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Evaluation of Water Quality through the Index of Saprobiedad, in Laguna De Zumpango

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Abstract: The hydrological basins are part of the vast biodiversity in Mexico. However, human activities favor the advancement of pollution. The Zumpango lagoon, located in the State of Mexico (Mexico State), presents problems due to the entrance of wastewater, accelerating the natural process of eutrophication. This study focused on evaluating water quality considering, chemical and biological components. Monthly samplings were carried out from March to November 2017 using five monitoring points at two levels, including: nutrimental analysis, identification of genera and study of phytoplankton diversity using the Shannon and Weiver index. The lagoon was classified using the Saprobiedad index and univariate and multivariate statistical tests were carried out. The results establish that the Zumpango lagoon is shallow and polymictic, the Saprobiedad index determines that the lagoon is a Mesotrophic system, the physical and chemical parameters determined that the main cause of contamination is organic matter, producing ideal conditions for the growth of phytoplankton. . The multivariate analysis; He indicated that the nutrients are significant for the behavior of the system. Therefore, it is concluded that the Zumpango lagoon is a contaminated system (Alpha-meso saprobio), abundant in nutrients and phytoplankton (Phormidium, Nitzschia, Microcystis).

Key words: eutrophication, pollution, phytoplankton

1. Introduction

Inland waters are a fundamental resource for the development and survival of human populations, due to the unique properties present in this group (rivers, lakes, and lagoons), characteristics that allow human consumption and the development of various economic activities [1]. The Zumpango lagoon located to the north of the Valley of Mexico Basin is a very important resource for nearby communities and this use has resulted in pollution problems, mainly due to the addition of organic matter caused by the entrance of wastewater. This problem generates the need for a study where the quality of its waters is determined. The physical, chemical and biological parameters are those that allow measuring the degree of contamination or water quality [2]. While the water quality indexes are two or more parameters that indicate healthiness and reflect the behavior of the ecosystem, with the purpose of simplifying in numerical expression the positive or negative characteristics, resulting in an estimate between zero and one or between zero and one hundred, which defines the degree of quality of a certain lotic body [3, 4].

One of these indexes measurable from the capacity developed by organisms to tolerate certain levels of contamination is the index of saprobity system proposed by Kolwitz and Marsson in 1902, this uses ecological and physicochemical data to evaluate organisms with the ability to survive under conditions of contamination, with it can objectively represent the system; that is, it tells us in a summarized way the impact that pollution has on each site through the study of living organisms [5]. The lentic systems maintain a great diversity of organisms even of equal or greater magnitude to the terrestrial ecosystems and

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the pollution produces changes in the structure of the communities, the biological function of the aquatic systems and to the organism itself, affecting its life cycle, growth and their reproductive condition [5]. Because of this, “some organisms can provide information of physical and chemical changes in the water, since over time they reveal changes in the composition of the community” [6].

The use of bioindicators is a tool to know the quality of water, this does not mean that it changes the traditional method of physicochemical analysis. But it greatly simplifies field and laboratory activities, since its application only requires the identification and quantification of organisms based on indexes of diversity adjusted with what is obtained; the detection, intensity and extent of contamination in the body of water by the affected organisms [1].

2. Objectives

- Evaluate the physical and chemical parameters that determine the quality of the water, in the surface and the bottom, through a Univariate and Multivariate statistical analysis in order to know the behavior of the system.
- Evaluate the Saprobity index using the Pantle and Buck method (1955) [7], using phytoplankton as a bioindicator organism.
- Determine the Shannon and Weiver index in a manner complementary to the Saprobiedad index, for the identification of phytoplankton genera as well as species diversity.
- Compare the physical and chemical variables with the standards (NOM-001-SEMARNAT-1996, NOM-127-SSA1-1994 and CE-CCA-001/89) that establish the limiting criteria (minimum and maximum) of water quality and protection to the environment.

3. Methods

A monthly sampling was carried out for eight months in 2015 with a total of five sampling stations taken on the surface and the bottom (Fig. 1). Determined by the activities of the place, as well as current inputs and outputs, the parameters that cannot be determined in-situ are made in the laboratory for which samples must be obtained and the required treatment must be given.

