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Physico-chemical Factors an Phytoplankton as Indicators of the Water Quality in Two Periurbans Lakes of a Natural Protected Area in Mexico City

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ABSTRACT

The protected natural area (ANP), Ejidos de Xochimilco and San Gregorio Atlapulco (SGA), is a priority area of ecological conservation in Mexico City (CDMX), that still have remnants of the ancient lake system of the Valley of Mexico watershed that have been modified for decades due to the impact of human activities and that threaten their continuity, despite been declared as a RAMSAR site and historical and cultural heritage of CDMX. Given the above, the present study aimed to compare the spatial-temporal variability of physical-chemical factors and phytoplankton as indicators of anthropogenic impact to diagnose the current state of this locality and propose possible alternatives for sustainable management in the study area. The research design considered comparing the area of channels and lagoons of the SGA wetland in two contrasting climatic seasons: dry and rainy. Eleven sampling stations were delimited: three in the channels area and eight in the lagoons, during the months of March and July. Nine physical-chemical variables were measured: temperature, pH, total solids, conductivity, dissolved oxygen, as well as the concentrations of ammonium, nitrites, nitrates, and soluble phosphorus in surface and bottom samples from each sampling station. The statistical design took into account a factorial design of fixed effects (epochs - locations and strata), with Tukey's "post hoc" test to delimit subsets and various multivariate analysis techniques. Phytoplankton samples were taken in both localities, which were identified down to the genus level, evaluating the relative frequency of the various taxa, as well as their association through the saprobity and diversity indexes. The water quality variables indicated that both the area of channels and the lagoons of the wetland are sites with hypereutrophic characteristics, but the wetland due to its semi-isolation is an area that presents on average levels of nitrates 2.4 times lower than in the channel zone, nitrite concentrations are almost imperceptible, and ammonia is within tolerable limits for the existing biota. It also presents space-time homogeneity in its physical-chemical dynamics, in contrast to the area of channels. The composition of species indicating saprobity also differed between both sites, denoting a lesser impact on the wetland area, so it is suggested to use this site for reintroduction activities of species removed from the channel area and preserve the remaining biota in the lake system.

Keywords: phytoplankton, pollution, Management, Water quality, Xochimilco.

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I. INTRODUCTION

At present, mankind is in a process of large-scale urbanization where most of the planet's inhabitants live in large cities, and this process is expanding rapidly globally. These changes are associated with multiple land use modifications that have dramatic impacts on the environment and lead to ecological degradation, as well as pressure and / or loss of ecosystem services in these areas, which has a negative impact on the social groups settled in these places [1].

One of the most valuable ecosystem services is fresh water, which is essential for human survival, and is being affected in terms of availability and quality, since it is polluted by multiple environmental stressors: e.g., excess nutrients, spillage of pesticides, proliferation of toxic algae, increased solids in the water column, presence of anoxic zones, urban and industrial wastes, etc., which directly affects the loss of biodiversity in the receiving water bodies, affecting their structural components, as well as their functioning and the loss of their biotic resources [2], [3]. The medium-term scenario of this resource is very discouraging, given that it has been estimated that by the year 2050, more than 3 X 10^6 million people on the planet will be impacted by these processes [4]. At the current stage, the case of megacities such as Mexico City (CDMX) [5] takes a special interest because the scenario of use, availability and impact on the water resource is already a core problem in sustainability of these large cities and the bodies of water that still persist, are subjected to extreme pressures.

In CDMX, the protected natural area (ANP), "Ejidos de Xochimilco and San Gregorio Atlapulco", constitutes a RAMSAR site of international importance [6] and in it are located the remnants of the great lake system of the watershed of the Valle de México: channel´s area and the San Gregorio Atlapuco Conservation Lake (SGA), which are the object of this research. Therefore, the purpose of this study focused on making a spatio-temporal comparison of both sites, in order to compare various factors of water quality and phytoplankton components that serve as indicators to define the current state and degree of impact anthropogenic in the study area.

II. Materials And Methods

A. *Study Area*

Two locations were delimited for comparison: (1) the area of channels and (2) the area of the San Gregorio Atlapulco wetland (SGA) with its three lagoons (see Map 1).

