Water Quality and Trophic State of the Tourism and Agricultural Zone in Lake Yojoa

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Abstract– ***Eutrophication, caused by excess nutrients such as phosphorus and nitrogen, alters the physical, chemical, and biological characteristics of water, negatively affecting biodiversity. This phenomenon, exacerbated by human activities such as agriculture and tourism, poses a growing threat to Lake Yojoa, the only significant freshwater body in Honduras. Population growth and human practices have raised nutrient levels, deteriorating water quality. This study evaluated the state of the lake using the Water Quality Index of the Canadian Council of Ministers of the Environment (WQI-CCME) and other trophic indices. Two analysis zones were established: Zone A, related to tourism, and Zone B, linked to agriculture. During 2023, quarterly sampling was carried out and eight physicochemical parameters were analyzed, such as pH, dissolved oxygen (DO), and total nitrogen (TN). The results showed "poor" quality in Zone A (WQI of 44) and "marginal" quality in Zone B (WQI of 45). According to the Carlson index, both zones were classified as eutrophic, indicating a high presence of nutrients and algae proliferation, confirmed by the attenuation coefficient (K). The T-test revealed significant differences in TN, with higher concentrations in Zone A, suggesting that tourism has a more negative influence than agriculture on the eutrophication of the lake.***

Keywords-- water quality; trophic state; IET; lake.

I. Introduction (Heading 1)

Lakes, essential guardians of the precious freshwater resource, shine by conserving approximately 77% of this invaluable reserve on the earth's surface [1]. However, as a consequence of anthropogenic activities, an alteration in the quality of its waters has been observed in recent years [2]. Eutrophication, the process that introduces excess nutrients to water, has emerged as one of the most critical challenges worldwide [3]. This problem is especially worrying due to its capacity to alter the functionality of lakes and other freshwater bodies, negatively affecting biodiversity and water quality [4].

The only freshwater lake in Honduras, Lake Yojoa, is one of the most valuable resources in the country, recognized for its role in generating hydroelectric power since the 1950s, as well as sustaining local communities through of fishing and agriculture, directly influencing the food security of the region. However, recent factors have caused significant changes to the lake environment, such as population growth, urbanization, industrialization, intensive agriculture, and tourism. These changes have increased pressure on the lake's water quality, raising concerns about its long-term sustainability.

Aquaculture, also known as pisciculture, is the set of techniques used to grow different types of fish under measurable and controlled conditions [5]. Aquaculture is vital for the contribution and food supply worldwide and is even used as a method of repopulation of different species. This technique boosts economic development, especially in coastal or rural locations, and expands the supply of products worldwide. The main collateral damage of aquaculture is water pollution due to excess nutrients (eutrophication). Generally, the most predominant are the following: total nitrogen, ammoniacal nitrogen ($NH4+$), nitrite nitrogen ($NO2-$), ($NO3-$), and other nitrogenous compounds, total phosphorus, nitrates, nitrite, and ammonia [6]. Contamination also occurs due to the different foods given to crops, the use of chemicals such as antibiotics to prevent diseases and even the use of fertilizers, whether natural or synthetic, that can affect both surface and groundwater.

Currently, the main tilapia producers are China, Egypt and Bangladesh, which cultivate the species Oreochromis niloticus, same species that Honduras cultivates in Lake Yojoa. This tilapia species is known as a fish with a high resistance to many factors, as well as with a tendency to reproduce early and without any problem to overpopulate a cultive [7], however, the different anthropogenic activities have been affecting those indexes that are vital for a healthy culture such as temperature, dissolved oxygen, turbidity, pH among others[8]. The consequences of a crop being exposed to inappropriate levels of these parameters cause a visible reduction in growth, tissue contamination, weakening of the immune system, and behavioral alterations and high levels of mortality [9]. Along with these parameters, to ensure a crop with prolific reproduction, it must be maintained within an adequate diet that is composed of the necessary nutrients for adequate growth [10].

