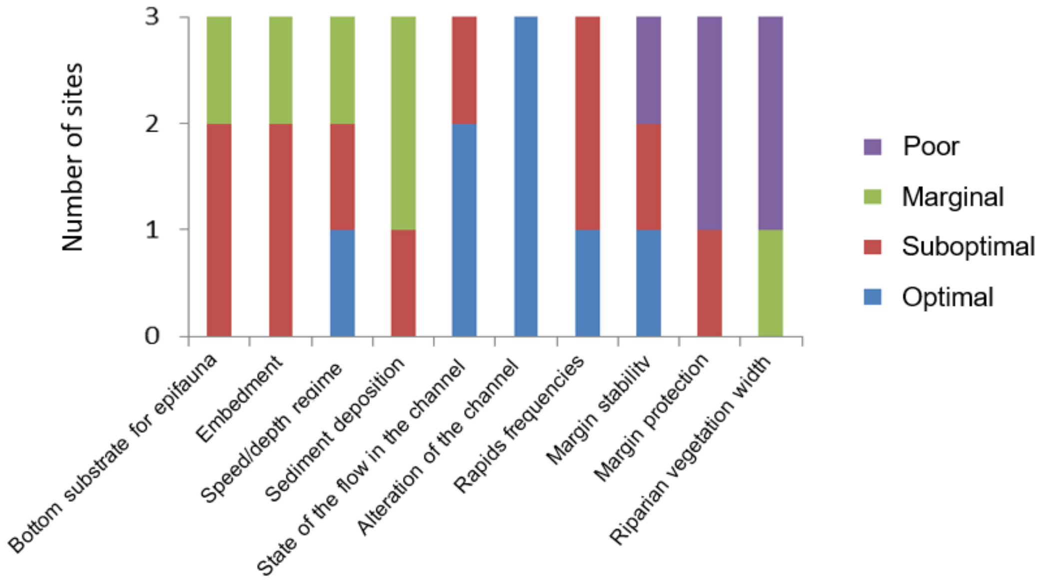

Figure 3. Status of each one of the attributes of the physical habitat of the protocol of Barbour et al, 1999 in the 3 sampling sites of the Margaritas River, Chiapas

Table 4. Depth, oxygen, electrical conductivity, salinity, temperature and pH of the water of the Margaritas River at the sampling sites

Site	Repetition	Depth (cm)	O_d (%)	O_d (mg/L)	EC 1 (µS/cm)	EC 2 (µS/cm)	Sal (ppm)	T (ºC)	pH
Margaritas 1	1- Left	28	95.2	7.86	80.5	82.1	0.00	24.1	8.2
Margaritas 1	2- Center	28	96.0	8.07	83.8	85.2	0.00	24.2	8.1
Margaritas 1	3- Right	20	91.6	7.64	83.6	85.2	0.00	24.1	8.0
Margaritas 2	1- Left	34	92.4	7.59	86.6	86.4	0.00	25.1	8.3
Margaritas 2	2- Center	62	98.5	8.14	86.6	86.4	0.00	25.1	8.0
Margaritas 2	3- Right	46	94.7	7.70	86.7	86.4	0.00	25.2	8.1
Ramón river	1- Left	14	81.2	6.79	76.10	77.4	0.00	24.2	8
Ramón river	2- Center	29	90.4	7.44	74.20	75.7	0.00	24	7.7
Ramón river	3- Left	56	92.8	7.83	74.00	75.4	0.00	24	7.6