Map 1. Study area. Ejidos de Xochimilco and San Gregorio Atlapulco (SGA), Mexico City (CDMX). 1 – Xochimilco´s channels, 2 – SGA wetland lagoons, 3 - buffer zone of wetland vegetation, modified from Google Earth map, 2020.

The total number of sampling stations was 11, 8 of which were located in the wetland area and 3 in the channel área: Cuemanco, El Bordo and Japan channel´s. The temporal component involved comparing the stations and sites referred to in two contrasting seasons of the annual cycle: the dry season (March) and the rainy season (July). The water quality variables measured were temperature, ° C, dissolved oxygen (O_2 mg / l), pH, conductivity (mS) and total dissolved solids (mg/l) with a HANNA multianalyzer and ammonium (NH_4), nitrites (NO_2), nitrates (NO_3) and phosphorus of orthophosphates (P-PO_4) with a HACH DR / 870 equipment (± 0.005 mg/l).

Phytoplankton sampling was carried out with an 80 micrometers Wisconsin net, by means of horizontal and vertical trawls at each sampling station in the channel area and two replicas in each of the lagoons. The samples were fixed with lugol's solution and 5 ml of pH 7 buffer solution and transferred in amber flasks for later identification and analysis in the laboratory. For the examination of the samples, an Axioscope-Carl Zeiss microscope was used at 40X magnification, for the phytoplankton count a Neubauer camera was used, the identification of the taxa was carried out by means of the keys of: Needham and Needham [7], Ortega [8], Prescott [9] and Figueroa-Torres [10].

A factorial design of fixed effects was used comparing spatio temporal factors (locations and months of sampling) and the possible interaction effect. Discriminant analysis was also used to contrast the spatio-temporal variation. The indicators measured were the nine variables of water quality, as well as the abundance and diversity data of phytoplankton taxa, for this purpose the SAS-JMP v. 10.0 [11], IBM-SPSS STATISTICS v.20.0 [12], and an Excel spreadsheet were used.

III. Results And Discussion

A. *Water Quality*

TABLE I: Comparison of Water Quality (WQ) Variables, Mean ± SD during Dry and Rainy Season in two Periurban Lakes of a Natural Protected Area (ANP) in México City

	Dry season		Rainy season	
WQ variable	Xoch – channels	SGA wetland	Xoch – channels	SGA wetland
T °C	$19.6^b \pm 0.6$	$25.5^a \pm 1.7$	22.3 ± 1.0	21.1 ± 4.5
O_2 mg/l	$7.4^a \pm 0.5$	$7.2^b \pm 1.3$	7.3 ± 0.7	6.2 ± 0.9
pH	$8.1^b \pm 0.17$	$8.9^a \pm 0.17$	$8.0^b \pm 0.24$	$9.1^a \pm 0.15$
Cond. µS*	$0.85^b \pm 0.03$	$4.3^a \pm 0.72$	4.02 ± 3.34	3.76 ± 0.81
TS mg/l*	$0.42^b \pm 0.02$	$2.14^a \pm 0.37$	2.76 ± 2.45	2.58 ± 0.64
NH_4 mg/l*	$3.7^a \pm 2.2$	0^b	0.13 ± 0.04	0.15 ± 0.14
NO_2 mg/l	$0.98^a \pm 0.51$	$0.08^b \pm 0.09$	$0.77^a \pm 0.45$	$0.04^b \pm 0.01$
NO_3 mg/l*	$65.0^a \pm 36.7$	$28.2^b \pm 37.5$	$25.0^a \pm 22.5$	$9.7^b \pm 2.7$
PO_4 mg/l	4.2 ± 1.3	5.0 ± 0	5.0 ± 0	4.7 ± 0.5

Means with different letters as superindex into season comparisons are statistically different ($p<0.05$), n= 10 – 15, WQ variable with * indicates significant differences between seasons.

The water quality variables indicated significant differences between the dry and rainy seasons in both locations, with total dissolved solids and conductivity being higher in the wetland area and very high ammonium, nitrite, and nitrate concentrations in the channel area, indicating the potential for toxicity that ammonium and nitrite concentrations would have for flora and fauna in this area, pH was always more alkaline in the wetland area.