Table 1 shows the physicochemical parameters evaluated and the procedures used in the field (measurements that can be obtained in situ) and Table 2; It shows the parameters and techniques used, which were performed in the laboratory and which complement the physicochemical evaluation of water quality.

3.1 Determination of Phytoplankton Genera

Identification and counting of the phytoplankton groups was carried out with an inverted microscope (Olimpus Lx 70, using the 40x objective), using the

Fig. 1 Laguna de Zumpango, sampling points, water inlet and outlet, taken from Google Earth.

Table 1 Techniques used in the field.

Parameter	Method	Description
Sampling	Van Dorn bottle	2.2 L capacity
Transparency	Secchi disk	(Rodier, 1990) [1]
Depth	Secchi disk	(Rodier, 1990)
Temperature	Thermometer	(APHA, 1995)
Dissolved oxygen	Oximeter	Multiparameter Hanna HI-9146 (APHA, 1995)
pH	Multiparameter	Multiparameter Hanna HI-9146 (APHA, 1995) [8]

Electric conductivity	Multiparameter	Multiparameter Hanna HI-9146 (APHA, 1995)

Table 2 Techniques used in the laboratory.

Parameter	Technique
Biochemical Oxygen Demand (BOD)	BOD5 test (APHA, 1995)
Chemical Oxygen Demand (COD)	Closed reflux, colorimetric method (APHA, 1995)
Ammoniacal nitrogen (NH_3 +)	Phenol salt method (APHA, 1995) Photometric multiparameter Hanna Hi-83200
Nitrites (NO_2^-)	Sulfanilic acid method (MTBPAAA, 1984) Hanna HI-83200 photometric multiparameter
Nitrates (NO_3^-)	Phenol-disulfonic acid method Hanna HI-83200 photometric multiparameter
Ortho-phosphates	Phospho-molybdate method (MTBPAAA, 1984) Hanna HI-83200 photometric multiparameter
Carbon dioxide (CO_2)	Volumetric method (APHA, 1995)
Determination of phytoplankton genera	Inverted Microscope Olimpus Lx70

method according to the standard: CENTC230/WG2/TG3/N83 (document of 11-05-2004); which, in turn, is based on the technique described by Utermöhl (1958) [9]. A sedimentation chamber or bucket is used: it consists of a vertical column of variable volume that allows a better analysis, identification guides are used, with the keys and descriptions existing in the works of Prescott (1962) [10]; Ortega (1984) [11]; Moreno *et al.* (1996) [12].

3.2 Desk Work

• Bibliographic compilation.

• Calculation of diversity (H') using the Shannon-Weiver index (used in Ecology to measure specific biodiversity).

• Determination of the saprobity index, proposed by Kolwitz and Marsson (1955) [13].

3.3 Statistical Analysis

The quantitative data obtained were subjected to a statistical analysis using the Statgraphics Centurion XVI.II program, within which a Univariate Non Parametric Test of Comparison of Several Samples, Kruskall-Wallis test and Multivariate Analysis by Pearson Correlation, Analysis of Principal Components and Conglomerate Analysis [14].

4. Results

The results establish that the Zumpango lagoon is shallow and polymictic with an average depth of 1.99 m, has a low salinity of 0.25 psu and a high alkalinity caused by the presence of carbonates and bicarbonates, has an average pE of 8.68 what the located above what is established by NOM-001-ECOL-1996 [15], the transparency has an average of 0.20 m, which is directly related to a high density of phytoplankton but with a low diversity (H' = 0.37), its density it determines the concentration (O_2) so the Zumpango lagoon is oxidative in surface (7.31 mg l^{-1}), while in the background they predominate in the reduction processes due to O_2 depletion. The multivariate analysis; indicate that this set of nutrients is one of the most important variables, since it describes the behavior of the system due to its direct relationship with organic matter and phytoplankton. In addition, it was determined through the analysis of conglomerates that the most contaminated point due to its anthropogenic activity was Carpas I (Fig. 3). Therefore, it can be concluded that the Zumpango lagoon is a polluted system (Alfa-meso saprobio), whose main problem is organic pollution, which causes excess nutrients and abundance of phytoplankton, a problem derived from anthropogenic influence: due to organic and inorganic waste, but mainly at the entrance of the municipal waters that reach the lagoon through the Santo Tomas channel; without any treatment

