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BEHAVIOR OF PHYSICAL AND CHEMICAL PARAMETERS AS INDICATORS OF WATER QUALITY AND TROPHIC LEVEL OF LA PALAPA MICRORESERVOIR, MORELOS, MEXICO

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Abstract: Microreservoirs (also called "bordos") are shallow aquatic environments with maximum depths between one and five meters, affected by the rainy season and have been considered eutrophic systems in the dilution season and hypertrophic in the concentration stage, in climates warm. The objective of this work is to determine the water quality and the trophic level during the rainy and dry seasons in the La Palapa microreservoir and to analyze the relationship between the physical and chemical variables of the water in the aquatic system. Due to the health contingency caused by the SARS-CoV-II (COVID 19) pandemic, the data was collected from a database of the Limnology laboratory, from February 2019 to February 2020. The water samples from two stations monitoring, were taken with a Van Dorn bottle for the analysis of physical and chemical variables of the water of the aquatic system. The results showed that La Palapa can be considered as a continuous warm polymictic system, with water temperatures between 18 and 30°C, well oxygenated waters (>5 mg/L), very hard and productive (>40 mg/L $CaCO_3$). Presents eutrophication processes, due to excessive enrichment by phosphorus and nitrogen, which allows proliferation of photosynthetic organisms, with a tendency to hypereutrophication, without significant differences between the rainy and dry seasons, and based on the different state indices used, no differences were observed in the behavior of the system between them, mainly due to the shallowness of the aquatic environment. It was determined that the hot dry season covers from mid-March to mid-June, the rainy season from late June to early November, and the cold dry season from early November to late February. The water from the "bordo" La Palapa is within the permissible limits of water quality according to regulations, so its use is suitable for carrying out agricultural and fishing activities.
Keywords: "Bordo", trophic indices, nutrients, physical and chemical parameters.

Today, Mexico faces a serious problem of scarcity of freshwater in many of its regions due to its topography and added to this, it is a country that has few natural lentic water bodies (70 lakes). These aquatic systems have surface sizes that vary between 1,000 and more than 10,000 hectares, which together cover an area of 370,891 hectares (De la Lanza and García, 2002). The problem has been tried to be solved for a long time, through the construction of artificial reservoirs such as dams, microreservoirs, etc., which occupy 67.13% of the aquatic systems; cover 188,781 ha and represent 14.74% of the flooded surface of epicontinental waters (Quiroz-Castelán *et al*., 2009).

Microreservoirs, also called "bordos" or "jagüeyes", have great ecological importance and high potential for generating resources. This importance is particularly notable in those areas where, due to the relief conditions, it is not possible for water reservoirs naturally occur from rain and runoff (Quiroz and Díaz, 2010).

In recent decades, population growth and industrial development are the main sources of pollution both in natural lakes and in artificial aquatic systems (dams or reservoirs). The most noticeable alterations in the ecological and limnological characteristics of these ecosystems consist of the accumulation of nutrients and sediments because of poor soil conservation in the reservoir basin, the depletion of dissolved oxygen in the deep layers, the fertilization and algal blooms in the water column (Margalef, 1976). The increase for carbon dioxide in aquatic systems causes reactions that change their chemical composition, through a process known as acidification (Garzón *et al*., 2019).

Microreservoirs have limnetic characteristics similar to those of shallow natural lakes. In general, they are shallow reservoirs with maximum depths between one and five meters, which are formed in the rainy season (Hernández-Avilés *et al.*, 2007), practically do not present stratification in temperature or nutrients, so there is no physical barriers (López-Blanco and Zambrano-González, 2001).

These aquatic systems have been classified as eutrophic (productive) in the dilution season and hypereutrophic (highly productive) in the concentration stage, in warm climates. These systems are characterized because during the rainy season, a stage of dilution of the materials in solution and suspension occurs, with a decrease in alkalinity, hardness and conductivity, because of the increase in the volume of water. Murdoch *et al.* (2000) mention that changes in rainfall patterns affect the quality of the dammed water.

In the concentration phase, the reduction of the volume can reduce the depth of light penetration due to greater turbidity, due to the increase in solids in suspension in the water column. Therefore, increase the decomposition zone and these components increase, as evaporation processes reduce the volume, use of water for irrigation and as drinking troughs (Gómez-Márquez *et al.*, 2022). Likewise, the concentration of nitrogen and phosphorus could be increased by the transport of materials from the basin in the flood period and by the release of these micronutrients from organic matter throughout the year, favoring high levels of productivity (Hernández-Avilés *et al.*, 2007).

