

RESEARCH ARTICLE

ASSESSMENT OF PHYSICOCHEMICAL VARIABLES IN WELLS, SPRINGS, AND SHALLOW WELLS FOR HUMAN CONSUMPTION IN MICHOCACÁN, MEXICO

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ABSTRACT

The rapid growth of the global population provides significant challenges in actuality due to an increased demand for water. The constant pressure on water resources has caused unsustainable and inefficient management of the natural supplies. Recently, the increase of chemical products used in food production has contributed significantly to environmental degradation, threatening the availability of drinking water. This study is an analysis of the pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), temperature, dissolved oxygen (DO), salinity, and resistivity of water in 6 locations of the Lake Basin. The measured values were compared with Mexican and international standards to determine the degree of contamination at the sampling sites. The majority of measured data in test sites are in an acceptable range, with the exception of Yunuen Island, which shows an electrical conductivity and salinity that exceeds the values of the norms as well as dissolved solids that are close to the limit. Although the islands of Janitzio and Yunuen are located inside of Lake Pátzcuaro, only the island of Yunuen presents a probable pollution that can be associated with anthropogenic activities.

KEYWORDS

physicochemical parameters, linear correlation, wells, springs, shallow wells

1. INTRODUCTION

1.1 Background of Study

In the last years, the global changes pose new challenges regarding the quantity and quality of water (Lin, et al., 2022; Torres, 1993). The efforts have been directed at global sustainability on Sustainable Development Goals (SDGs), in particular Goal 6, which ensures universal access to clean water and sanitation by 2030. The constant pressure on the water resources grows due to such things as global warming, the increase of the population, and deficient management of the natural resources. It has direct consequences for human health, sustainability, and food security (Gabr, 2025; Cejudo et al., 2022). Although scientific articles warn about the increase in pollution from fertilizers and pesticides due to agriculture, the chemicals commonly end up in bodies of water, rivers, and lakes, causing eutrophication, which promotes excessive algae growth, degrades the quality of water, and damages the aquatic environments (Espinoza-Rodríguez, et al., 2019; Wang, et al., 2017; Hartman, et al., 2022; Lyons, et al., 2019). Urban areas are not an exception, as they produce large amounts of wastewater, which contains chemicals, pathogens, and other contaminants that directly affect the natural bodies of water (Heshmatzad and Vaissi, 2023).

In México, a principal source of pollution of lakes and bodies of water is the indiscriminate use of agricultural products and sewage discharge, which significantly affects the water quality. In the last years, Lake Pátzcuaro in Michoacán has been affected by the use of pesticides, agricultural fertilizers, and deforestation, which has altered the physicochemical properties of wells, springs, and shallow wells around the basin that are used for the community's water supply (Ramírez-Morales,

et al., 2021). A factor that contributed to the pollution of bodies of water is the accumulation of the chemical substances on the soil, which posteriorly are filtered in the aquifers (Fernandez-Torrez, et al., 2024). A study analyzed the spatial and temporal variations of water quality during thermal stratification in Lake Zirahuén, Michoacán (Mendoza-Ramirez, et al., 2025). The obtained results showed acceptable water quality; nevertheless, in months when the breakdown of thermal stratification occurred, the quality was slightly better.

Moreover, a group researcher analyzed the chemical characteristics in basins that supply the communities of Escárcega, Campeche, to determine the variables associated with polluted water (Martin-Canché, et al., 2021). The results showed variations in the sampling sites with the presence of fecal coliforms (*E. coli*). On the other hand, worked on a study to correlate the physicochemical parameters in springs of Araro, Michoacán (Prieto, et al., 2017). The obtained data revealed slight variations among the samples, with the exception of temperature and arsenic level. Additionally, a studied the water quality in ten urban sites in Zamora, Michoacán. The study included a physicochemical analysis (Reyes-Toscano, et al., 2020). The results presented a slight tendency to alkalinity in the samples. This study looked at the water quality in six towns around Lake Patzcuaro. The variables were pH, conductivity, turbidity, total dissolved solids, temperature, dissolved oxygen, salinity, and resistivity. The measured values were compared to the official Mexican and international standards, as well as the flavor, color, and odor (NORMA Oficial Mexicana 1994; NORMA Oficial Mexicana 2021).

