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Water Quality of the Guayaquil Estero Salado from Measurements of Dissolved Oxygen, Chlorophyll *a* and pH

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ABSTRACT

The main objective of the research was to determine the water quality of the Estero Salado de Guayaquil by assessing the measurements of pH, dissolved oxygen, and chlorophyll in 7 stations from March to December 2020. The samples were analyzed in the laboratory according to the methodology used for each parameter. The ANOVA test of a factor with a significance level of 0.05 was used and the results showed that there are no significant differences in pH and chlorophyll a; however, 12 significant differences were found in the dissolved oxygen. The pH means to comply with the provisions of the Ecuadorian environmental regulations, and the average dissolved oxygen value is below the required. For Chlorophyll A, it helped to determine that the estuary presents an oligotrophic state. Results showed that the waters of the Salt Estuary of the study area are not suitable for the development of aquatic organisms.

INTRODUCTION

Water quality in adjacent coastal and marine ecosystems has been influenced by anthropogenic activities **(Brezonik *et al.*, 2005; Urrego Giraldo & Uribe Pérez, 2009; Manju *et al.*, 2012)**, mainly by seepage from agriculture, aquaculture, human settlements, among others **(Duke *et al.*, 2007)**. One of the most important activities for water resource management is the periodic monitoring of water bodies **(Castro *et al.*, 2014)**.

Mangroves are complex systems that predominate on most tropical and subtropical coasts **(Granda Velepucha *et al.*, 2015)**, forming forests rich in biodiversity and high in productivity **(Pardos Carrión, 2020)**. Biodiversity in forests includes microscopic organisms and larger structures such as bacteria, fungi, algae, invertebrates, birds and mammals **(Sosa-Rodríguez *et al.*, 2009)**, which can contribute to the complexity of the variation of dissolved compounds due to active and passive transport, affecting the stability of the mangrove **(Licero, 2013)**. Besides, it has an impact in changing the stoichiometry of the same **(Castellanos, 2009)**. This would subsequently influence the concentrations of the physico- chemical environmental indicators in the bodies of water and soil **(Ritchie *et al.*, 2003; Harvey *et al.*, 2015)**, causing habitat destruction due to human encroachment as the main cause of mangrove loss **(Agraz-Hernández *et al.*, 2006; Cruz Portorreal & Pérez Montero, 2017)** and environmental stress, alterations in the dynamics of the coastal food web **(Da Silva Junio & Moutinho Tavares, 2016)**.

This situation has escalated to an international emergency, with effects evident in different coastal forests such as the Ciénaga de Zapata, the largest wetland in Cuba, which is contaminated by pesticides, used in rice paddies and sugarcane fields **(Linares *et al.*, 2002)**, the coasts of Paraná, Brazil that have suffered constant contamination by hydrocarbons obstructing the pneumatophores of the aerial roots causing suffocation and death of seedlings and mangrove trees **(Cavazos-Arroyo *et al.*, 2014)**. In addition to the afore- mentioned negative impacts of contamination, the anaerobic conditions that the substrate develops due to the oily surface layer **(Olguín *et al.*, 2007)** can also be considered; the bay of Puerto Pizarro in Peru, where moderate levels of contamination have been reported with the possibility of becoming severe since they continue to accumulate, affecting the body of water and substrate of this place, disturbing its flora and fauna **(Montero, 2019)** due to anthropic factors such as tourism, the contributions of wastewater from the town and the remains of the viscerate of artisanal fishing in the sector. This is verified by the most affected environmental factors; namely, the aquatic fauna with 250 IPU (12.5%) water with 233 IPU (11.65%), aquatic flora with 228 IPU (11.4%) and soil with 216 IPU (10.8%), surging a territorial reorganization that improves the environmental conditions and the quality of life of the population **(Morán & Hidalgo, 2018)**.