In the dilution phase, the grazing chain is favored, by presenting a larger photic zone and a concentration of nutrients that allows a greater phytoplankton and zooplankton diversity. On the other hand, as there is a reduction in volume, the nutrient contents and plankton blooms increase, with the detritus chain predominating (Hernández-Avilés *et al.*, 2007).

Water quality is a measure of the physical, chemical and biological properties of the aquatic ecosystem that is essential to know in order to use it properly and safely. To measure it, specific standards are defined based on the intended use for example, drinking water, for agricultural or industrial use (UNDP *et al.*, 2000). Some parameters can be easily measured, such as temperature, conductivity, turbidity, pH and dissolved oxygen. Other measurements focus on nutrients, total dissolved solids, heavy metals, pathogens and organic compounds, etc. (SEMARNAT, 2015).

There are studies that have been carried national and internationally, among which we can mention Fraile *et al.* (1995), Drovandi *et al.* (2005), Rosas (2009), Rivera and Hernández (2011), Sánchez and Zamora, (2012), Gómez-Márquez *et al.* (2013), Carrasco-Vargas *et al.* (2014), Granados-Ramirez *et al.* (2014), García-Rodríguez *et al.* (2015), Retana (2019), Gómez-Márquez *et al.* (2021) and Gómez-Márquez *et al.* (2022). Therefore, the objective for this study was to analyze the physical and chemical conditions of the water and to determine the trophic state during an annual cycle in a microreservoir in the state of Morelos.

MATERIAL AND METHODS

STUDY AREA

The “bordo” or microreservoir La Palapa is located in the municipality of Ayala, in the state of Morelos, at 18°43’17.07” North latitude and 98°54’44.56” West longitude, at 1,220 meters above sea level (INEGI, 2000). The climate recorded in these areas is warm sub-humid, with summer rains (Aw´´(w) (i, g). The average annual precipitation and temperature is 800 mm and 24°C respectively (García, 2004). The type of vegetation that prevails in the study area is low deciduous forest (Figure 1).

PHYSICAL AND CHEMICAL PARAMETERS

To carry out this study, two sampling stations were established at two depth levels (0.30 and 1.0 m). The samplings were carried out monthly between February 2019 and February 2020. In each site, transparency and depth were determined with the Secchi disk. Ambient temperature, water temperature, and dissolved oxygen were measured with a HANNA oximeter, Model HI9146; pH and electrical conductivity, were regsitered with a HANNA model HI 991300 multiparameter. The water samples were taken from a Van Dorn bottle and stored in one liter polyethylene bottles for the determination of total alkalinity, total hardness and nutrients (nitrites, nitrates, ammonium, soluble reactive phosphorus, total phosphorus, silicates and sulfates), were evaluated using conventional colorimetric techniques (APHA, AWWA, and WPCF, 1999; Gómez-Márquez *et al*., 2014).

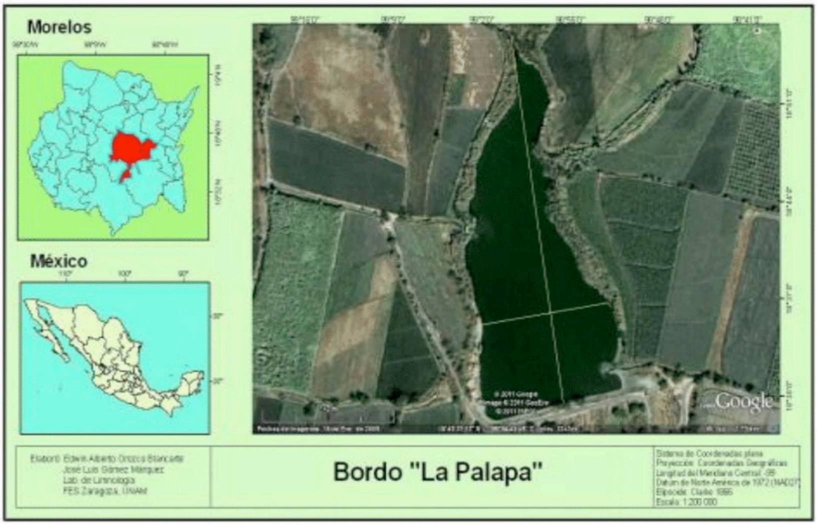
Chlorophyll a analysis was determined by means of a spectrophotometer. To record the degree of eutrophication of aquatic system, the Carlson index (Carlson, 1977), the TRIX index (Muciño-Márquez *et al*., 2017) and the Toledo index (Toledo *et al*., 1983) were used. An exploratory data analysis was carried out using graphic methods before to realice the multivariate statistical analysis. Non-parametric methods (Mann Whitney or Kruskal-Wallis U test) were applied with a significance level of $P=0.05$. Subsequently, the Principal Component Analysis (PCA) was applied, a statistical technique that allows the reduction of the dimension of the number of variables and the synthesis of information. Based on mentioned by Ledesma *et al*. (2013), with the use of the PCA, relationships between the variables could be identified, through the construction of artificial axes that allow the observations and variables to be projected simultaneously on the same plane. All analyzes were carried out using the Statgraphics v. 5.0® and the Microsoft Office 2013® Excel spreadsheet.