On the other hand, the canonical correlation analysis of the discriminant epochs-lakes-strata, identified 7 variables that significantly interacted to explain the spatio-temporal variability between the area of channels and the lagoons of the SGA wetland, these being: pH, TS, conductivity, and dissolved oxygen ($p < 0.00$) and temperature, nitrates, and phosphates ($p < 0.02$), the variables that were significant are represented as vectors in Fig. 1.

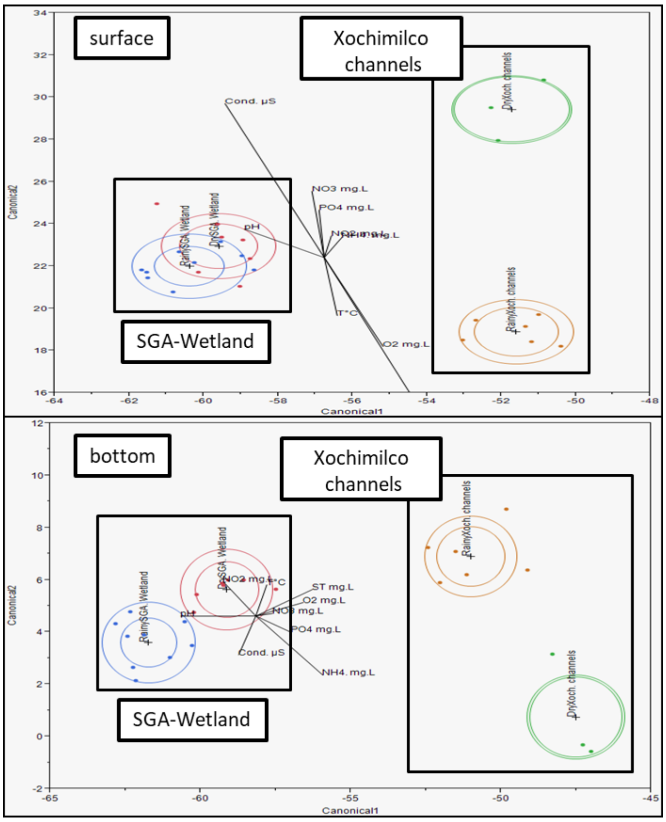

Fig. 1. Multivariate (canonical) means of the discriminant analysis. Comparison of lakes - epochs and strata in the protected natural area (ANP), ejidos of Xochimilco and San Gregorio Atlapulco (SGA), Mexico City.

The comparison of epochs – localities and strata indicate a more homogeneous habitat with less impact in the wetland area.

B. *Phytoplankton*

1) Composition of phytoplankton in the two epochs. Channels area

In both epochs the structure of the phytoplankton community was composed of 10 classes, 18 orders, 26 families and 33 genera (see Table II), eight genera were present in the two seasons, presenting similarity indexes of 0.21 and 0.29 for the indices by Jaccard and Sörensen, respectively.

The dominant groups were chlorophytes and diatoms. 25 genera were recorded during the dry season and 19 in the rainy season (Simpson diversity of 0.28 and 0.21 respectively), see Fig. 2. The global abundance was 62% in dry season and 29.8% in rainfall, indicating an algal bloom during the dry season. Two well-defined groups were formed according to their abundance (hierarchy).

The dominant groups (5 genera: *Cyclotella*, *Coelastrum*, *Navicula*, *Scenedesmus* and *Melosira*) were similar in both seasons, varying their proportion between seasons. In the second group, the gender relationship was completely different between the seasons, these being: *Chlamydomona*, *Microspora*, *Closterium*, *Oocystis* and *Microcystis* in the dry season and *Pediastrum*, *Ankistrodesmus*, *Protococcus*, *Golenkinia* and *Bottryococcus* in the rainy season.