Mangrove forests in the Ecuador, distributed in approximately 157 000 hectares of coastline **(MAE & FAO, 2014)** are anthropically affected by logging, the construction of shrimp farms and urban development,as well as the unsustainable fishing activities, which have caused alterations in the fractions of biological variables and their ecological relations **(Reyes *et al.*, 2014; Mariscal-Santi *et al.*, 2018; Pernia *et al.*, Zambrano, 2019)**. Thus, the study of the environmental conditions of the body of water of the Estero Salado in the urban area of the city of Guayaquil has been carried out in order to determine the quality of water and define its trophic state. The general objective of this study was to determine the water quality of the Estero Salado de Guayaquil considering the measurements of dissolved oxygen, chlorophyll A and pH.

MATERIALS AND METHODS

Study area

The study area comprised 7 stations located in branches A, B, C, D and E of the Estero Salado of Guayaquil; the area was selected considering the criteria of accessibility and representativeness. The location was recorded in georeferenced coordinates using a GPS model Etrex garmin (Table 1).

Table 1. Coordinates of the monitoring stations in the Estero Salado of Guayaquil, Ecuador

Station	Description	Branch	Coordinates	
			East (X)	North (Y)
S1	Portete Bridge	E	618269.759	9757242.711
S2	Calle 17 Bridge	D	620955.392	9757922.772
S3	Velero Bridge	C	622175.035	9758008.777
S4	Ecological Bridge	A	621985.718	9761491.857
S5	Kennedy Bridge	A	622152.997	9760273.784
S6	Zigzag Bridge	A	621951.911	9759191.294
S7	Las Monjas Bridge	B	620900.952	9759846.521

The monitoring stations were mapped in GIS (Geographic Information System) according to the branches and geographical coordinates (Fig. 1).

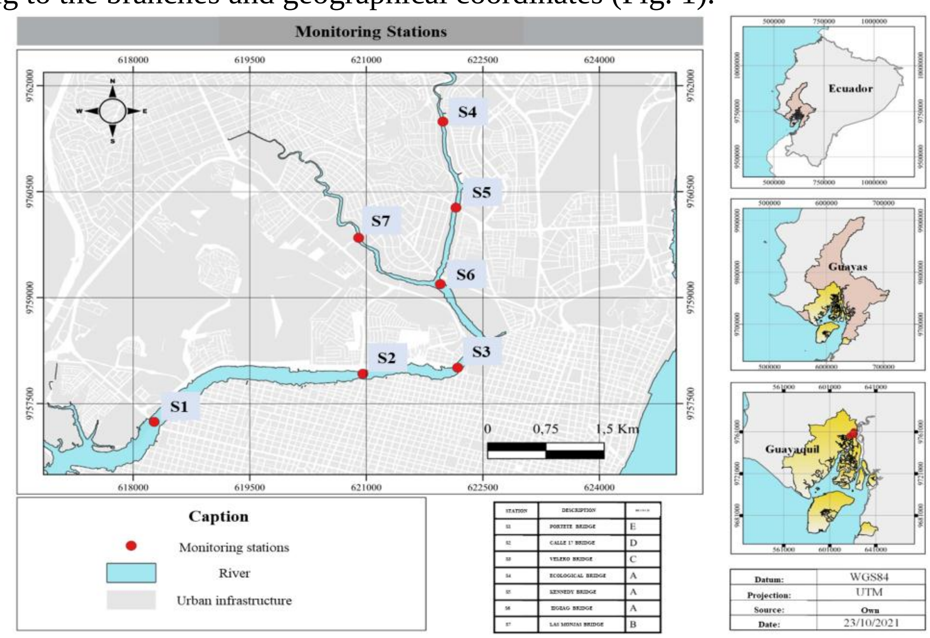

Fig. 1. Map of the study area (monitoring stations)

Samples collection

7 samples were monthly collected from the study area (Fig. 1) and distributed in branches A, B, C, D and E of the Estero Salado de Guayaquil, using a Niskin bottle with a capacity of 5 liters, which were taken from surface water (1m under the water mirror), where the *in-situ* measurements of the hydrogen potential (pH) were performed, and aliquots were extracted for the analysis of dissolved oxygen (DO) and chlorophyll A (Chlo-A). The samples were uniquely identified, stored in the relevant containers and transported in compliance with quality assurance standards and applied methodological conditions. The study period extended from March to December 2020.