The objective of the research is to determine the trophic state index and the level of water quality of the tourism and agricultural zone in Lake Yojoa. This investigation is significant due to the ecological and economic dimensions that characterize the lake, as well as the growing concerns related to its environmental deterioration. It also seeks to identify the main parameters that must be analyzed to determine the quality of water in tilapia crops in Lake Yojoa. The rigorous evaluation of these parameters is carried out to provide accurate information that will contribute to the promotion of sustainable management of the lake and the preservation of its natural environment

II. Methodology

A. Study area

Lake Yojoa stands out as the largest freshwater lake in Honduras, with a surface area of nearly 83 km^2 and a water capacity of around 1.4 km^3. At the same time, it contributes uniqueness and relevance to the Honduran geographic panorama by presenting a maximum annual depth that fluctuates between 24.6 and 29 m [11]. Locals in the area hold the opinion that anthropogenic activities carried out in the lake have affected the quality of the water in the last two decades [12]. To obtain precise knowledge about the situation and state of the water of Lake Yojoa, the lake was geographically divided into two main zones: Zone A and Zone

These zones were carefully selected, to identify the areas that possibly experience the greatest anthropogenic impacts. The study was carried out over four quarterly periods to cover seasonal variations and possible changes throughout the year 2023. Each quarter was assigned to a specific sampling phase, allowing a temporal evaluation of water quality in both contexts. This technique also allows the evaluation of possible seasonal variations in water quality, which in turn facilitates a more complete and precise evaluation of its condition. The locations of the sampled sites are found in Table 1
below.

TABLE I
Locations of sites where water samples were taken.

Zone	Latitude	Longitude
A	14°48'02.8"N	87°58'53.6"W
	14°53'56.7"N	88°01'39.0"W
	14°53'56.7"N	88°01'39.0"W
B	14°52'44.0"N	87°58'48.1"W
	14°50'47.5"N	87°59'22.6"W
	14°55'42.2"N	88°01'45.4"W

Zones A and B were stipulated for the study of the water quality and trophic state of Lake Yojoa, shown in Figure 1 in which zone A corresponds to the sites linked to human activity that predominates in tourism, specifically in hotels and restaurants which are busy throughout the year. Zone B corresponds to the sites in which agricultural activity is concentrated, mainly in livestock and agriculture.

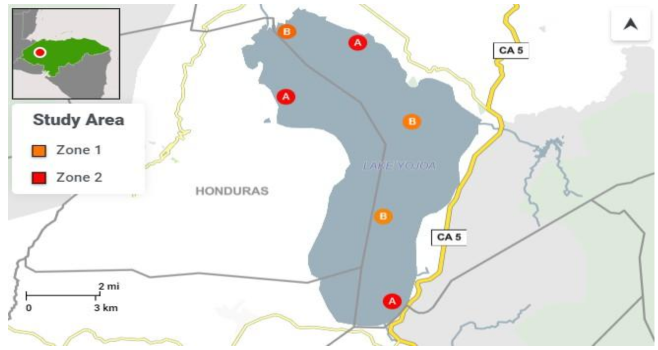

Figure 1. This map represents the studied area.

The analyzed parameters, which included physical, chemical, and biological aspects of the water, are shown in Table 2.

TABLE II
Parameters Selected for the Study of the Water Quality of Lake Yojoa.

Classification	Parameter
Physicists	Turbidity Conductivity
Chemicals	Total Nitrogen Total Phosphorous Chemical Oxygen Demand Dissolved Oxygen
Biological	pH E. coli

B. Water Quality Index of the Council of Ministers of the Environment of Canada (ICA – CCME)

For the purposes of this research, the Canadian Council of Ministers of the Environment Water Quality Index (CCME – WQI) was adopted, which offers notable versatility when evaluating water quality in lakes, whether at a single sampling point or at several, whether which allows adjusting the quality parameters and guidelines according to the specific characteristics of each lake [8] which enhances its usefulness in monitoring and comparing water quality within lake ecosystems. Its application in multiple investigations has validated being an effective approach to analyze the general condition of lakes [9–11]. In this context, the Canadian Council integrated the components of reach F1, frequency F2 and amplitude F3, to create the quality index that is calculated with (1)

$$CCME-WQI = 100 - \frac{\sqrt{F12+F22+F32}}{1.732} \quad (1)$$

Where the components can be calculated using (2), (3) and (4)

$$\left(\frac{F}{1}\right) = +[\frac{nnmo}{npar}].100 \quad (2)$$

$$\left(\frac{F}{2}\right) = +[\frac{nfaill}{ntotal}].100 \quad (3)$$

$$\left(\frac{F}{3}\right) = [\frac{nnse}{0.01 \cdot nnse+0.01}].100 \quad (4)$$

Where $nnse$ represents the number of parameters that did not reach the target, $npair$ represents the total number of parameters n_{fail}, represents the number of tests that were unsuccessful, $ntotal$ represents the total number of tests performed and n_{nse} represents the normalized sum of excursions, or the number of tests individuals who do not meet the objectives.