RESULTS

The Mann-Whitney U test was applied to the physical-chemical parameters, and it was obtained that did not show significant differences between the sampling stations for each of the parameters; therefore, it was decided to take the average of both stations. There was not significant statistical differences between stations, the Kruskall-Wallis test ($P<0.05$) was used and it was verified that there were significant differences between the parameters between the sampling months for all the water quality parameters.

The study area is located in a warm sub-humidclimate, with low deciduous forest vegetation; this means that the area has two very marked seasons throughout the year, the dry season and the rainy season (Figure 2). During the rainy season (from June to October), the volume of precipitation completely changes the landscape and significantly influences the water system, and it is during this season that the microreservoir undergoes a nutrient dilution process and increases its volume to a large extent.

In the dry period (from March to June) there is a period of concentration of nutrients during this time, the volume of water in the system is considerably affected by the increase in surface temperature, the loss of water due to the evaporation of the system. As well as, the use of water resources by the inhabitants for agricultural activities close to the system, thus affecting the system with a constant concentration of nutrients. Therefore, the behavior of the physical and chemical characteristics of the "bordo" or microreservoir



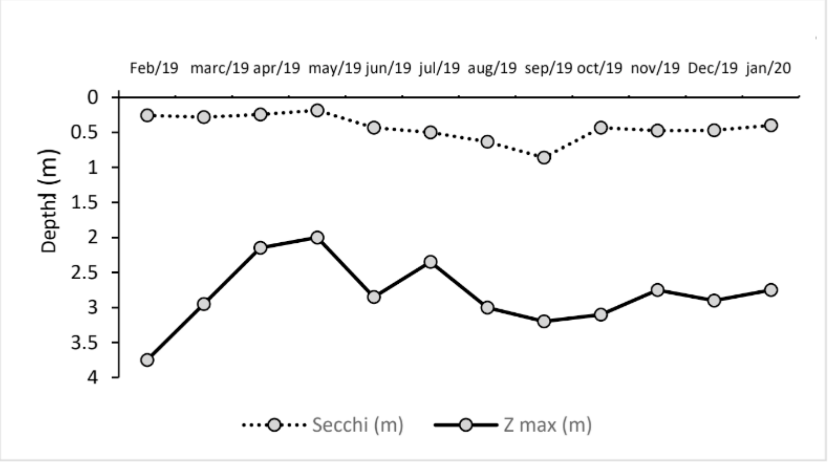


Figure 2. Temporal variation of transparency as a function of depth.

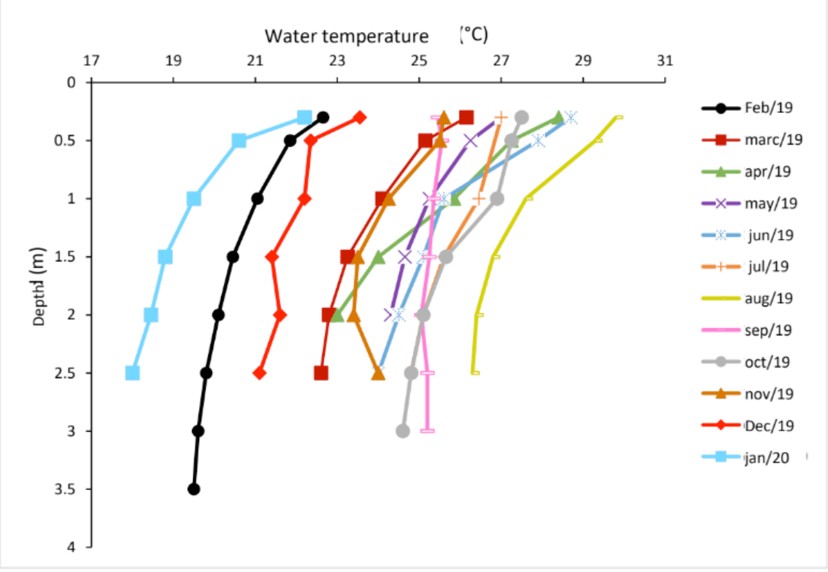


Figure 3. Temporal behavior of the water temperature in the bordo La Palapa

was governed by the hydrodynamics of the aquatic system.