Methods used in the study

The methodology applied for the determination of DO and pH corresponds to the standard methods for the examination of water and wastewater 23rd edition of the American Public Health Association **(Baird, 2017)** (Table 2).

Table 2. Laboratory methodology according to parameters

Parameter	Methodology
Dissolved Oxygen (DO)	Metric iodine method (SM 4500 O-B)
Hydrogen Potential (pH)	Potentiometric method (SM 4500-H+-B)
Chlorophyll A (Chlo-A)	Total fluorometric method dried at 103-105°C (SM 2540-D)

The results of the parameters studied were compared to the permissible limits specified in the current Ecuadorian Environmental Regulations **(Ministry of Environment and Water, 2011)** to define the quality condition of the body of water studied (Table 3).

Table 3. Permissible limits according to parameters

Parameter	Permissible limit
Dissolved Oxygen (DO)	>5 mg/l
Hydrogen Potential (pH)	6.5 – 9.5 pH Units
Chlorophyll A (Chlo-A)	According to trophic state*

*Trophic status according to **(López Martínez & Madroñero Palacios, 2015)**.

Statistical analysis

Statistical analysis was performed using the statistical programs SPSS version 25 and Minitab v.19. A descriptive analysis was carried out, obtaining measures of central tendency and dispersion.

For the inferential statistics, an analysis of variances of a factor (ANOVA) was carried out after evaluating the homogeneity of the variances of each group with the Levene test. The data of each group of parameters were averaged and compared using an analysis of variance (ANOVA) of measurements for the results and a post hoc using the Tukey test for the comparison of the factors that were significant between the monitoring stations ($P < 0.05$).

RESULTS AND DISCUSSIONS

Homogeneity of variances test

The Levene test based on the mean was used to check the homogeneity of variances in the water quality of the Estero Salado based on the measurements of pH, DO and chlo-A. Given the column of assumption of homogeneity of variances in Table (4) and the results of the homoscedasticity test of the data, the hypothesis of the equality of variances is accepted, if the significance value > 0.05 **(Quintana-Bernabe *et al.*, 2002; Dagnino, 2014)**.

Levene's statistic takes a sufficiently small assessment not to reject the hypothesis of equality of homogeneity at the usual significance levels **(Bisquerra, 1987; Mastrantonio *et al.*, 2005)**, demonstrating that the results indicate that the variances in the water quality of the Estero Salado from the pH measurements ($Levene_{(6, 56)} = 0.844$; $P = 0.541$), OD ($Levene_{(6, 56)} = 1.106$; $P = 0.371$) and Chlo-A ($Levene_{(6, 56)} = 2.260$; $P = 0.051$) are homogeneous **(Morales *et al.*, 2019)**.

Table 4. Test of homogeneity of variances in the water quality of the Estero Salado from measurements of pH, DO and Chlo-A

	Levene's statistic	gl1	gl2	Sig.
It is based on the mean pH	0.844216	6	56	0.541366
It is based on the mean DO	1.105878	6	56	0.370593
It is based on the mean of Chlo-A	2.259746	6	56	0.050534

One Factor ANOVA

The F statistic is the quotient between two different estimators of population variance. The estimator (variation between groups) is obtained from the variation between the means of the groups, while the estimator (variation Within Groups) is obtained from the variation between the scores within each group **(Toledo, 2010)**.

Tables (5, 6, 7) show a quantification of both sources of variation (Sums of squares); the degrees of freedom associated with each sum of squares (gl), and the concrete value adopted by each estimator of population variance (quadratic means), which are obtained by dividing the sums of squares by their corresponding degrees of freedom **(Jiménez-Caballero *et al.*, 2015)**.

Thus, the quotient between these two quadratic means provides the value of the F statistic, which is presented together with its corresponding critical level or observed level of significance (Sig.), which is the probability of obtaining values such as the one obtained or greater under the hypothesis of equality of means, and finally demonstrating whether there are significant differences or not of pH, DO and Chlo-A measurements between monitoring stations.