TABLE II: FLORISTIC COMPOSITION OF THE PHYTOPLANKTON STRUCTURE IN THE XOCHIMILCO CHANNEL AREA DURING THE DRY AND RAINY SEASONS OF THE ANNUAL CYCLE

Class	Order	Family	Genus
Clorophyceae	Sphaeopleales	Scenedesmaceae	*Coelastrum*
			Scenedesmus
		Microsporoceae	*Microspora*
		Hydrodictyaceae	*Pediastrum*
		Selenestraceae	*Ankistrodesmus*
			Monoraphidium
		Treubariaceae	*Treubaria*
	Chlamydomonadales	Chlamydomonadaceae	*Chalmydomona*
		Micractiniaceae	*Golenkinia*
		Volvocaceae	*Pandorina*
		Phacotaceae	*Pteromonas*
	Chaetophorales	Chaetophoraceae	*Protococcus*
Trebouxiophyceae	Chlorellales	Oocystaceae	*Oocystis*
			Lagerheimia
		Chlorellaceae	*Micractinium*
			Chlorella
			Actinastrum
	Trebouxiales	Botryococcaceae	*Botryococcus*
	Incertae sedis	Incertae sedis	*Crucigenia*
Desmidiaceae	Desmidiales	Closteriaceae	*Closterium*
Zygnemophyceae	Desmidiales	Desmidiaceae	*Staurastrum*
			Cosmarium
Diatomea	Thalassiosirales	Stephanodiscaceae	*Cyclotella*
	Naviculales	Naviculaceae	*Navicula*
	Melosirales	Melosiraceae	*Melosira*
	Bacillariales	Bacillariaceae	*Nitzchia*
Bacillariophyceae	Naviculales	Pleurosigmataceae	*Girogsigma*
	Mastogloiales	Achnanthaceae	*Achnanthes*
Fragilariophyceae	Fragilariales	Fragilariaceae	*Fragilaria*
			Synedra
Heliozoa	Actinophryida	Actinosphaeridae	*Actinosphaerium*
Centrohelea	Centrohelida	Acanthocystidae	*Acanthocystis*
Cyanophyceae	Chrococcales	Microcystaceae	*Mycrocistis*