Regarding temperature, the highest values were obtained at the end of the dry season and the beginning of the rainy season, and the lowest in the cold months. During all the months of sampling at the time it was carried out, it was a behavior of stratification in the water column, so the bordo shows a continuous warm polymictic behavior (Figure 3).

The relationship between oxygen and temperature is inversely proportional and during the months of study, the oxygen concentrations showed a clinograde type behavior (Figure 4). This is higher oxygen values on the surface and lower ones towards the bottom of the system, with the highest concentrations during the coldest months, and the lowest values during the dry season; the highest and lowest concentration was recorded during the month of February, reaching values close to anoxia in the deepest zone.

This behavior is because during the cold months the water column in aquatic systems remains almost stable without presenting circulation between its layers,

Regarding the pH values, these fluctuated between 7.5 and 9 units; the values showed a variation from February to June, June to October and October to January, variations that correspond to the hot dry seasons, the rainy season and the cold dry season respectively. Regarding chlorophylls, these showed a higher concentration between the months of February to April during the decrease in the volume of water, low rainfall, an increase in pH and a decrease in the transparency of the system, which favors a higher concentration of organism's photosynthetic cells in the photic layer in the microreservoir during these months (Figure 5).

The total hardness, which refers to the sum of calcium and magnesium cations, and the alkalinity to anions such as carbonates, bicarbonates, and hydroxides present in the systems. They show values that indicate most of the water-soluble substances in the system La Palapa are calcium carbonates, since, when comparing the alkalinity values with those of calcium hardness, the concentrations are almost similar throughout the year. Regarding total hardness, the water can be considered as very hard water, and the alkalinity indicates that they are productive waters, reaching the maximum concentration in the month of January, corresponding to the concentration stage and the lowest concentration and being the exception, from qualifying in February, where it drops to hard water (Figure 6).

The conductivity of water depends on the total concentration of dissolved substances in the water column; therefore, it is also an estimate of the dissolved solids content. In La Palapa microreservoir, the conductivity values indicate according to Bauder*et al*. (2011), that the classification of the water is considered to be between light and moderate in salts and according to the classification of water for agriculture, it has a normal water quality, with the highest values during the rainy season. Therefore, this indicate that the system does not have a contamination by dissolved solids.

Nutrients showed different behavior in the aquatic system. Phosphorus, an essential nutrient for the growth of organisms, registered high concentrations of orthophosphates and total phosphorus in the system, exceeding in some months (June, September and November) twice the normal concentration for fertilized bodies. Thus indicating that external compounds, made from phosphorus, are fertilizing the aquatic body in this case the increase in these nutrients is attributed to the fertilizers and pesticides used by the inhabitants in the crops near the system. The highest concentrations of orthophosphates