4.1 Phytoplankton Analysis

72 samples were reviewed, in which 33 genera classified as follows were found: four Divisions, six Classes, fourteen Orders, eighteen Families. The

divisions are represented as follows: Cyanophyta 34.28%, Chlorophyta 34.28%, Chrysophyta 28.57 and Euglenophyta 2.85%. The most representative genera of the Zumpango lagoon (Annex D), according to their relative abundance, are the following: Phormidium (0.9317), Pseudanabaena (0.0183), Microcystis (0.0107), Rhabdoderma (0.00561) and Aphanocapsa (0.0045). Analysis of phytoplankton diversity The Shannon and Weiver index handles a range of 0.0 to 4.5 where the values close to zero represent a low diversity and values close to 4.5 a high diversity, for this case all the sampled sites presented a low diversity with values lower than 0.5 (Table 3), this indicates that there are few species that dominate the system.

4.2 Saprobiety Index Analysis

The value of the Saprobiedad index for the Zumpango lagoon is 3.37, which is in the range of 2.60 to 3.50 which establishes a classification according to Sládecek (1972) as alpha-mesosaprobia, the months with the highest value were recorded during April and November with values of 3.42 and 3.44 (Table 4).

4.3 Univariate Analysis

4.3.1 Dissolved Oxygen

Table 3 Shannon-Weiver Index, by sampling site.

Sampling site	Sannon-Weiver H’	Dominant genus (Cell/ml)	Classiffication of wáter accordingto Roldan (1992)
Dock	0.4357*	*Phormidium* (348,574) Dominance 0.86	Contaminated water
Island	0.4119*	*Phormidium* (343,701) Dominance 0.87	Contaminated water
crushes 1	0.4186*	*Phormidium* (340,813) Dominance 0.87	Contaminated water
crushes 2	0.4190*	*Phormidium* (349,657) Dominance 0.87	Contaminated water
Soap	0.4682*	*Phormidium* (344,874) Dominance 0.85	Contaminated water

* Shannon-Weiver index value per sampling site. Where: H': 0 < 1.5: Contaminated waters, from 1.5 to 3.0: Moderately polluted waters, from 3 to 5: Very clean waters, according to Roldán (1992).

The lagoon has a monthly average of 7.31 mg L¯1 (Fig. 1), there were variations in the sampling months (value P = 000308, $P \geq 0.05$ KW), the month outside the criterion of protection of aquatic life; March, which gave an average of 4.51 mg L^{-1}, while the maximum concentration occurred in September with 9.42 mg L^{-1}, these values are the result of the primary productivity due to the concentration of O_2 in the lagoon is correct for the amount of phytoplankton.

Domínguez (2006) reported drastic variations between their samplings in the Zumpango lagoon, ranging from; 1.2 mg L^{-1} in the month of December and 9.0 mg L^{-1} for the month of March, this because the concentration of O_2 depends on the amount of photosynthetic organisms.

The monthly average recorded was 86.52 mg O_2 l^{-1}, the temporal analysis shows that the lagoon has a heterogeneous behavior (value -P = 9.89667E-7, P =

Table 4 Saprobiety index value by sampling month and classification according to Sládecek (1972).

Month of sampling	Saprobiety Index	Classification granted according to Sládecek (1972)
March	3.31	Contaminated water
April	3.42	Contaminated water
May	3.41	Contaminated water
June	3.34	Contaminated water
July	3.32	Contaminated water
September	3.35	Contaminated water
October	3.38	Contaminated water
November	3.44	Contaminated water

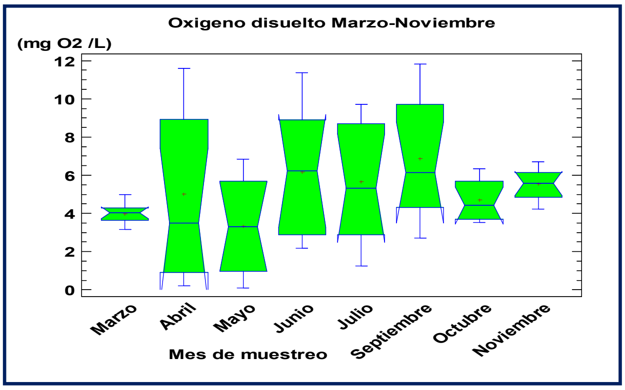

Fig. 2 Box and mustache diagram for dissolved oxygen of 2015.