The term "excursion" refers to the number of occasions in which the concentration of an element is higher (or lower, when the goal is a minimum) than the required value. And (5) represents that sum.

$$n = [\frac{\Sigma_{i=1}^{n}\ excursioni}{ntest}] \quad (5)$$

The excursion can be calculated in two different contexts, depending on the case: (6) when it is sought that the test value exceeds the objective and (7) when it is sought that the test value should not be less than the objective.

$$excursion_i = [\frac{xfail,i}{y\ obj}]-1 \quad (6)$$

$$excursion_i = [\frac{y\ obj}{xfail,i}]-1 \quad (7)$$

Thus, within the framework of this research, the monitoring of the water quality of Lake Yojoa will be carried out through the application of the CCME-WQI, which establishes the index in a range from 0 to 100. Depending on the result obtained, determines the state of water quality. This classification is detailed in Table 3.

Table III. Qualification of the state of water quality according to the Ccme – Wqi model.

Index Value	**Quality Status**	**Degree of Deterioration**
95-100	Excellent	Null
80-84	Well	Minimum
65-79	Acceptable	Occasional
45-64	Marginal	Frequent
0-44	Poor	Always

2.3 Carlson Index for Nitrogen

Measurement of eutrophication is carried out extensively through the application of the Carlson IET[13], which was developed in 1977[14]. The Carlson TSI is a method consisting of simple formulas for evaluating water[15].

In this research, the Carlson IET for Nitrogen is used, which measures the parameters of phosphorus and nitrogen, which are important elements in the phenomenon of eutrophication.[16]. Identifying total nitrogen constitutes a valuable tool when combined with the IET proposed by Carlson, since it allows precise evaluation of lakes that present restrictions.[17]. The following equations are used to determine total phosphorus, total nitrogen, and their average:

Total Phosphorus (TF)

$$TSI_{TP} = 10 \times (9.40 + 1.62 \ln TP) \quad (8)$$

The formula that links the amount of total phosphorus with the ETI is:

Total Nitrogen (TN)

$$TSI_{TN} = 10 \times (5.24 + 1.86 \ln TN) \quad (9)$$

The formula that establishes a connection between water quality and the ETI is:

$$IET = \frac{TSI\ (TP)+TSI\ (TN)}{2} \quad (10)$$

Equation (10) is used to determine the trophic state of a lake with the guidance of Table 4

Table IV. Scale of state values trophic in bodies of water

State Eutrophy	**IET**	**FT (*mg/L*)**
Oligotrophic ETI < 30	0	0.75
	10	1.5
	20	3
	30	6
Mesotrophic 30 < ETI <90	40	12
	50	24
	60	48
Eutrophic 60 < ETI < 90	70	96
	80	192
	90	384
Hypereutrophic 90 < TEI <100	100	768*

The Secchi Disk method originated in 1865 and is used as a practical method to measure the transparency of water. Its application is simple in which it consists of submerging a generally white circular disk from the surface of the water and identifying the point at which the disk becomes invisible [18]. The depth at which a Secchi disk becomes invisible to an observer, Ds, decreases as the sum of the attenuation coefficients of light in its diffuse and collimated form increases [18]. Poole & Atkins [19] They originally created an equation to calculate the opacity of water in the ocean. Nevertheless, Idso & Gilbert [20] They modified the equation so that it could be applied to any type of water. This modification is presented in (11).

Table V. Limits of Trophic States

Types of Lakes	KM-1	Boundaries
Oligotrophic lakes	0.19	0.10-0.28
Mesotrophic lakes	0.53	0.28-0.90
Eutrophic lakes	1.86	0.97-3.20
Lakes rich in humic substances	2.51	0.81-4.51
Turbid Lakes	6.70	0.34-35.30

2.5 Selected parameters for evaluation of water quality in tilapia crops

To carry out the water quality analysis model in tilapia crops, 13 parameters have been selected, these being the same to analyze water quality by adding nitrites, nitrates and phosphorus. Based on the results, an analysis and comparison will be carried out that allows us to determine the current quality standards. These results will allow us to determine if tilapia crops have a decisive impact on water quality.

The point selected for collecting the samples is located in the tilapia crops in Lake Yojoa. Once located at the crop site, we will take a tour of the different crops and choose the crop in which the tilapia has advanced growth. We will take the tests using the sterile bottles provided by the laboratory. Based on the results, an analysis and comparison will be carried out that allows us to determine the current quality standards. These results will allow us to determine if tilapia crops have a decisive impact on water quality. The process to develop the research is shown in Fig. 2.