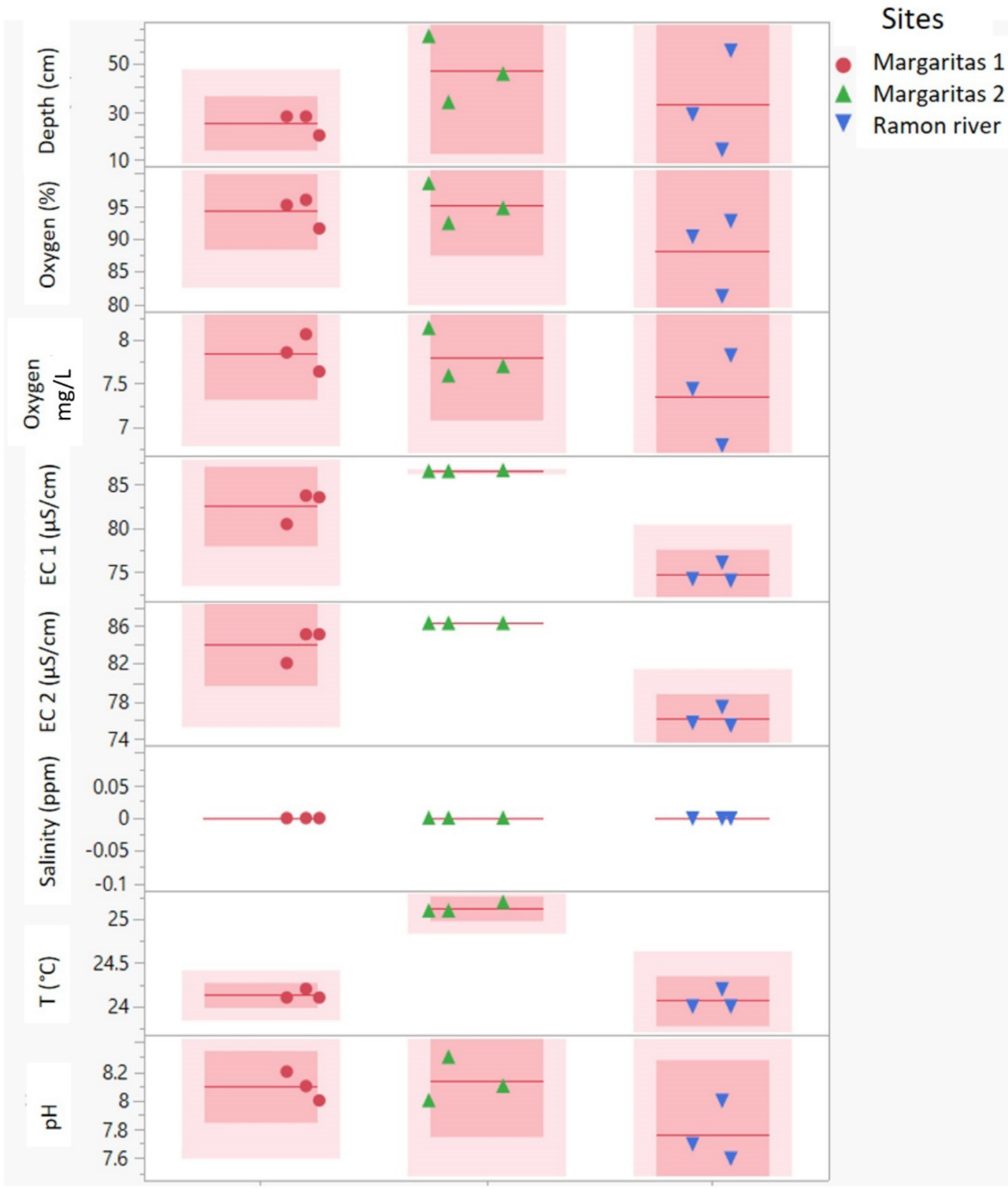

Figure 4. Graphic interpretation of each of the physical-chemical parameters evaluated at each study site and their respective repetitions with respect to the mean

Table 5. Average values of depth, oxygen, electrical conductivity (EC), salinity, temperature and Hydrogen potential (pH) in Río Margaritas ± D.E. Tukey-Kramer test, $p \leq 0.05$