0.05 KW), that is to say there are differences between each month of sampling (Fig. 2); with this we identified the months of April and July, with the highest BOD5 (140 mg O_2 l^{-1}), which is understood as a reflection of the amount of organic matter, as well as the oxygen demand required by the metabolic processes of aquatic organisms. The month with the lowest biochemical oxygen demand was obtained in September with a value of 50 mg O_2 l^{-1}.

The CONAGUA in 2003 reported for the Zumpango lagoon, a value of 104.20 mg l^{-1} and similar values found in the lake of Xochimilco with 78.4 mg l^{-1}; so for both sites, given the classification of contaminated water, these O_2 requirements are consistent with the values found during this work. Therefore, it can be established through this parameter that the Zumpango lagoon is; a contaminated system.

The behavior of the BOD_5 during the sampling months is heterogeneous, this may be due to the various changes in the water inlets and outflows, which are not constant, in addition to agreeing the sampling period with the rainy season (June to September).

4.3.2 Chemical Oxygen Demand (COD)

The value of the monthly average is 160.42 mg O_2 l^{-1}, the maximum value was registered in July (238.12 mg O_2 l^{-1}) and the minimum value was registered during the month of March (104.77 mg O_2 l^{-1}), in the Mexican normativity there are no determined values with respect to this parameter; however, according to NOM-001-SEMARNAT-1996 there are proposed values between 100 and 120 mg l^{-1} and according to the National Water Commission, values greater than 40 mg l^{-1} are classified as contaminated water. The analyzes carried out by CONAGUA in 2003, they reported a COD of 205.7 mg l^{-1} for the Zumpango lagoon; so they report it as; a heavily polluted lagoon.

According to the monthly analysis, the lagoon presented a heterogeneous behavior (value -P = 0.000757225, $P \geq 0.05$ KW), with values between 100 and 200 mg l^{-1}. However, July is the only month that exceeded 200 mg l^{-1} (Fig. 3), this is due to two causes:

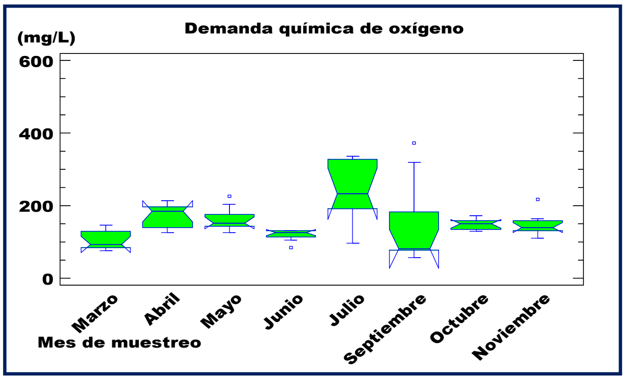

Fig. 3 Monthly variation of chemical oxygen demand.

the entrance of waste water with greater organic load and the increase in phytoplankton density, since this is when dying sedimented in the bottom increased the amount of organic matter to degrade.

4.3.3 Nitrites (NO_2^-)

A monthly average of 0.15 mg l^{-1} was obtained, the lowest average was obtained during the month of September with 0.10 mg l^{-1} and the month of highest concentration October with 0.32 mg l^{-1}. In general, the nitrites showed a heterogeneous behavior (value -P = 1.5881E-10; $P \geq 0.05$ KW) (Fig. 4); with low concentrations, this means that the nitrogen cycle: ammonification and nitrification occur rapidly due to the potential positive reduction oxide that the lagoon; this quickly transforms nitrogenous compounds into nitrates, an assimilable form for bacteria and phytoplankton organisms.

4.3.4 Nitrates (NO_3^-)

In general, the nitrates showed a heterogeneous behavior (value -P = 0.000086678, P ≥ 0.05 KW) with which it could be established that statistically significant differences were identified, forming three homogeneous groups: one; September and October; with low concentrations lower than 6.0 mg l^{-1}, two; April, June and November with average concentrations of 10.0 mg l^{-1}; and three; March, May and July with maximum concentrations of up to 20.0 mg l^{-1} (Fig. 5).