Figure 2. Summary of methodology

3. Results

3.1. Physicochemical Tests

The physicochemical evaluation carried out in zones A and B of Lake Yojoa throughout 2023 and the detailed results of the tests are presented in Table 6. The limits or permissible values were selected according to Class A of Environmental Standard on Water Quality.[21], Class II of the Environmental Quality Standard for Surface Waters [22], and the Technical Standard for Water Quality of the Pan American Health Organization [23]. This table offers a complete view of water quality, highlighting seasonal variations and possible anthropogenic influences in both geographic areas.

It is important to mention that there were some limitations regarding the detection of the concentration of COD, TF, and E. coli, since the laboratory equipment had a detection limit, up to 5 mg/L, 0.03 mg/L, and 1.8 NMP/100mL, respectively. For these last two, their values were the same throughout the year. In addition, normality tests were carried out for each parameter, and all passed the test except for the COD of Zone B, Turbidity of both Zones. TF and E. coli did not present a normal distribution due to the laboratory detection limit.

Table VI. Results of the Physicochemical Parameters of Lake Yojoa in 2023

Zone	pH	NT (mg/L)	EC (µΩ/cm)	COD (mg/L)	O.D. (mg/L)	Turb. (NTU)
Zone A	8.98	10.84	170.3	11	6.3	5.31
	8	10.08	161.1	24	7	1.34
	9	8.32	155.6	13	6.1	1.43
	7.54	10.78	169.5	5	5.1	1.3
	7.28	10.32	166.9	5	11.2	1.68
	7.24	13.58	166.1	5	7.7	1.88
Zone B	8.57	8.32	170.7	6	6.8	6.18
	8.46	7.56	171.6	5	6.2	8.45
	9	9.58	157.5	5	6.6	1.89
	8.6	9.7	169.7	5	5.3	1.2
	8.3	7.54	168.2	5	5.1	1.51
	7.44	9.78	165.7	5	10.7	0.81
Boundaries	6.5-8.5	<0.5	<400	<15	>6	<1

3.2. ICA – CCME

The results of the CCME Water Quality Index for each of the areas sampled in Lake Yojoa provide a detailed evaluation of the health of the water throughout the year 2023. A total of 12 indices were obtained, six corresponding to the Area A and six to Zone B. These indices, which cover a scale from 0 to 100 according to the CCME methodology. The results are shown in Table 7 below.

Table 7. Ica Results – CCME

Zone	ICA CCME	Category
Zone A	40.47	Poor
	42.36	Poor
	44.39	Marginal
	41.95	Poor
	48.96	Marginal
	46.26	Marginal
Zone B	42.04	Poor
	48.37	Marginal
	42.81	Poor
	35.22	Poor
	45.22	Marginal
	55.39	Marginal

Figure 3 shows the results of the ICA graphically. These have revealed distinct patterns in water quality, but almost all values are between 40 and 45. In Zone A, most values are classified as "Poor" with some samples reaching the "Marginal" category. In contrast, Zone B shows a broader variability, ranging from the lowest index of 35.22 to the highest value of 55.39, among all values, including those of Zone A. This diversity reflects the complexity of agricultural activities. present in the area, evidencing the significant influence of these practices on water quality. The presence of indices in both the 'Poor' and 'Marginal' categories indicates the multifaceted response of water quality to agricultural activities.

These findings could indicate that both areas face challenges in terms of water quality, but the specific characteristics of each area, related to predominant human activities, contribute to the differences in the ICA results. For future research or projects, it is important to consider these variations throughout the year to develop management and conservation strategies for Lake Yojoa.

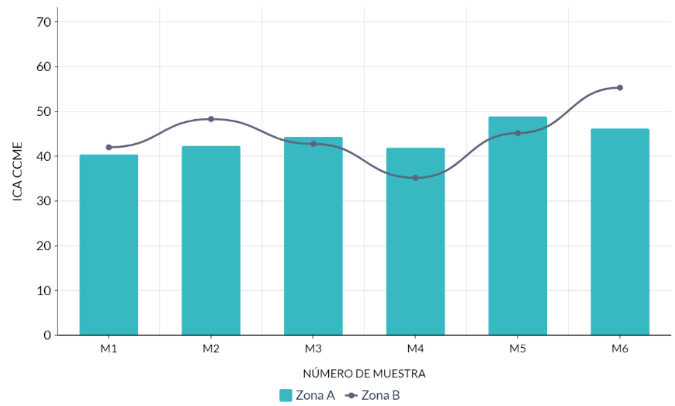

Figure 3. CCME Water Quality Indices Results for Lake Yojoa

3.3. Descriptive Statistics of Zone A and B

For each of the nine physicochemical and biological parameters, the various descriptive statistics that summarize the distribution of data in Zones A and B were calculated. The summary is shown in Tables 8 and 9, showing the mean, standard deviation, minimum, maximum and the range of the results.