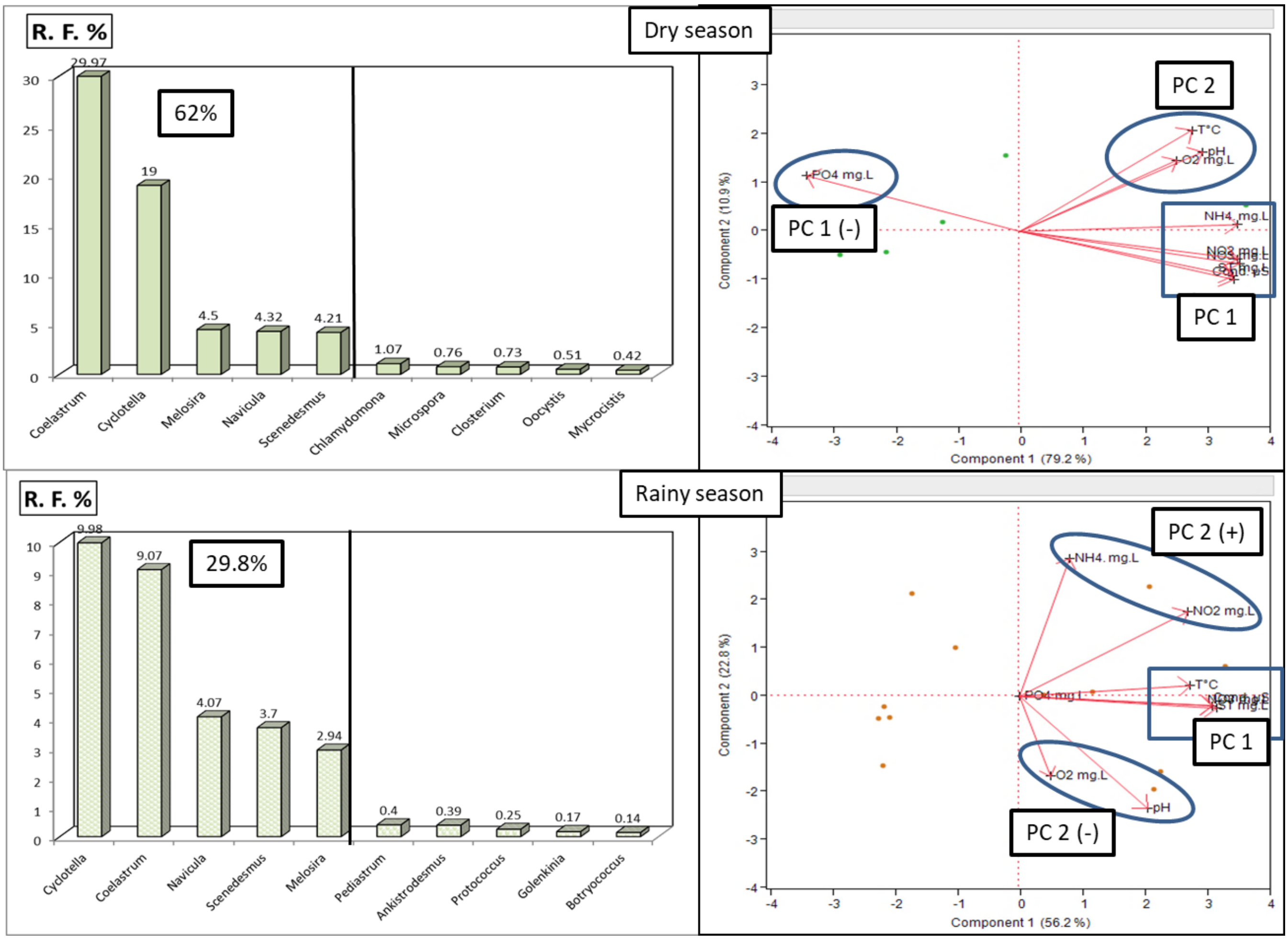

Fig. 2. Abundance – dominance (relative frequency, RF. %) showing the main phytoplankton genera and water quality variables vectors of principal component analysis (PCA) in the Xochimilco channels during the dry and rainy season.

The most influential factors in the environmental dynamics in both seasons were: ammonium, nitrite, and nitrate concentrations in conjunction with pH and total dissolved solids. During the dry season, the concentrations of dissolved phosphorus, temperature and dissolved oxygen were added to this environmental heterogeneity. Fig. 2 shows the results of the principal component analysis (PCA), from which the vectors of the variables that were most influential are indicated by ellipses during both epochs.

2) Phytoplankton composition. Channel area – SGA wetland. Comparison

9 classes, 12 orders, 21 families and 32 genera of phytoplankton were recorded in both locations. In the channel zone, the abundance, dominance and diversity of families and genera was higher than in the wetland area. In both figures (Fig. 2 and Fig. 3), those genera that are considered to be of high saprobity have been indicated with superscript stars [13].

It should be noted that the trophic status of an aquatic habitat can be determined by considering the physicochemical factors of the water and the abundance and composition of the plankton community. Phytoplankton is a bioindicator that responds quickly to various pollutants that affect natural cycles, as well as changes in environmental conditions. This is due to the fact that algae have short life cycles, which allows it to react quickly to the physicochemical alteration of the water [14].

Among the groups that stand out in phytoplankton with indicator potential are the Cyanophyceae, which have the ability to fix molecular nitrogen and thus maintain the regulated nitrogen-phosphorus (N/P) ratio, in addition to being sensitive to various metals. Other groups of interest are the Chlorophyceae, Dinophyceae, Euglenophyceae, Bacillaryophyceae or diatoms that are very common in the freshwater environment, Cryptophyceae, Xanthophyceae and Chrysophyceae, the latter generally associated with oligotrophic environments.

The presence of organic pollutants in fresh waters is called saprobity, which can be measured by the presence of bioindicator species, that is, by means of the composition of a certain community that indicates the saprobic level, one of the most used is the Palmer´s saprobic index [13].

In this sense, the comparison of the channel area with the SGA wetland lagoons, indicated a higher level of saprobity in the channel area (s=5.6 and s=4.3 in the wetland, respectively). In both cases, it is considered as very strong organic pollution, but with notable differences in the average concentrations of nitrates and ammonium (these being 2.4 and 25.5 times higher in the channels than in the wetland area, respectively).