4.3.5 Ammonia (NH_3^-)

The monthly average is 0.66 mg l^{-1}, the highest concentration was presented during the month of October with 2.17 mg L-1 and the lowest concentration in the month of June with 0.21 mg l^{-1}, these values reflect a Eutrophic state (Table 5). Work done in Coyuca de Benítez, Guerrero reported values of 0.44 mg L-1.

The behavior of the ammonia was heterogeneous (value -P = 4.21343E-8; P ≥ 0.05 KW), so it shows statistically significant differences between the medians of each of the sampled months (Fig. 6), four homogeneous groups were formed. October, two; November, three; July, September and March and four; June, April and May. The spatial analysis shows no statistically significant differences (value -P = 0.120874, P ≥ 0.05 KW).

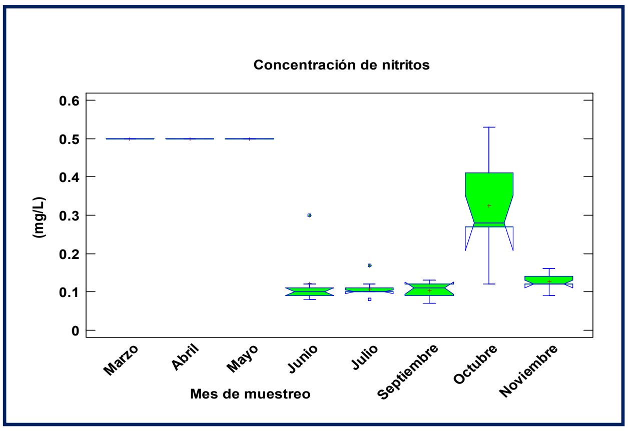

Fig. 4 Monthly variation of nitrites.

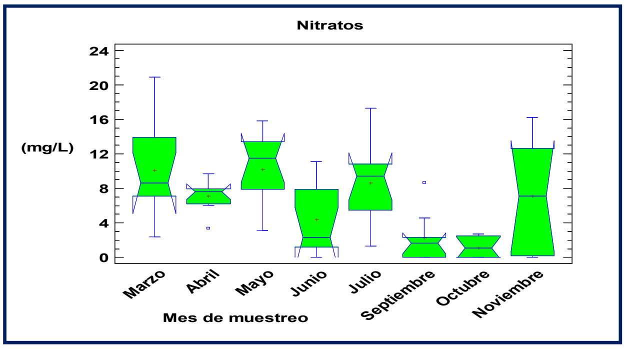

Fig. 5 Monthly variation of nitrate concentration.

Table 5 Relation of nutrients with the trophic level, taken from (Esteves, 1998).

Trophic state	Ammonia (mg L^{-1})	Nitrites (mg L^{-1})	Nitrates (mg L^{-1})
Oligotrophic	0.0-0.3	0.0-0.5	0.0-1.0
Mesotrophic	0.3-2.0	0.5-5.0	1.0-5.0
Eutrophic	2.0-15.0	5.0-15.0	5.0-50.0

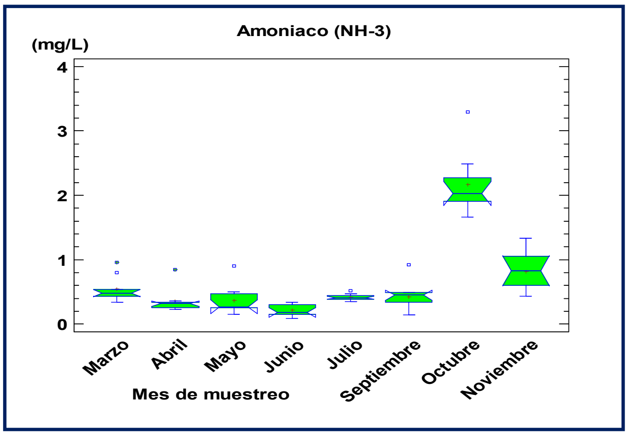

Fig. 6 Monthly variation of ammonia from March to November.

In Table 5, the classification of the Zumpango lagoon according to the concentrations found is shown in color. So according to the concentration of ammonia the lake has a status: Mesotrophic, according to the nitrites the classification is Mesotrophic and finally according to the concentration of nitrates is a Eutrophic system.