Table 8. Descriptive Statistics of Zone A

Parameter	Mean	Std. Dev.	Minimum	Maximum	Range
pH	8.01	0.81	7.24	9.00	1.76
FT (mg/L)	0.03	0.00	0.03	0.03	0.00
NT (mg/L)	10.65	1.70	8.32	13.58	5.26
EC(µΩ/cm	164.92	5.60	155.60	170.30	14.70
COD (mg/L)	10.50	7.48	5.00	24.00	19.00
OD (mg/L)	7.23	2.13	5.10	11.20	6.10
Turb. (NTU)	2.16	1.56	1.30	5.31	4.01
E. coli (NMP/100mL)	1.80	0.00	1.80	1.80	0.00
ICA CCME	44.07	3.14	40.47	48.96	8.49

Table 9. Descriptive Statistics of Zone B

Parameter	Mean	Std. Dev.	Minimum	Maximum	Range
pH	8.40	0.52	7.44	9.00	1.56
FT (mg/L)	0.03	0.00	0.03	0.03	0.00
NT (mg/L)	8.75	1.07	7.54	9.78	2.24
EC (μΩ/cm)	167.23	5.20	157.50	171.60	14.10
COD (mg/L)	5.17	0.41	5.00	6.00	1.00
OD (mg/L)	6.78	2.04	5.10	10.70	5.60
Turb. (NTU)	3.35	3.17	0.81	8.45	7.64
E. coli (NMP/100mL)	1.80	0.00	1.80	1.80	0.00
ICA CCME	44.84	6.76	35.22	55.39	20.17

In Zone A, the pH varies between 7.24 and 9, with the maximum peak of NT in November (13.58 mg/L). EC and COD show wide annual variations, while turbidity exceeds limits in several samples, indicating possible impacts of eutrophication on the water quality of Lake Yojoa.

In Zone B, a relatively higher pH is observed than in Zone A, close to the maximum limit of 8.5. Although the EC shows normality, the variability in the NT and the temporary decrease in COD suggest possible agricultural and industrial influences, while lower levels of DO and greater turbidity indicate additional impacts on the water quality of Zone B of Lake Yojoa.

3.4. t tests

The results of the CCME ICAs were subjected to a two-sample t test. The null hypothesis stated that there is no significant difference, while the alternative hypothesis suggests the opposite. In the results, obtained in Minitab, the p value = 0.806 is greater than the significance level of 0.05, suggesting that there is not enough evidence to reject the null hypothesis. Although lack of evidence does not imply absence of differences, monthly sampling is recommended to improve the precision of hypothesis testing, considering possible reasons for lack of evidence, such as natural variability and sample size.

The NT data were also analyzed with a two-sample t test, assuming unequal variance, to better understand the factors that affect water quality, considering that NT is one of the nutrients that causes eutrophication and alters water quality. of the lake, as it was one of the parameters with the most variability.

The null hypothesis was that there is no significant difference in NT levels between Zones A and B, while the alternative hypothesis indicated that there was a significant difference. The t test resulted in a p value of 0.049. Since this value is lower than the significance level of 0.05, the null hypothesis is not accepted, providing statistical evidence that the population means differ between the tourist and agricultural areas.

With this result, it was decided to perform a graphical comparison between the NT levels in Zone A and B shown in Fig. 4. The graphical analysis supports the quantitative results of the t test, visually showing the differences in the NT concentrations between zones A and B.

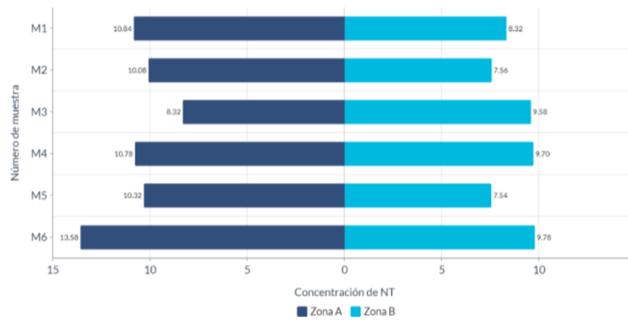

Figure 4. Comparison of NT in zones A and B.