2. MATERIALS AND METHODS

2.1 Description of Study Area

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The locations are situated around the banks of Pátzcuaro Lake, distributed across diverse communities (Figure 1).



Figure 1: Map of the sampled communities, © 2013 Google.

The region is subtropical with an average temperature of 16°C (Weather Atlas 2025) (Figure 2).

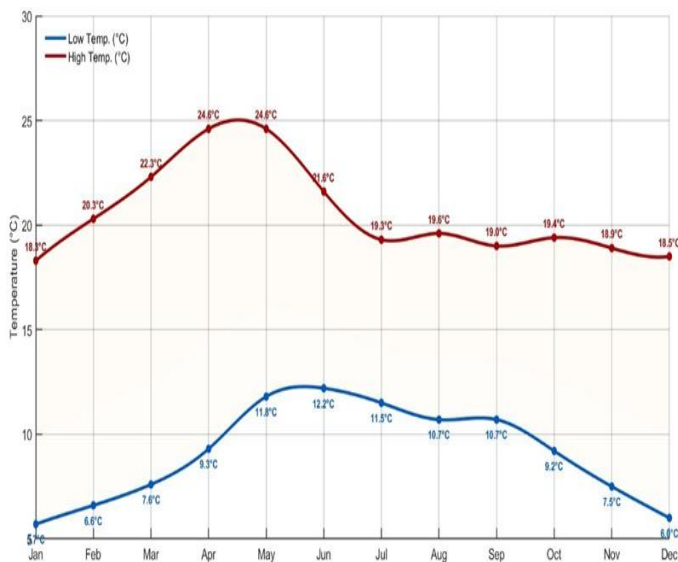


Figure 2: Climate and monthly weather conditions.

The proximity of the sampling zones to Lake Pátzcuaro allows the development of wells, springs, shallow wells, wetlands, and streams. These water bodies play an essential role for the ecosystems of the region and support diverse flora and fauna. Furthermore, they are vital for agriculture and the water supply (Medina-Orozco, et al., 2019; Garcia-Gil, et al., 2022). However, the closeness represents a disadvantage for bodies of water from the agriculture practices and sewage discharge. Furthermore, since the aquatic environments are often used as potable resources, this increases health risks of the local population Table 1 (Carro, et al., 2008).

Station	Latitude	Longitude	Altitude
Erongancuaro	19°35'19" N	101°43'18" W	2080 masl
Sanabria	19°34'17" N	101°34'22" W	2045 masl
San Bartolo Pareo	19°31'44" N	101°40'36" W	2061 masl
Noria Cetac Tzetzénguaro	19°31'59" N	101°38'28" W	2045 masl
Janitzio Island	19°34'28" N	101°39'04" W	2045 masl
Yunuen Island	19°35'58" N	101°38'45" W	20491

2.2 Experimental procedure

The samples were obtained from seven different locations. The procedure was to open the valve for 3 to 5 minutes to evacuate the water contained in the pipe and posteriorly obtain a final sample. In the place without a valve, a container was used to collect the sample at a depth of 15 to 20 cm, avoiding touching the walls of the wells, springs, and shallow wells, according to (NORMA Official Mexicana 1993; Medina-Orozco, et al., 2019). The samples were measured with a HANNA (HI9829) instrument. This device has the capacity to identify fourteen different parameters of the water. The samples of water were collected in glass bottles with a capacity of two liters. The first step was to rinse the bottles with water from the sampling site. Second, the containers were hermetically sealed and labeled with the date, time, and place of sampling to send to the laboratory. In all measurements, the range of temperature was between 4 and 10°C. The process was repeated three times for each sample to minimize the measurement error (Figure 3).