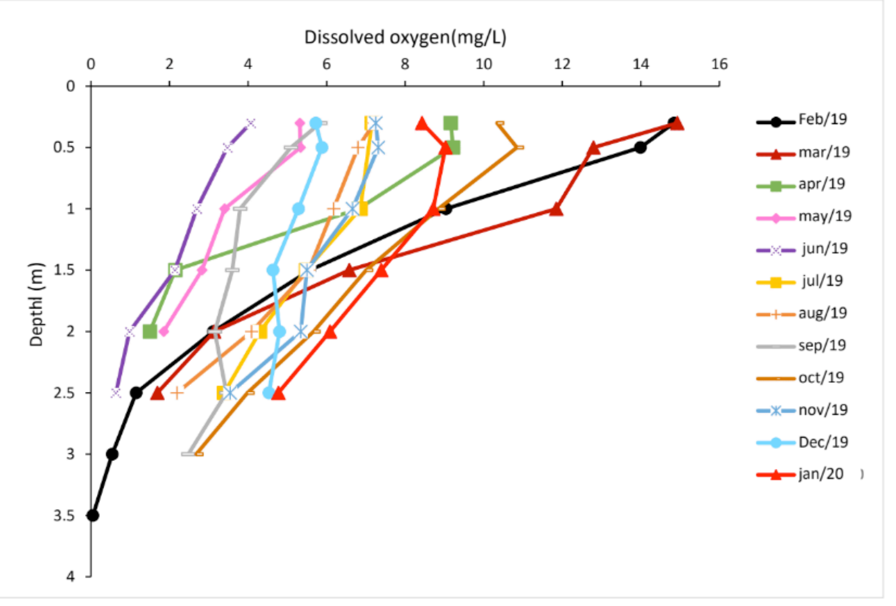


Figure 4. Temporal variation of dissolved oxygen concentration in La Palapa

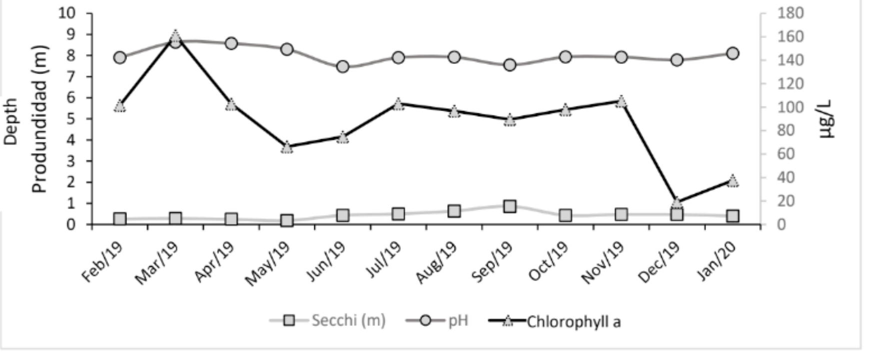


Figure 5. Temporal variation of chlorophyll a, Transparency and pH in the“bordo” La Palapa

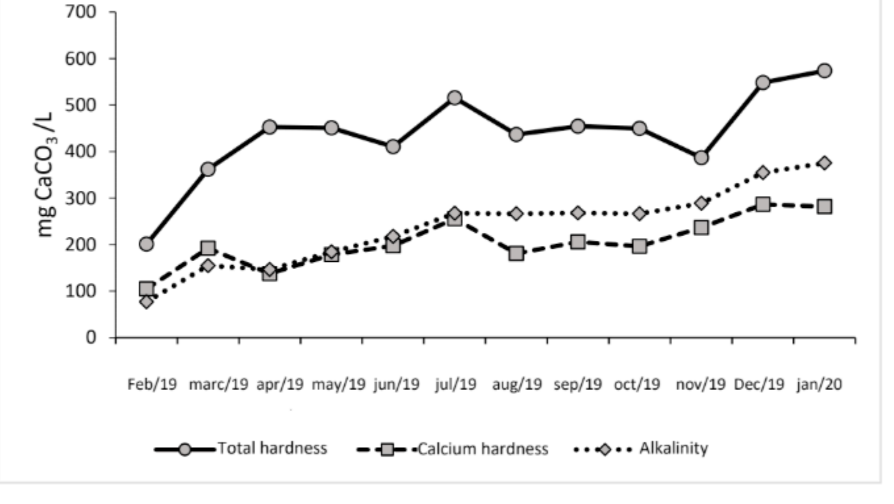


Figure 6. Temporal behavior in the concentrations of Total Hardness, Calcium Hardness and Alkalinity in the“bordo” La Palapa

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and total phosphorus were found during the rainy months (Figure 7), which contrasts with the decrease in photosynthetic organisms and nutrient transport by leaching.

The most important nitrogen compounds within aquatic systems are nitrates, nitrites and ammonium. The determination of their concentrations serves fundamentally as indicators of the condition and contamination of a system throughout the water column. The concentrations for the three forms of nitrogen were less than 1 mg/L throughout the entire sampling year, which indicates that the system has high primary productivity. The maximum concentrations of the three nutrients were observed in the rainy months (Figure 8).

Sulfates have a highly variable concentration throughout the year, presenting the lowest values during the dry season, and the highest values during the cold rainy and dry seasons, with values ranging from 10 to 80 mg/Lt indicates good quality water. Regarding silicates, the values obtained show a very stable behavior throughout the year, presenting the highest values between the months of the cold dry season and with lower values in the rainy season, and it will be use by diatoms.

The trophic state of a system is affected by eutrophication, due to the enrichment of the water by nutrients. According to the Carlson and TRIX trophic status indices, the La Palapa aquatic system is considered hypertrophic most of the year, except in October and December when it was observed as eutrophic.

Regarding the Toledo Index, this indicates that the system is Eutrophic, but with a tendency to hypereutrophy in the months of January, June, August and November. Although there are slight variations in the indices, it can be considered that the system is located as Eutrophic with a tendency to Hypereutrophy (Figure 9).

The principal component analysis showed that for the La Palapa ecosystem, there are six components that explain the behavior of the system in relation to the sampling times. The six main components together represent 86.6% of the variability of the original data.