One Factor ANOVA (pH)

The results of the ANOVA analysis of a pH factor in Table (5) show that the F statistic with its level of significance $P > 0.05$ **(Arias *et al.*, 2017)** accept the hypothesis of equality of means, indicating that there are no significant differences in pH measurements between the monitoring stations ($F_{(6, 56)} = 0.217$; $P = 0.969$).

Table 5. ANOVA of a pH factor

	Squares sum	**gl**	**Root mean square**	**F**	**Sig.**
Between groups	0.085	6	0.014	0.218642	0.969268
Within groups	3.630	56	0.065		
Total	3.715	62			

One Factor ANOVA (OD)

The results of the ANOVA analysis of a DO factor in Table (6) show that the F statistic with its significance level at $P < 0.05$ **(Espinal Carreón *et al.*, 2013)** rejects the hypothesis of equality of means, postulating that there are significant differences in DO measurements between the monitoring stations ($F_{(6, 56)} = 14.914$; $P = 4.221E-10$).

Table 6. ANOVA of a DO factor

	Squares sum	gl	Root mean square	F	Sig.
Between groups	25.718	6	4.286	14.914200	4.221E-10
Within groups	16.095	56	0.287		
Total	41.813	62			

One Factor ANOVA (Chlo-A)

The results of the ANOVA analysis of a Chlo-A factor in Table (7) show that the F statistic with its level of significance at $P > 0.05$ **(Hahn-von Hessberg et al., 2009)**, accepts the hypothesis of equality of means, noting that there are no significant differences in Chlo-A measurements between the monitoring stations ($F_{(6, 56)} = 1.831$; $P = 0.109$).

Table 7. ANOVA of a Chlo-A factor

	Squares sum	gl	Root mean square	F	Sig.
Between groups	30.275	6	5.046	1.831	0.109
Within groups	154.286	56	2.755		
Total	184.561	62			

Post Hoc Test (OD)

Since no significant differences were detected in pH and Chlo-A measurements, a Post Hoc test was not necessary. However, ANOVA's analysis of a dissolved oxygen factor showed that there are significant differences in its measurements between monitoring stations **(Tello *et al.*, 2019)**, which can be observed in Fig. (2).