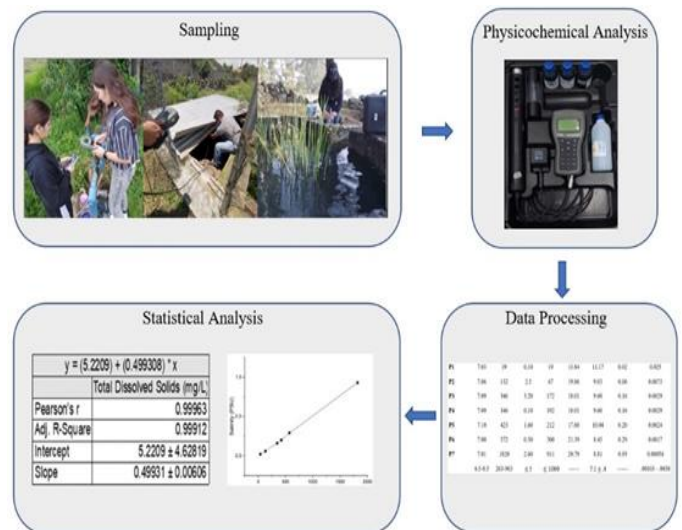


Figure 3: Flowchart for research methodology.

3. RESULTS AND DISCUSSION

3.1 Analysis of the data

The data in Table 2 represent the measurements for each well, spring, and shallow well, which were then compared to Mexican and international standards as well as the flavor, color, and odor.

Location	pH	EC (µS/cm)	Turbidity (FNU)	TDS (mg/L)	Temp. (°C)	DO (mg/L)	Salinity (PSU)	Resistivity (MΩ.cm)
P1	7.03	39	0.10	19	13.84	11.17	0.02	0.025
P2	7.06	132	2.5	67	19.86	9.03	0.06	0.0075
P3	7.09	346	3.20	172	18.01	9.60	0.16	0.0029
P4	7.09	346	0.10	192	18.01	9.60	0.16	0.0029

Table 2 (Cont): Physicochemical values comparison of wells, springs, and shallow wells for different locations.

Location	pH	EC (μS/cm)	Turbidity (FNU)	TDS (mg/L)	Temp. (°C)	DO (mg/L)	Salinity (PSU)	Resistivity (MΩ.cm)
P5	7.10	423	1.60	212	17.60	10.04	0.20	0.0024
P6	7.00	572	0.50	300	21.39	8.45	0.29	0.0017
P7	7.01	1820	2.60	911	20.79	8.81	0.93	0.00054
Permissible Range Reference	6.5-8.5 [15, 16]	≤ 800 [21, 22]	≤ 4 [15, 16]	≤ 1000 [15, 16]	-----	5.95-13.84 [23]	-----	.0038-.00103 [21]

P1: Erongaricuaro spring; P2: Well of Sanabria; P3: Well of San Bartolo Pareo; P4: Water source of San Bartolo Pareo; P5: Water source of Tzetzenguaro; P6: Well of Janitzio Island; P7: Well of Yunuen Island.

3.2 Relationship of variables

Most values are in an acceptable range; nonetheless, a site has significant deviations. Although these variations provide information about pollution in some sampling sites, determining the cause is a difficult task, as it

involves various factors, such as agricultural runoff and sewage runoff. To decrease the possible pollution effects, a first step is the monitoring of the physicochemical parameters in the sampling sites that present high deviation, which may cause pollution in the study zones (Latif, et al., 2024; Karadeniz, et al., 2024; Roy, et al., 2023). Figure 4 shows a correlation matrix that analyzes the level of relationship for each couple of variables shown in table 2. It evaluates the positive and negative coefficient correlations that may influence the interpretation of the variables to identify possible patterns in the evaluation of water.