Of the six main components, the first and second components obtained the highest eigenvalues with a cumulative percentage of 50.05% between the two. For component 1, the variables that have the most weight are the edaphic factor (conductivity, alkalinity and total hardness, with values of 0.37, 0.38 and 0.31 respectively) and the Carlson index (-0.31). For component 2, the variables that registered the greatest influence were depth (0.44), the Toledo and TRIX indices (with values of 0.38 and 0.32 respectively), and in the third component, Temperature (0.54), silicates (0.47), chlorophylls (0.44) and transparency (0.32) are the ones with the greatest weight. The nutrients were observed with greater influence between the fourth, fifth and sixth component.

In Figure 12, it can be seen that in the first quadrant are the cold warm dry months (February, March and June) and the variables of nitrates, ammonium and the Carlson and TRIX indices are associated, the latter affected by the phase concentration of nutrients by reducing the volume of water. In the second quadrantre presented by the rainy months, in which are the Depth, Transparency, Total Phosphorus, Orthophosphates, Sulfates, and Nitrites, variables that they are influenced by climatic factors and increased volume of water. The third quadrant shows the warm dry months (April and May), dissolved oxygen and pH, which are influenced and governed by the increase in phytoplanktonic organisms (chlorophyll "α"). In addition, in the last quadrant, the cold dry months (December and January), mainly have a strong association with the edaphic variables (alkalinity, conductivity, total hardness and silicates), and during this period the phytoplanktonic organisms are

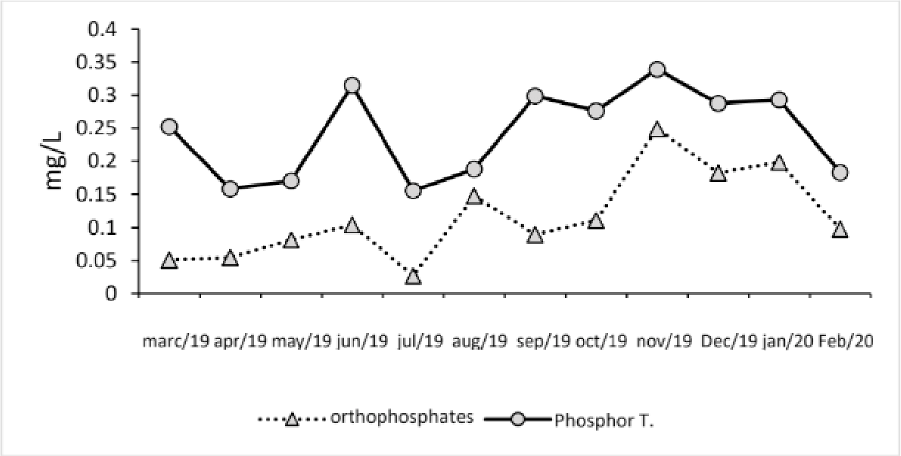

Figure 7. Relationship of orthophosphates and total phosphorus for the microreservoir La Palapa