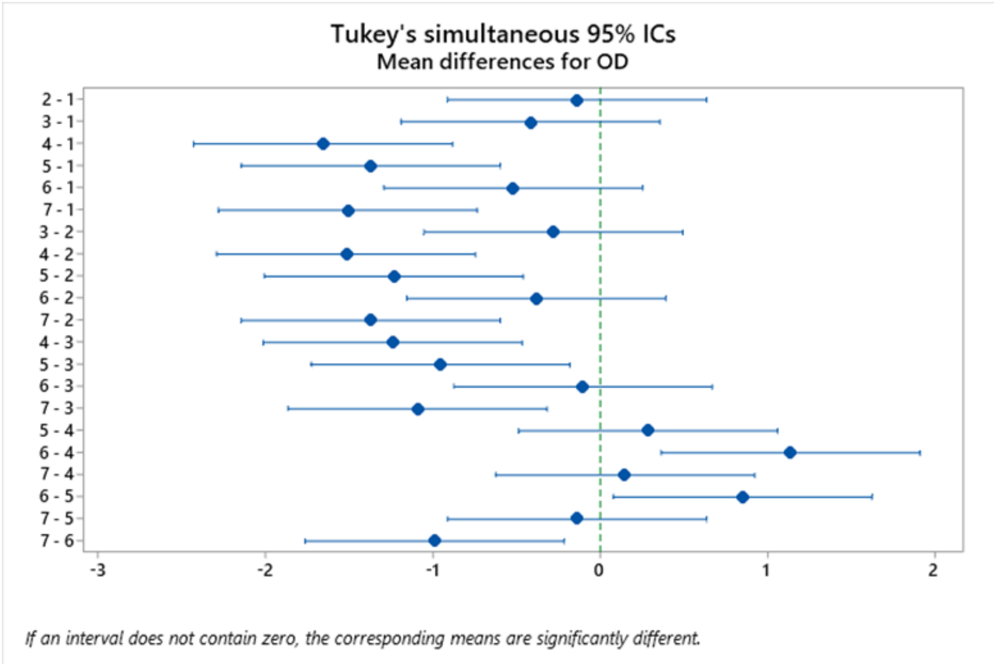

Fig. 2. Post- Hoc DO Test (Tukey 95% Simultaneous ICs).

It was noticed that:

Monitoring station 1 presents mean differences with stations 4, 5 and 7, that is 1-4 (-1.654), 1-5 (-1.369) and 1-7 (-1.507).

Monitoring station 2 presents mean differences with stations 4, 5 and 7, that is 2-4 (-1.517), 2-5 (-1.231) and 2-7 (-1.369).

Monitoring station 3 presents mean differences with stations 4, 5 and 7, that is 3-4 (-1.238), 3-5 (-0.952) and 3-7 (-1.090).

Monitoring station 4 presents mean differences with stations 1, 2, 3 and 4, that is 4-1 (-1.654), 4-2 (-1.517), 4-3 (-1.238) and 4-6 (1.136).

Monitoring station 5 presents mean differences with stations 1, 2, 3 and 6, that is 5-1 (-1.369), 5-2 (-1.231), 5-3 (-0.952) and 5-6 (0.850).

Monitoring station 6 presents mean differences with stations 5 and 7, that is 6-5 (0.850) and 6-7 (-0.988).

Monitoring station 7 presents mean differences with stations 1, 2 and 6, that is 7-1 (-1.507), 7-2 (-1.369) and 7-6 (-0.988).

Analysis of descriptive statistics of the parameters studied and their impact on the current Ecuadorian regulations

pH measurements

Fig. (3) shows that station 5 had the lowest measurement (7.49 ± 0.21) UpH, and station 1 recorded the highest measurement (7.59 ± 0.38) UpH. Finally, the average value of the pH measurements in the monitoring stations was presented with (7.54 ± 0.24)

UpH, a value verified with the Ecuadorian environmental regulations in force, which complies with the maximum permissible limit of 6.5 to 9.5 UpH of the admissible quality criteria for the preservation of flora and fauna in marine and estuarine waters **(Ministry of Environment and Water, 2011)**.