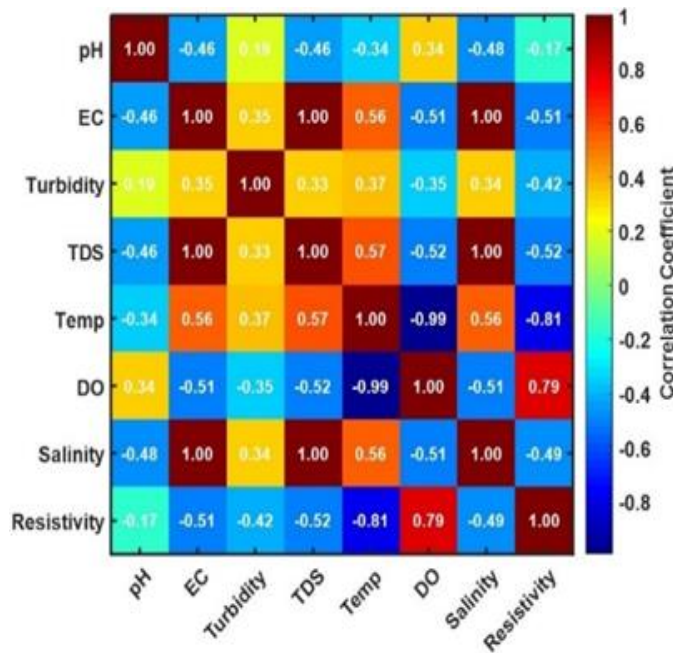


Figure 4: Correlation matrix for the physicochemical parameters.

On the other hand, Table 3 shows the description for each pair of variables and depends on the fact that the values decrease or increase to represent

the level of linear correlation. This analysis helps to identify probable multicollinearity issues.

Table 3: Analysis for each variable couple.

Parameter pair	Correlation R ²	Interpretation
DO vs Temp	-0.9928	Strong negative correlation: an increase in the temperature of the water decreases the oxygen levels.
EC vs TDS	0.9996	High positive correlation: both variables reflect ionic content.
EC vs Salinity	0.9997	Strong positive correlation: the conductivity increases with salinity.
TDS vs Salinity	0.9992	High positive correlation: both variables measure dissolved ions.
EC vs Resistivity	-0.5064	Moderate negative correlation: when electrical conductivity goes up, resistivity goes down.
DO vs EC	-0.5126	Moderate negative correlation: an increase of the ions may reduce the oxygen quantity.
pH vs EC	-0.459	Moderate negative correlation: low pH indicates an acidic substance with a high concentration of hydrogen ions.
Turbidity vs Others	0.3705	Weak correlation: turbidity is independent in the dataset.

Although the Mexican norm establishes an acceptable range for the pH of 6.5 to 8.5, it is well known that a value of 7 is considered neutral, and it is used as a reference point to specify acidity or alkalinity in a substance. In the samples, the pH minimum value is 7.0 for P6 vs. a maximum of 7.10 for P5, which are ideal conditions for aquatic life and human use, as it is the balance of acidity and alkalinity (Saalidong, et al., 2022; Reyes-Toscano, et al., 2020). On the other hand, the EC is 39 $\mu\text{S}/\text{cm}$ for P1, while for P7 it is 1820 $\mu\text{S}/\text{cm}$, which represent minimum and maximum values, respectively. But P7 attracted the attention, as it exceeds established limits of the Mexican and international standards for electric current. Equation 1 describes the order to detect the water's ability to conduct current based on the concentration of dissociated ions (McNeil and Cox 2000).



Despite the conductivity being a reference for evaluating the level of dissolved salts in water, TDS is also related to EC as an indirect measure of

the total concentration of dissolved substances, such as salts and minerals (Rusydi, 2017; Shao, et al., 2019). In this study, all TDS values are below the limit established by the Mexican standard; however, the sample value P7 is near the permissible maximum, which is a trend of water pollution.

3.3 Adjusted for dissolved oxygen

A technique used to verify the accuracy of dissolved oxygen (DO) in the water was comparing the measured data with results published by (Montgomery, et al., 1964) First the temperature and DO measured values were averaged; posteriorly they were compared to the reference. The DO

percent error between measured and adjusted samples was calculated by Equation 2.

$$\% = \frac{\text{measured samples} - \text{adjusted values}}{\text{measured samples}} \times 100 \tag{2}$$

Table 4: Comparison of oxygen solubility at different temperatures between adjusted and measured data.