Site	Average	S.D.		
Depth (cm)				
Margaritas 1	25.33	4.61		$F_{2,6}$=1.67
Margaritas 2	47.33	14.04	n.s.	p = 0.26
Ramón river	33	21.28		
Oxygen (%)				
Margaritas 1	94.26	2.34		$F_{2,6}$=2.52
Margaritas 2	95.2	3.08	n.s.	p = 0.15
Ramón river	88.13	6.12		
Oxygen mg/L				
Margaritas 1	7.85	0.21		$F_{2,6}$=1.71
Margaritas 2	7.81	0.29	n.s	p = 0.25
Ramón river	7.35	0.52		
EC 1 (μS/cm)				
Margaritas 1	82.63	1.85	b	$F_{2,6}$=68.77
Margaritas 2	86.63	0.05	a	$p \leq 0.0001$
Ramón river	74.76	1.15	c	
EC 2 (μS/cm)				
Margaritas 1	84.16	1.78	a	$F_{2,6}$=59.67
Margaritas 2	86.4	1.74e-14	a	p = 0.0001
Ramón river	76.16	1.07	b	
Salinity (ppm)				
Margaritas 1	0			
Margaritas 2	0			
Ramón river	0			
T (ºC)				
Margaritas 1	24.13	0.05	b	$F_{2,6}$=160.66
Margaritas 2	25.13	0.05	a	$p \leq 0.0001$
Ramón river	24.06	0.11	b	
pH				
Margaritas 1	8.1	0.1		$F_{2,6}$=4.82
Margaritas 2	8.13	0.15	n.s.	p = 0.06
Ramón river	7.76	0.2		

According to the average values obtained in each of the sites, there were significant differences in electrical conductivity, which was evaluated under two conditions: site-specific electrical conductivity (EC1) and electrical conductivity at 25 ºC (EC2). The results show differences between the three sites evaluated for both conditions. For EC1, the highest value corresponds to the Margaritas 2 site (86.63 ± 0.05 μS/cm), while, in EC2, the Margaritas 1 (84.16 ± 1.78 μS/cm) and Margaritas 2 (86.4 ± 1.74e-14 μS/cm) sites were much higher. For both EC1 and EC2, the results obtained for the Río Ramón site were significantly lower (Table 5).

Water temperature also presented significant statistical differences, having a higher value at the Margaritas 2 site (25.13 ± 0.05 ºC) with respect to the Margaritas 1 site (24.13 ± 0.05 ºC) and the Río Ramón site (24.06 ± 0.11 °C), as shown in Table 5. Depth (Prof.), dissolved oxygen (O_d) and pH values did not present significant differences in the three evaluated zones within the Margaritas River (Table 5).

As for the chemical parameters, ammonium only presented one value for the Margaritas 2 site, which was very low (Table 6). The amount of nitrate was higher at the Margaritas 2 site with an average value of 6.83 ± 0.55 mg/l while the Río Ramón site only presented 0.2 ± 3.40E-17 mg/l (Table 6).

Table 6. Results of the physicochemical parameters of the water of the Margaritas River at three sampling sites during the rainy season with standard deviation values

Site	Parameter			
	NH_4^+ (mg/L)	NO_3^- (mg/L)	NO_2^- (mg/L)	PO_4^- (mg/L)
Margaritas 1	0 ± 0	2.57 ± 2.60	0 ± 0	0.02 ± 0.02
Margaritas 2	0.01 ± 0.02	6.83 ± 0.55	3.67 ± 1.15	0.05 ± 0.12
Ramón river	0 ± 0	0.2 ± 3.40E-17	0.67 ± 0.58	0.12 ± 0.05

NH_4^+ = ammonium, NO_2^- = nitrites, NO_3^- = nitrates, PO_4^- = phosphates

Nitrites had similar behavior to nitrates at the Margaritas 2 site, obtaining the highest values (3.67 ± 1.15 mg/l) with respect to the Río Ramón and Margaritas 1 sites (Table 6). For phosphate analysis, the site that presented the highest values was Río Ramón (0.12 ± 0.05 mg/l) as shown in Table 6. Thus, it is considered that ammonium and phosphate concentrations were low in the three sites analyzed.

Discusion

The results of the habitat assessment showed that in the Margaritas River, human activities such as cattle ranching have caused a decrease and/or change in riparian vegetation towards other types of vegetation or its disappearance. This may be accompanied by a human disturbance in the landscape, geological aspects, and precipitation that tend to naturally affect stream conductivity (Vander Laan *et al.,* 2013) and could have contributed to the destabilization of the banks, which was observed in the case of the Río Ramón site.