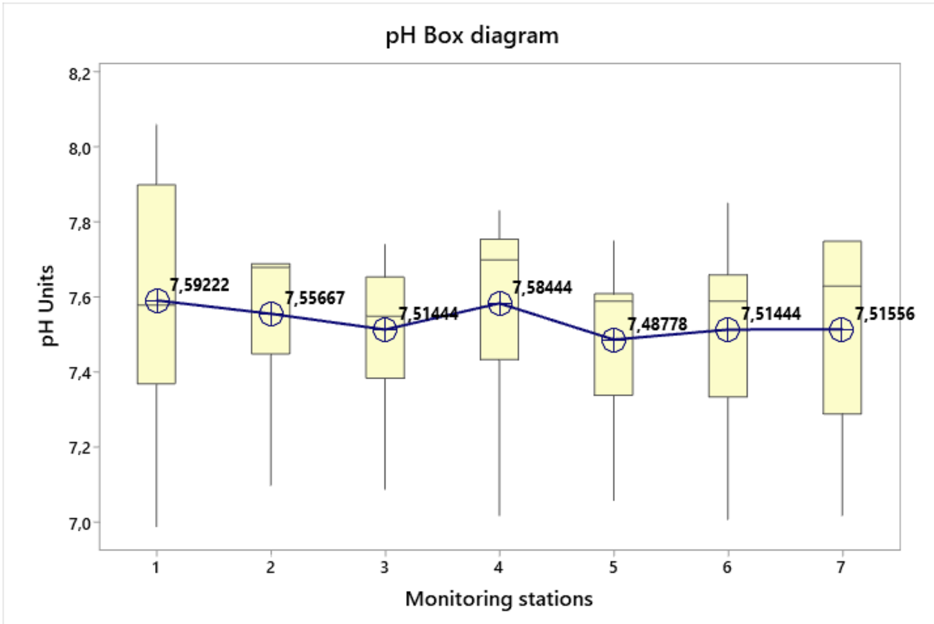

Fig. 3. Box diagram of UpH measurements by monitoring stations

OD measurements

Figure 4 shows that station 4 had the lowest measurement (0.37 ± 0.33) mg/l, and station 1 had the highest measurement (2.02 ± 0.46) mg/l. Finally, the average value of the DO measurements in the monitoring stations was presented with (1.22 ± 0.82) mg/l, a value that verified with current Ecuadorian environmental regulations, does not comply with the maximum permissible limit of DO > 5 mg/l of the admissible quality criteria for the preservation of flora and fauna in marine and estuarine waters **(Ministry of Environment and Water, 2011)**.

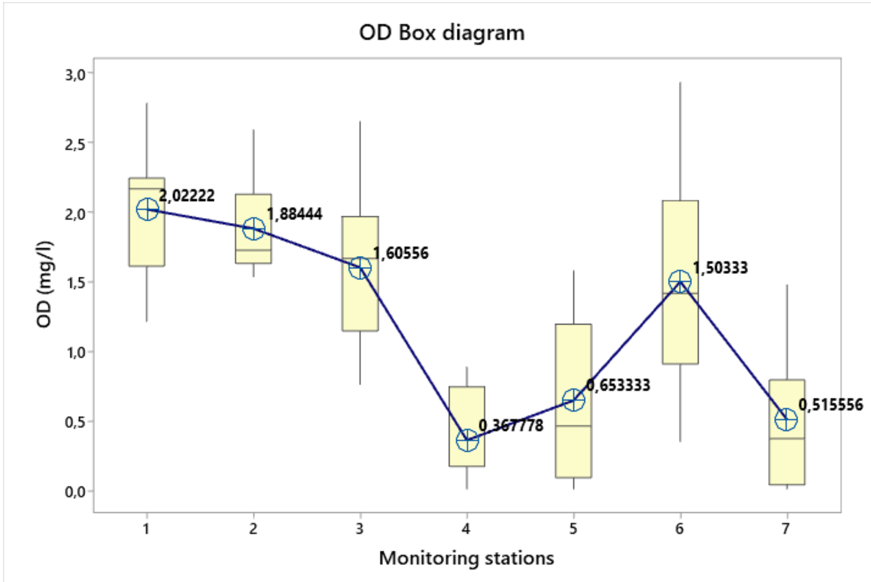

Fig. 4. Box diagram of OD measurements by monitoring stations

Chlo-A measurements

Chlorophyll A measurements revealed that station 1 had the lowest measurement (0.70 ± 0.59) µg/l, and station 5 had the highest measurement (2.48 ± 2.04) µg/l. Furthermore, the average value of the Chlo-A measurements in the monitoring stations was presented with (1.58 ± 1.73) µg/l, an assessment that refers to the fact that the water of the Estero Salado de Guayaquil presents a trophic state: Oligotrophic **(López Martínez & Madroñero Palacios, 2015)**.

Relationship between parameters studied and water quality of the Estero Salado de Guayaquil

The Post Hoc test was performed to determine whether or not there are differences between parameters studied, which was obtained as a result of what is shown in Fig. (5), where the levels of Chlo-A did not present significant differences with the DO, which manifests low levels of oxygen in these waters. On the other hand, the pH differs from the DO and Chlo-A measurements, presenting significant differences in their measurements.