Locations	Measure Temp. (°C)	Measure DO (mg/L)	Adjusted Temp. [28] (°C)	Adjusted DO [28] (mg/L)	DO Difference	Error (%)
P1	13.84	11.17	13.5	10.41	0.76	6.80
P2	19.86	9.03	19.5	9.175	0.14	1.61
P3	18.01	9.60	18	9.46	0.14	1.46
P4	18.01	9.60	18	9.46	0.14	1.46
P5	17.60	10.04	17.5	9.55	0.49	4.88
P6	21.39	8.45	21.5	8.82	0.37	4.38
P7	20.79	8.81	21	8.91	0.10	1.14

The DO difference between the measured and adjusted data was 0.76 and 0.10, corresponding to 10.41 and 8.9 mg/L for each sample with percent errors of 6.80 and 1.14 for P1 and P7, respectively. Although the adjusted DO data are in the established values of Mexican and international standards, the variations between samples are probably due to increased temperature. However, an additional test should be implemented to rule out human activities or seasonal changes associated with pollution at the study sites.

3.4 Analysis of variable correlation

The Pearson coefficient is a parameter used to measure the level of correlation between a pair of variables. This tool was used to determine the linear relationship among the physicochemical parameters of the water samples. Although the set of variables was analyzed in the correlation matrix of Figure 4, it did not include a dispersion model that views the behavior of the data (Figure 5).

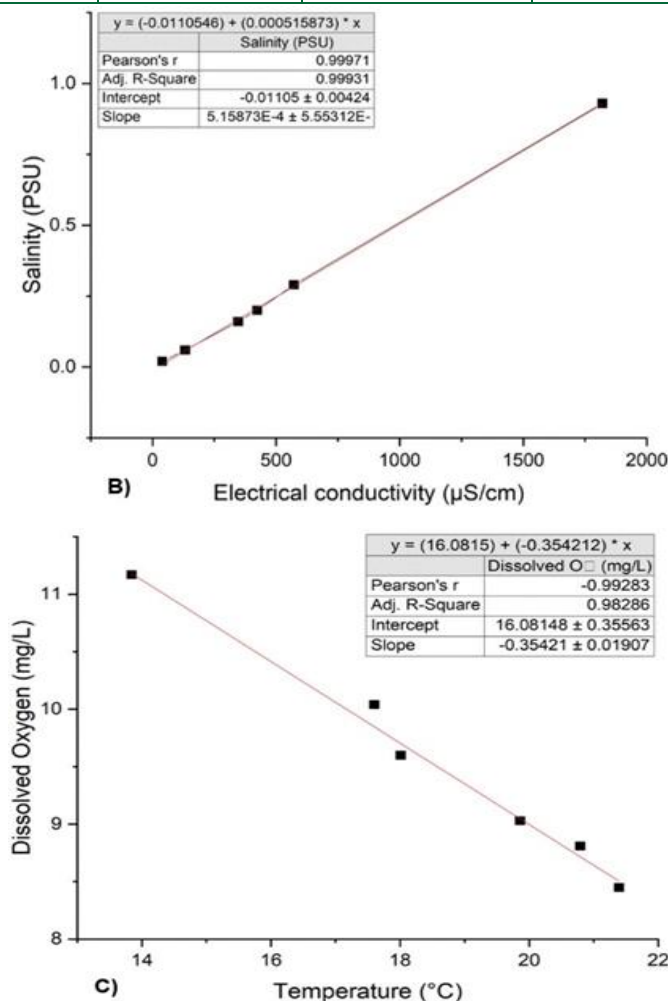
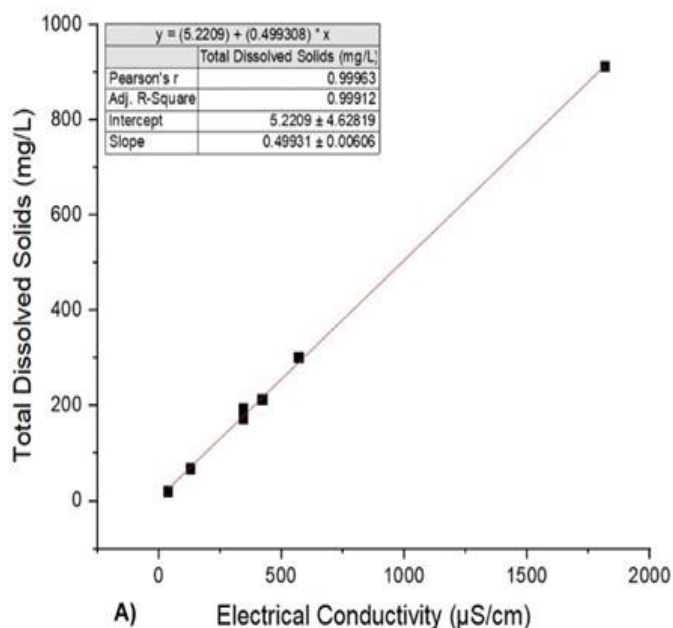