Precipitation, soil fertility, watershed slope, and river size affect the location and intensity of agricultural and urban land use because they regulate crop growth, erosion, transport, and water supply (Ramankutty *et al.,* 2006). These regional-scale natural factors also determine land use and cover changes at the watershed level (Dodds *et al.,* 2015). The habitat condition, structure, and functionality of ecosystems determine the potential for the existence of their vulnerability (Micheli *et al.,* 2014). Therefore, riparian ecosystems such as the Margaritas River that present suboptimal (Margaritas 1 and 2 sites) and marginal (Ramon River site) conditions in their tributaries, give the first indication of habitat degradation. So, from a management perspective, as Tang (2020) points out, human activities can be managed to reduce pollutants and ecosystem alterations in the evaluated sites.

The physical-chemical parameters Prof, O_d and pH show similarity in the three zones evaluated within the Margaritas River. Water pH showed a certain level of alkalinity in the waters of the Margaritas River in the three sites evaluated, which is very similar to that reported by Garcia et al. (2019) applying linear regression models in which no differences were presented in the alkaline pH of the Chimbo River, Ecuador. On the other hand, the EC shows significant differences in which the Río Ramón site has low values with respect to the other study sites, however, the obtained values at study sites turn out to be higher than those reported by Arroyo and Encalada (2009) in the Guajalito (58.8 μS/cm), Palmeras (55 μS/cm) and Brincador (30 μS/cm) rivers which are within the permissible standards as established by Ríos and Prat (2004). Thus, some physicochemical conditions in the stream such as high nutrient concentrations have been widely associated with natural and human factors at the watershed scale (Golden *et al.,* 2016), which makes it more evident a higher concentration of dissolved solids at site Margaritas 2. The above could be derived from a higher emission of organic waste, fertilizers, or materials from agricultural and livestock practices that increase these values.

In the case of chemical parameters such as phosphates, it was observed that these showed a decrease as the altitude decreased and the river flow increased, also increasing due to seasonal rainfall. Similar results were obtained by Hernández (2014) for the Cacaluta River. This decrease in phosphates could be explained due to the dilution effect that water has on this compound, this is because the Río Ramón site is located in a headwater river, while the Margarita 1 and Margarita 2 sites are located on the main channel, much wider and with greater flow. Marcarelli and Wurtsbaugh (2007) note that high phosphorus concentrations benefit the abundance of nitrogen-fixing taxa and an increase in their rate of fixation as nitrogen input into the waters increases; however, nitrate concentrations at the Río Ramón site were lower concerning the Margaritas 1 and Margaritas 2 sites. This low nitrogen fixation at the Río Ramón site, in addition to the altitude, may be due to a very limited light energy whose fixation rate in shaded rivers is lower (Marcarelli *et al.,* 2008) as is the case in this higher altitude zone within the Margaritas River.

Ammonium concentrations only showed very low values for the Margaritas River 2 site but related to the higher EC obtained for this site, they are indicative of greater contamination in its waters. This result is also influenced by the concentration of oxygen and pH, which causes it to oxidize rapidly to nitrite (Hernández, 2014), which could be related to the fact that the Ramón 2 site obtained the highest results in nitrites. Agricultural activities (nitrogen fertilizers and cattle manure) that are carried out in this watershed could be influencing the concentration of these parameters (Auquilla et al. 2005; Hernández, 2014).

Conclusions

In the Margaritas River, the ecological condition reported for the three sections evaluated is favorable according to the information obtained. Habitat conditions and dissolved oxygen values generate suboptimal conditions for the development of aquatic life. However, it is necessary to implement management strategies at the Margaritas 2 site, since this site has a higher electrical conductivity and a greater presence of nitrites, which indicate the degradation of this area of the river.

Obtained data provide an overview of the ecological condition of the Margaritas River in the three zones evaluated. However, it is recommended that a more extensive and intensive study be carried out, increasing the number of sites at different altitudes. It will also be important to include climatic conditions (rainfall and dryness) to complete the information generated in this research so that more concrete management strategies can be proposed for each zone of the Margaritas River.

Contribution of the authors

Raisa Yarina Escalona Domenech: Conceptualization of the work, development of the methodology, data management, writing and preparation of the manuscript, writing, revision and editing. Romeo de Jesús Barrios Calderón: Conceptualization of the work, experimental validation, analysis of results, writing and preparation of the manuscript, writing, revision and editing.

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The authors declare no conflict of interest.

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