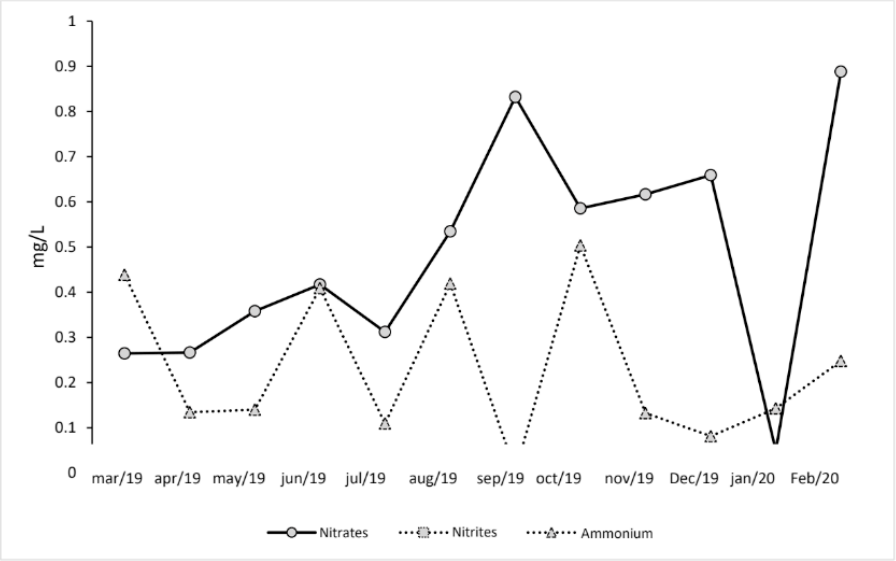

Figure 8. Temporal values of nitroderivatives in the microreservoir La Palapa

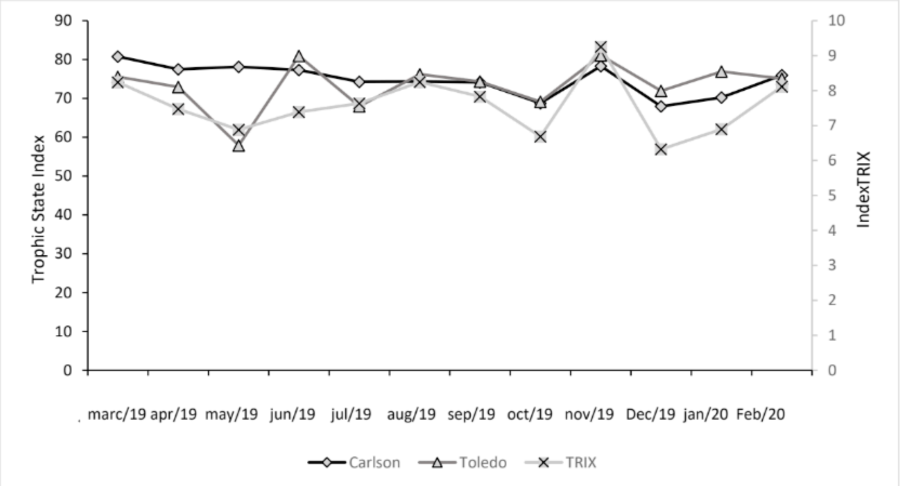

Figure 9. Monthly variation of the Trophic State Indices for the“bordo” La Palapa

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reduced and the edaphic component govern the behavior of the system.

DISCUSSION

Reservoirs are aquatic systems used to satisfy the needs of society and the environment. Among the most outstanding are the generation of energy, the provision of water for human and animal consumption, irrigation, attenuation of floods, the refill of underground layers and the provision of habitat for a large number of animal and plant species (Sriwongsitanon*et al*, 2011).

Descriptively, the "jagüeyes", "bordos" or microreservoirs, are depressions in the ground or small and medium sized artificial reservoirs, which allow the storage of water from surface runoff and allocate it for livestock, agricultural purposes, or to satisfy human needs. They are systems that remain relatively stagnant and are somewhat unstable, with variations in the water level depending on the rainfall regime, with an average depth of less than 8 meters and with a concave shape. This depth tends to cause turbidity that causes less transparency in the water, which frequently turns brown due to the presence of organic matter, the growth of algae and the presence of suspended solids (Fernández *et al*., 2017).

Among the various environmental problems that arise for aquatic systems, eutrophication is one of the most frequent, this being a process which enrich an aquatic system with limiting nutrients for phytoplankton, mainly phosphorus and nitrogen. These nutrients promote the excessive growth of algae and their accumulation, which decompose, depleting the available oxygen, causing turbidity in water bodies, generating anoxic conditions and, as a result, death and decomposition of aquatic flora and fauna (Harper, 1992).

This phenomenon is part of a natural aging process of the lakes, which occurs lowly (Bonansea*et al*., 2012). Although eutrophication occurs naturally, it is normally associated with anthropogenic sources of nutrients (Moreno *et al*., 2010), which is why many lakes have suffered serious damage from the daily activities of society, which affect their aesthetics, tourism and the economy in general. Poor quality water has associated economic costs, including ecosystem degradation, health problems, impact on activities such as agriculture, livestock or tourism, and of course, the cost of its treatment rises (Ertug and Hoekstra, 2012).

Changes in climatic conditions have significantly affected aquatic systems. For this reason, the determination of the main physic-chemical and biological parameters associated with the water quality of small reservoirs, has become essential to establish their possibility of use and get to know the cause or origin of contaminants that may be present, ensuring this way a better use and exploitation of the microreservoir (Moreno *et al*, 2010).

Ndebele-Murisa *et al*. (2010) cite that variables such as pH, conductivity, dissolved oxygen, nutrient concentration and light intensity, influence primary production and these, in turn, are affected by thermal stratification, a common characteristic in tropical lakes.

Wetzel (2001) points out that lakes that have a large amount of calcium and magnesium bicarbonates and carbonates generate high pH and alkalinity values, as mentioned for the La Palapa microreservoir. These hard waters favor eutrophication processes because they contain high concentrations of phosphorus and nitrogen that generate blooming of microalgae and consequently, the decrease in the concentration of dissolved oxygen (Arredondo and Ponce, 1998).