Figure 5: Correlation analysis for A) concentration of dissolved solids versus electrical conductivity, B) salinity versus electrical conductivity, and C) dissolved oxygen versus temperature.

It was observed that EC was the predominant factor influencing TDS and salinity, as indicated by the Pearson coefficients (R^2) of 0.9996 and 0.9997 (Figures 5A and 5B). Although it is true that Figure 5C shows greater data dispersion, it is important to note that the deviation occurs only at two sampling sites, and the Pearson coefficient for the data set is -0.9928, which is an acceptable approximation. Therefore, the data variation is attributed to external factors such as measurement errors or pollution

sources at the sampling sites (Mohamed and Hirayama, 2025).

3.5 Statistical analysis

To complete the data analysis, a statistical evaluation for each correlation shown in Figure 5 was proposed, including the t-value, standard error, linear fit, associated statistics, and ANOVA (Table 4).

Table 5: Statistical analysis for all samples.

Electrical conductivity Vs Total dissolved solids						
Parameters		Value	Standard Error	t-Value	Prob> t	
Linear Fit	Intercept	5.2209	4.62819	1.12807	0.31049	
	Slope	0.49931	0.00606	82.33281	5.00902E-9	
Statistics						
Number of Points	7					
Degrees of Freedom	5					
Residual Sum of Squares	394.32935					
Pearson's r	0.99963					
R-Square	0.99963					
Adj. R-Square	0.99912					
ANOVA		DF	Sum of Squares	Mean Square	F Value	Prob>F
Linear Fit	Model	1	534607.38493	534607.38493	6778.6912	5.0090E-9
	Error	5	394.32935	7886587		
	Total	6	535001.71429			
At the 0.05 level, the slope is significantly different from zero.						
Electrical conductivity Vs Salinity						
Parameters		Value	Standard Error	t-Value	Prob> t	
Linear Fit	Intercept	-0.01105	0.00424	-2.60849	0.04776	
	Slope	5.15873E-4	5.55312E-6	92.89786	2.73991E-9	
Statistics						
Number of Points	7					
Degrees of Freedom	5					
Residual Sum of Squares	3.30631E-4					
Pearson's r	0.99971					
R-Square	0.99971					
Adj. R-Square	0.99931					
ANOVA		DF	Sum of Squares	Mean Square	F Value	Prob>F
Linear Fit	Model	1	0.57067	0.57067	8630.01204	2.73991E-9
	Error	5	3.30631E-4	6.61261E-5		
	Total	6	0.571			
At the 0.05 level, the slope is significantly different from zero.						
Temperature Vs Dissolved Oxygen						
Parameters		Value	Standard Error	t-Value	Prob> t	
Linear Fit	Intercept	16.08148	0.35563	45.2193	9.9864E-8	
	Slope	-0.35421	0.01907	-18.57332	8.32647E-6	
Statistics						
Number of Points	7					
Degrees of Freedom	5					
Residual Sum of Squares	0.06992					
Pearson's r	-0.99283					

Table 5 (Cont): Statistical analysis for all samples.