The average 1.58 µg/l of Chlorophyll A measurements among the monitoring stations indicate that the Estero Salado de Guayaquil has an oligotrophic state **(Bastidas Pantoja, 2011)**, which corresponds to a low productivity in phytoplanktonic biomass **(Campos-González *et al.*, 2011)**, low concentration of nutrients and high water transparency **(Rodríguez Garzón, 2012)**. The low levels of Chlorophyll A affect the production of the dissolved oxygen of the estuary; this implies that low levels are present, with the highest measurement of 2.02mg/ l< 5mg/ l (Ecuadorian Standard), a value that denotes that the quality of the water of the Estero Salado is not good for the development of aquatic organisms in zone **(Oña Loachamin & Tonato Cazagallo, 2017)**.

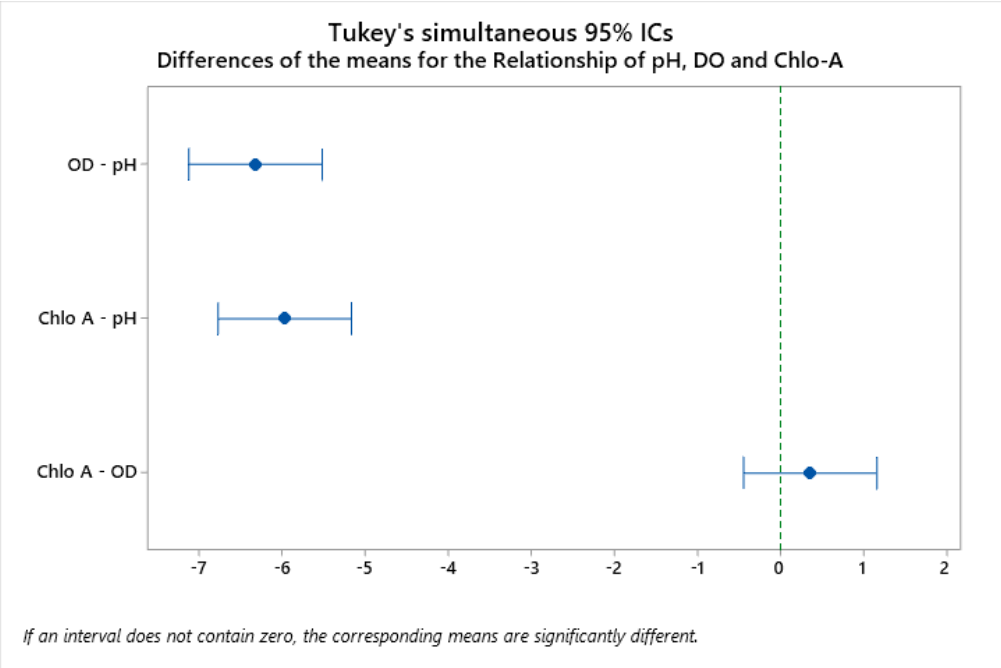

Fig. 5. Post- Hoc test of the relationship between parameters studied (simultaneous ICs of 95% Tukey)

CONCLUSION

The test of homogeneity of variances determined by the means of the Levene statistic showed that a homoscedasticity was recorded between the variances of the measurements of the water quality of the Estero Salado, based on the measurements of pH, DO and Chlo-A. The three indicators presented a significance > 0.05.

The ANOVA of a factor of the parameters studied indicated that for pH and Chlorophyll A, no significant differences were detected between their estimated values in the 7 monitoring stations. However, the dissolved oxygen values showed significant differences. To verify these data, the Post- Hoc test was applied by Tukey, obtaining 12 mean differences between the measurements of this parameter.

The average pH measurement indicates that it complies with the provisions of Ecuadorian regulations; however, the DO does not meet the required quality standard (5 mg/l). In addition, chlorophyll A helped to determine that the water of the Estero Salado of Guayaquil presents an oligotrophic state.

The study shows that the waters of the Estero Salado of the study area are not good for the development of aquatic organisms. This is evidenced by the low values of Chlo-A and DO despite the fact that the pH values comply with current Ecuadorian environmental regulations. This was demonstrated with the Post- Hoc test, which did not present significant differences between chlorophyll A and dissolved oxygen. Finally, the development of eutrophication processes of the studied body of water is evident.

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