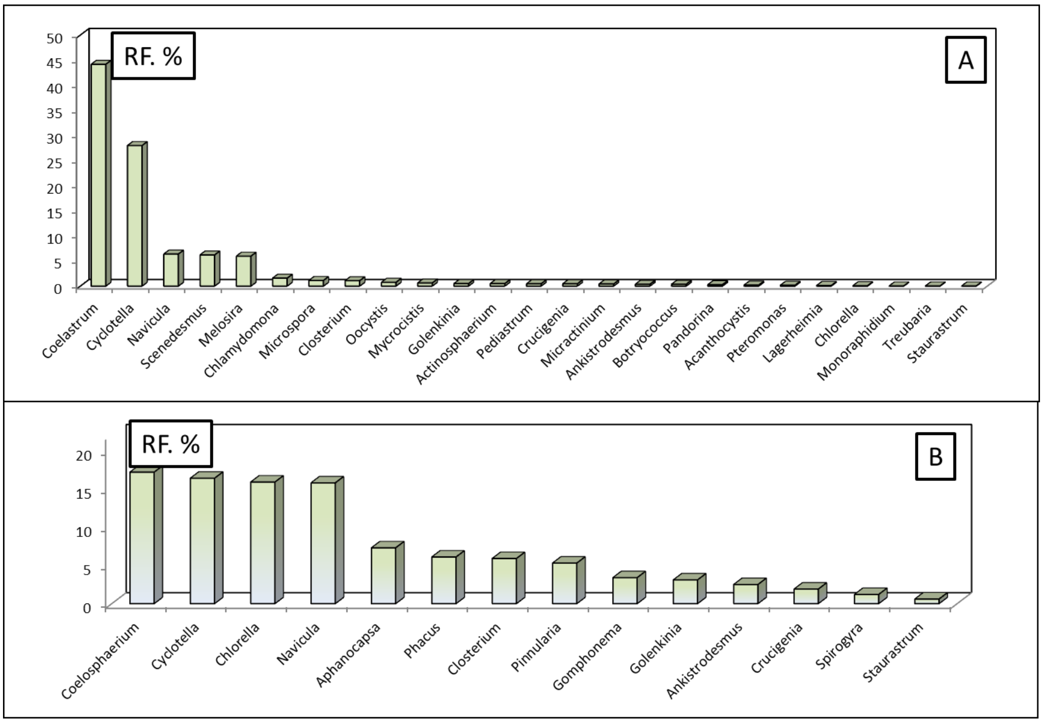

Fig. 3. Abundance – dominance phytoplankton taxa during dry season in two periurban lakes in a natural protected area of México City. A – Xochimilco channels, B – SGA wetland.

IV. Concluding Remarks

The Xochimilco channels area and the San Gregorio Atlapulco wetland lagoons are a peri-urban water habitat, that still remain as vestigial sites of the great lake system of the Valley of Mexico, these areas are unique strongholds of the great biodiversity that this ecosystem had, in which there are still species of great ecological and economic value, e.g. crayfish, white fish ("charal") and axolotl, but which are subject to enormous environmental pressure [15], and represent a bastion of the enormous biodiversity of our country, which is at risk of disappearing due to the human impact that has increased in recent decades.

In this sense, government institutions must consider in their legislation the development of public policies that provide scenarios for mitigation and adaptation to these challenges and that allow the transition to a more sustainable environment for social and economic activities, with the lowest possible impact in the environment of megacities and their peri-urban areas, since dependence on ecosystem resources is very often even higher in rural and peri-urban areas compared to cities.

Therefore, if one takes into account that the government of Mexico City, formerly the Federal District (GODF), presented the ANP Management Plan "Ejidos de Xochimilco and San Gregorio Atlapulco [16], whose objective consists on "establish the lines of action, criteria, guidelines and activities to which the administration and management of the Protected Natural Area will be subject", the results of this research have an impact on it, by virtue of which they contribute to the monitoring and evaluation for the conservation of the natural resources in the study area, indicating scenarios of spatial and temporal variation in the water quality of two localities, one located according to the zoning of the management plan at the confluence of the public use areas and the "chinampera" and agricultural zone of temporary (channels), and the second in the protection zone (SGA wetland lagoons). The results obtained indicate that the lagoons of the San Gregorio Atlapulco wetland present a physicochemical dynamic that denotes greater homogeneity than the channel area. Which defines this area as a site with less impact within the ANP, so it is more conducive to the performance of the populations of flora and fauna that still persist in the study area and therefore, it would be a suitable site that could be used to preserve and give continuity to the genetic heritage that still remains in the lake watershed of the Valley of Mexico [17].

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