Table 5 (Cont): Statistical analysis for all samples.						
R-Square		0.98571				
Adj. R-Square		0.98286				
ANOVA		DF	Sum of Squares	Mean Square	F Value	Prob>F
Linear Fit	Model	1	4.82436	4.82436	344.96831	8.32647E-6
	Error	5	0.06992	0.01398		
	Total	6	4.89429			
At the 0.05 level, the slope is significantly different from zero.						

The ANOVA test shows a detailed analysis of all involved parameters that agree with equivalent studies reported by for similar experiments (Ahmadianfar, et al., 2020). Although the Pearson coefficient is commonly used in a linear dispersion as a good approximation, Yunuen Island presents TDS and EC values close to or higher than the established limits by Mexican and international standards. Nevertheless, the origin may be related to the presence of calcium (Ca) and magnesium (Mg) in the water (Alzahrani, et al., 2025).

Equations 3 and 4 describe the relationship of the variables TDS and salinity with EC and, indirectly, with the dissolved ions that contribute to increased conductivity.

$$TDS = 5.2209 + 0.499308EC \quad (3)$$

$$Salinity = -0.0110546 + 0.000515873EC \quad (4)$$

On the other hand, the linear equation that relates the DO and temperature can be a parameter used to predict for the oxygen levels of the samples and the growth of anaerobic bacteria that generate disagreeable odors and flavors of the water (Anuska and Mishra, 2022; Chatziantoniou, et al., 2024).

$$DO = 16.0815 - 0.354212T \quad (5)$$

The linear models were used as a factor to predict the variability between parameters over time (Hernández-Mena et al., 2021). Although multiple statistical techniques can be applied to analyze the relationship between two variables, linear correlation provides useful information for identifying atypical or extreme values in data dispersion (Hu, et al., 2019; Hazra and Gogtay, 2016). Moreover, the ANOVA test complemented the analysis to identify statistically significant differences. To determine a complete study, it is fundamental to calculate the Water Quality Index (WQI); nevertheless, the present work was focused on the variation of physicochemical parameters (Chidiac, et al., 2023; Moeinzadeh, et al., 2024).

4. CONCLUSION

The physicochemical values of water samples were compared with the parameters established by the Mexican and international standards. The majority of the measured parameters at the sampling sites are inside of the established limit, so it suggests acceptable values. An exception is Yunuen Island, which presented elevated parameters. The first was the electrical conductivity that exceeds the permissible limits; it is related to a high salinity and elevated ionic concentration in the water. The second is the total dissolved solids that are near to the accepted limit. Both parameters are an indicator of probable pollution that involves risks for human health and native aquatic organisms. Although the Pearson value is acceptable, it does not show the deviation of the physicochemical parameters of Yunuen Island. Another factor to consider is that Equation 3 is not strictly linear; nevertheless, it is used in various studies as an approximation for natural freshwater systems. Despite the necessity of measuring additional parameters to determine the WQI in the sampling sites, the present analysis is the first step of an integral study to evaluate the water quality and determine the health of aquatic environments. With regard to flavor, color, and odor, the samples did not show variability.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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AUTHOR CONTRIBUTIONS

Manuel Vázquez-Nambo: conceptualization, methodology, original draft preparation, investigation, supervision, reviewing and editing of the writing. Alejandro Soto-Castro: investigation, funding acquisition, supervision. Rosa-Elena Aguilar-Martínez: validation, funding acquisition. Monserrat Pacheco-Reyes: Writing, reviewing, and validation. Ana-Lidia Pérez-Ortega: reviewing. Leticia Oseguera-Figueroa: reviewing.

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