Nitrogen (N_2) enters the lagoon in three different ways: one organic matter, this in the form of organic nitrogen which is found in proteins as an example: we have the amino group (NH_2^-), these compounds through the process of assimilation they are transformed into ammonium (NH_4+). Two by means of the fixation by means of cyanobacteria, which transform the atmospheric nitrogen (N_2) into ammonium (NH_4+), this by the phytoplankton that uses specialized cells called heterocysts for this process. Three; through the waste of animals and humans that enter the lagoon in the form of ammonia (NH_3) which if not used in this assimilable form quickly becomes ammonium (NH_4+). Once the ammonium is in dilution it transforms very quickly into nitrites (NO_2^-); temporary state, since this is only an interface before transforming into nitrates (NO_3^-), this process is known as nitrification and occurs due to the positive potential of oxide-reduction of the lagoon.

4.3.6 Total Phosphorus (P)

A monthly average of 0.53 mg l^{-1} was obtained, the highest concentration value was obtained during the month of April with 0.92 mg l^{-1} and the lowest during the month of September with 0.23 mg l^{-1}, these concentrations are considered as minimum and coincide with what was reported (Domínguez, 2006), since the found values varied from 0.5 to 2.0 mg l^{-1}. According to NOM-001-SEMARNAT/1996, the established maximum values are not exceeded, which for agricultural irrigation use is 30.0 mg l^{-1} and in the case of urban use 5.0 mg l^{-1}.

The statistical analysis shows a heterogeneous behavior (value -P = 0.000102576, $P \geq 0.05$ KW), so significant differences were identified between the sampling months, variations that are maintained between the ranges of a or 1.50 mg L^{-1} (Fig. 7). The multiple test for phosphorus shows three homogeneous groups with differences between them: one; March and April, two; October, June and November and three; May, July and September.

5. Multivariate Analysis

5.1 Principal Components Analysis (PCA)

The Principal Component Analysis was used to determine which parameters most influence the behavior of the system; was performed using 17 variables, within which component one obtained 38.59% and component two 59.07% in cumulative percentage, as shown in Table 6. The analysis indicates that with components one and two, they can explain the behavior of more than half of the variables evaluated.

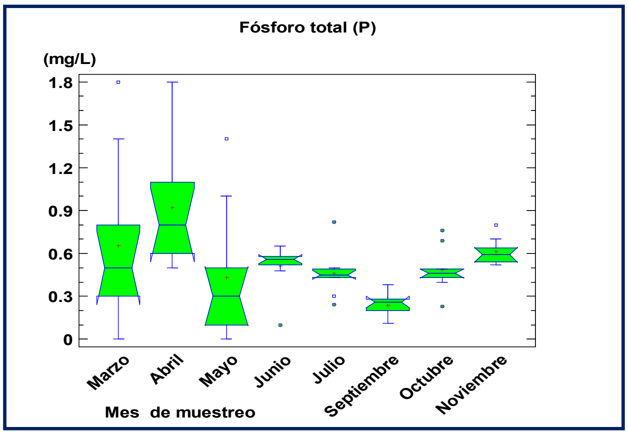

Fig. 7 Monthly variation of total phosphorus.

Table 6 Main components and accumulated percentage.

Component Number	Eigenvalue	Percentage of Variance	Percentage Accumulated
1	6.9471	38.59	38.595
2	3.6862	20.47	59.074
3	2.7532	15.29	74.370
4	1.5481	8.60	82.971
5	1.3177	7.32	90.291
6	1.0872	6.04	96.332
7	0.6603	3.66	100.000

The variables and contribution loads for which component one is represented are the following: depth (-0.3400); because the availability and redistribution of the nutrients depends on it since it is a shallow system that has constant mixtures propitiated by wind currents and its warm temperature, in addition to the concentration of dissolved gases, mainly the oxygen that is affected. In Fig. 8, the behavior of the variables is graphically shown, the graph consists of four numbered quadrants against the clock hand (quadrant I to quadrant IV). The variables are ordered according to the relationship they have with each other and their magnitude determines the degree of importance for both components.

5.2 Conglomerate Analysis

For this analysis, 18 variables were used, which are the evaluation parameters: chemical and biological physicists. All evaluated in the nine monitoring points of the lagoon, with the values of these parameters conglomerates were formed between the sampling sites, this from the greater amount of similarities between the behavior of the parameters (Fig. 8).