3.5. Carlson type Trophic State Index for Nitrogen

Samples were taken from zone A, which corresponds to tourist activities, in which the results indicate a high level of NT and TF, which produces a greater number of algae and productivity in the waters [24]. In zone B, high results were also obtained in terms of the parameters of total nitrogen and total phosphorus, this is due to the practice of fishing [25]. The results of the Carlson Index for Nitrogen can be seen in Table 10.

Table 10. Carlson IET Results for Nitrogenen

Zone	IET (NT)	IET (FT)	Average TEI	Trophic State
Zone A	96.72	37	66.86	Eutrophic
	96.62	37	66.81	Eutrophic
	95.37	37	66.18	Eutrophic
	95.81	37	66.40	Eutrophic
	100.91	37	68.95	Eutrophic
	91.80	37	64.4	Eutrophic
Zone B	91.80	37	64.4	Eutrophic
	94.66	37	65.83	Eutrophic
	90.02	37	63.51	Eutrophic
	89.97	37	63.48	Eutrophic
	94.43	37	65.71	Eutrophic
	94.81	37	65.91	Eutrophic

3.6. Trophic State Index Based on the Attenuation Coefficient (K)

The attenuation index was used to validate the results obtained from the Carlson nitrogen index, through measurements taken in situ. Zone A has an average of 1.60m of transparency, which is classified as eutrophic. In zone B the average water transparency is 1.45m, which also classifies as a eutrophic state. Both areas are classified as eutrophic using the index; these results are due to the low visibility of the water due to the amounts of algae and nutrients in the water [26]. Table 11 shows the classification of the points according to the zones based on the coefficient (K).

Table 11. IET based on Attenuation Coefficient (K)

Zone	Secchi transparency (m)	Attenuation Coefficient (K)	Classification
Zone A	1.70	1	Eutrophic
	1.60	1.06	Eutrophic
	1.40	1.21	Eutrophic
	1.75	0.97	Eutrophic
	1.50	1.13	Eutrophic
	1.50	1	Eutrophic
Zone B	1.70	1	Eutrophic
	1.50	1.13	Eutrophic
	1.50	1.13	Eutrophic
	1.30	1.30	Eutrophic
	1.40	1.21	Eutrophic
	1.30	1.30	Eutrophic

III. CONCLUSION

An evaluation of the water quality in Lake Yojoa was carried out, dividing the area into two areas: Zone A, associated with tourist activities, and Zone B, related to agricultural practices. By applying the CCME Water Quality Index (WQI) methodology in detail, it was determined that the water quality in the tourist area is classified as "poor", while in the agricultural area it is classified as "marginal", with values of 44 and 45, respectively. The application of t tests for both indices did not reveal sufficient evidence to affirm a significant difference between the means, leading to the conclusion that this lack of difference can be attributed to other variables, such as sample size. However, it should be noted that, according to the calculation of the index, it cannot be ruled out that Lake Yojoa is experiencing a deterioration in its quality.

The evaluation of the trophic state of Lake Yojoa for the year 2023 was carried out through two IETs. According to the Carlson Nitrogen Index, both study areas were classified as eutrophic. However, zone A is considered inappropriate due to its tourist and occasional use for human consumption, which is harmful due to the high concentration of nutrients in the water. The eutrophic condition is only considered suitable for zone B, intended for aquaculture, where the presence of nutrients is essential for cultivation. Regarding the Index Based on the Attenuation Coefficient (k), determined through in situ samples with the Secchi Disk, the lake was classified as eutrophic, indicating a significant presence of algae in its depths.

When comparing the results obtained, they revealed conditions conducive to the healthy development of the study crop. Most parameters, such as temperature, pH, and chemical oxygen demand, are within appropriate ranges for the well-being of tilapia. However, the high concentration of ammonia and nitrogen, which are too close to reach the maximum range, could represent a problem for the development of the crop. This situation is aggravated by the presence of high levels of nitrites and nitrates, which requires continuous regulation and monitoring to prevent these levels from becoming totally toxic to the crop, affecting the health of the fish, or even causing high mortality of the crop, which symbolizes the loss of monetary investment in the crop.

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