Currently, the La Palapa "bordo" has a strong eutrophication problem, being classified as a system in transition between

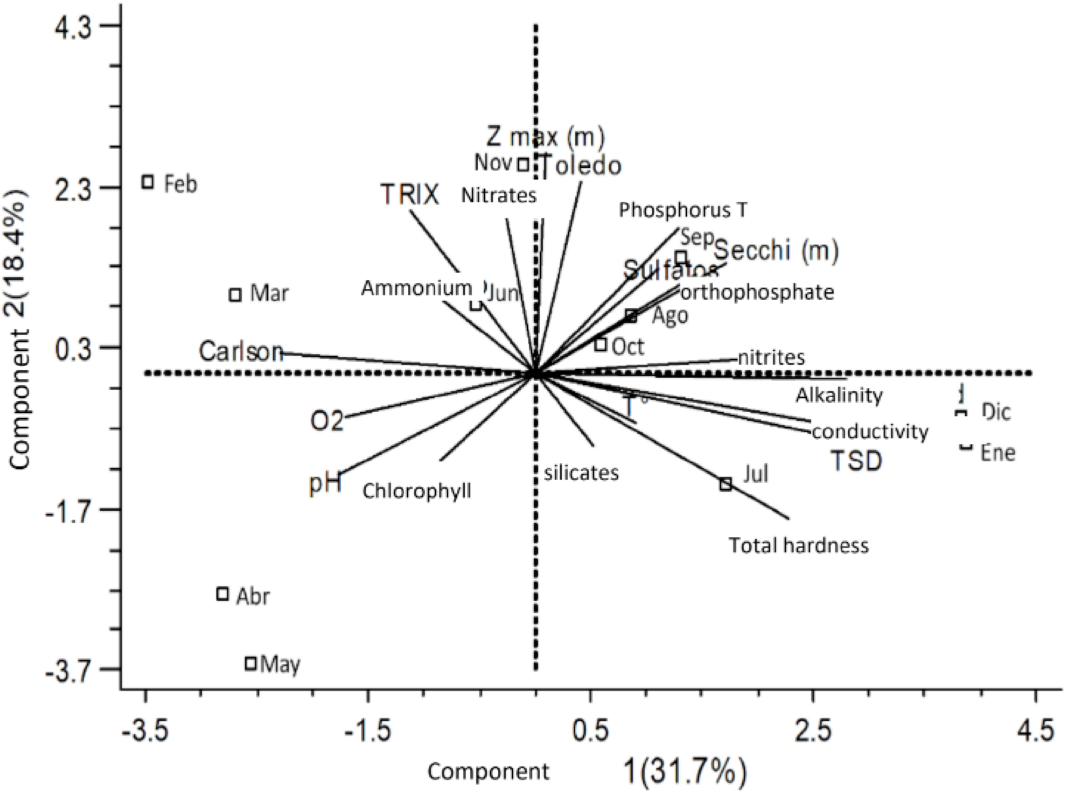

Figure 12. Bigraphic of the Principal Components Analysis (PCA) of the variables of the water quality of the"bordo" La Palapa

the eutrophic and hypereutrophic state. This state of the system is not surprising, since the main function of the microreservoir is for the storage of water for agricultural irrigation for the crops surrounding the system, which promote a large amount of nutrients through the contribution of fertilizers and pesticides normally used during the rainy months, helping to enrich the system.

Kratzer and Brezonik (1981) describe that the most adequate method to evaluate the state of the lakes is through indices that reflects aid condition, the most used being those that integrate more than one criterion for their classification. In this case, the IET of Carlson (1977), Toledo *et al*. (1985) and the mathematical formulation of the IET of TRIX, they suit to the climatic conditions of tropical environments.

Rivera and Hernández (2011), and Retana (2019) determined that aquatic system was at a eutrophic level, with a tendency to hypereutrophy according to Carlson's IET. Currently and according to this index, the system is considered hypereutrophic in 10 of the 12 months of the year. However, if the Toledo Trophic State Index is considered, this marks a greater tendency to the eutrophic state, so that, as previously stated, it can be determined that the system continues to be in a transition state between the eutrophic state and the hypereutrophic. This processes of enrichment and aging of the system have currently been increasing significantly, changing its condition and registering high values of trophic state in less than 10 years, then the contribution of total phosphorus and inorganic materials are altering transparency of the system, and accelerating the problems of this eutrophication.

Therefore, the water from the La Palapa microreservoir is considered to be within the permissible limits of water quality based on the regulations applied for the Mexican Republic, so its use in agricultural and fishing activities is appropriate.

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