The relationship between them is shown in Fig. 9, which establishes which monitored sites have a similar behavior, giving a relationship value which, being closer to zero, means more variables with a similar behavior. The first conglomerate is formed by: the island-surface and I-surface tents, since the distance that marks its relationship is less than five, which indicates that these two sites have the most similar

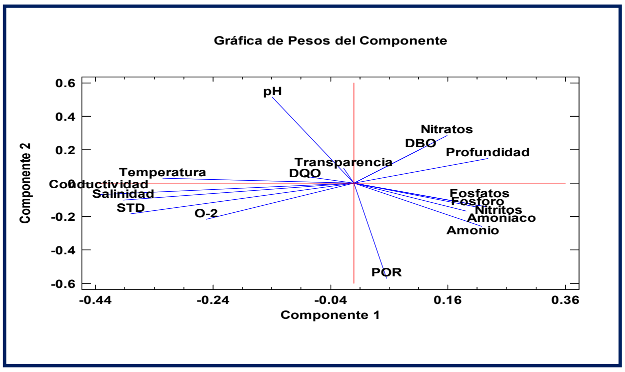

Fig. 8 Main components analysis.

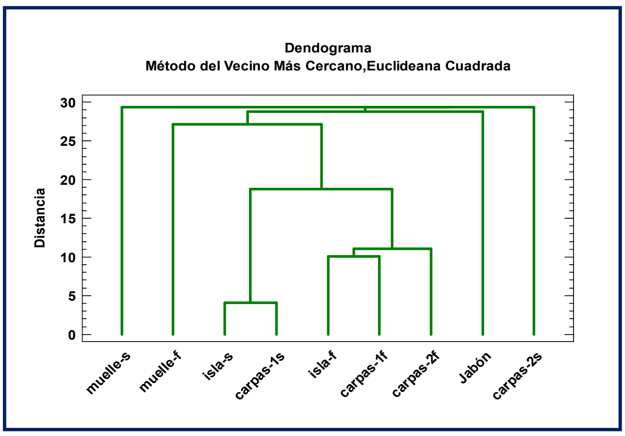

Fig. 9 Dendogram, method of the nearest neighbir.

behavior; This can be explained because both sites are located in the center of the lagoon. The second conglomerate is; Island bottom, Carps I bottom and Carps II bottom, which indicates that the bottom of the lagoon, in the center area has a similar behavior because of the proximity to the main effluent of the lagoon.

6. Conclusions

The Zumpango de Ocampo lagoon is a shallow polymictic system, composed of fresh water, has a high alkalinity due to the presence of carbonates and bicarbonates, oxidative on the surface and reducing at the bottom.

The physical and chemical variables that are outside the limits established by NOM-001-SEMARNAT-1996 are: BOD_5, COD, pH and O_2 and according to the Ecological Criteria for Water Quality (CE-CCA-001/89) are: Transparency, pH, BOD_5, COD, NO_3^- and NH_3.

A high organic load was found, which increases the availability of nutrients; ammonium, nitrites and phosphorus that are the basis of the high phytoplankton density, although with a low diversity since the dominance of the genus Phormidium is $\geq$ 0.85.

The phytoplankton analysis of diversity and abundance as well as the identified genera (Phormidium, Euglena, Nitzschia, Microcystis, Navicula, Scenedesmus) locate the Zumpango Lagoon as a Mesotrophic System.

According to the results of the saprobity index, with an interval of 2.6 to 3.5, it locates the Zumpango lagoon as Alfa-mesosaprobia, water quality III. While the diversity index of Shannon and Weiver with values from 0 to 1.5 classifies the system as: contaminated water.

7. Recommendations

It is necessary to complement this analysis with an evaluation of pathogenic bacteria (total coliforms, fecal coliforms and Escherichia coli) because these are organisms that cause infectious diseases in humans. It is advisable to carry out an evaluation of inorganic pollutants (heavy metals), mainly in carp tissues (Cyprinus carpio) because it is the species that is commercialized, since the last study was carried out in 1998 by the Iztacala FES and in this case they were found dangerous levels of nickel and lead. Finally, it is recommended to consider wastewater treatment techniques, (through biological organisms) mainly in the effluents that supply the Zumpango lagoon since it is the main cause of the high organic load.

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