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Abstract

Climate variability is one of the main challenges faced by mankind, and understanding its relationship with water quality will generate knowledge that will enable the development of early adaptation strategies and the integral management of water resources. This study assessed the impact of the different intensities of the “El Niño-Southern Oscillation” (ENSO) climate phenomenon on Dissolved Oxygen (DO) from 1985 to 2015, at two monitoring stations on Cauca River. Spatial-temporal variation analysis of DO was performed using descriptive and inferential statistical techniques under different ENSO phases. The correlation between DO and the intensities of the ENSO phases was assessed using the Spearman correlation coefficient. No statistical differences were found in DO concentration at the two studied stations ($p = 0.1164$). Statical differences of DO were found depending on the ENSO phases at the Mediacanoa station ($p = 0.002556$); it was also found that the highest median concentrations of DO took place when La Niña was present. No correlation was found at the studied stations between the intensities of the ENSO phases and DO. The water quality of the Cauca River, at the Yotoco and Mediacanoa stations, showed very poor conditions, which has produced negative social, economic and environmental effects.

Keywords: dissolved oxygen, ENSO, spatial-temporal variability, Cauca River.

Impacto del fenómeno ENOS en el oxígeno disuelto en dos estaciones del Río Cauca-Colombia: años 1985 a 2015.

Resumen:

La variabilidad climática es uno de los principales desafíos de la humanidad, y estudiar su relación con la calidad del agua permitiría generar conocimiento para la adaptación temprana en la gestión del recurso hídrico. En este estudio se evaluó el impacto de las intensidades del fenómeno “El Niño-Oscilación Sur” (ENOS) en el Oxígeno Disuelto (OD) entre 1985-2015 en dos estaciones del río Cauca. Se realizó un análisis de la variación espacio-temporal del OD a través de técnicas estadísticas descriptivas e inferenciales en distintas fases del ENOS. Finalmente, se estudió la correlación entre el OD y las intensidades del ENOS con el coeficiente de correlación de Spearman. No se presentaron diferencias estadísticas en el OD en las dos estaciones estudiadas (p=0,1164). Se encontraron diferencias estadísticas del OD según las fases del ENOS en la estación Mediacanoa (p=0,002556), además se evidenció que las mayores concentraciones medianas del OD se presentaban cuando ocurrió La Niña. En ninguna de las estaciones estudiadas se determinó correlación entre las intensidades de las fases del ENOS y el OD. La calidad del agua del río Cauca, específicamente en Yotoco y Mediacanoa, presentó condiciones muy lamentables, lo que ha desencadenado afectaciones en aspectos sociales, económicos y ambientales.

Palabras clave: oxígeno disuelto, ENOS, variabilidad espacio-temporal, río Cauca.

1. Introduction

Fresh water is extremely important for the biological development of living beings worldwide (Zambrano et al., 2022). However, the availability of this resource has decreased over time, and its quality is being increasingly affected (Herrera-Morales et al., 2022); according to Cao et al, (2021) one of the main parameters to determine water quality is OD, which decreases its concentration due to the presence organic matter because of degradation that occurs in the oxidation process (Zhu et al., 2021).

On the other hand, ENSO interferes in water quality by altering global climate patterns (Ng et al., 2018)thereon influencing freshwater quality and security. In the advent of a strong El Niño warming event in 2016 which induced an extreme dry weather in Malaysia, water quality variation was investigated in Kampar River which supplies potable water to a population of 92,850. Sampling points were stratified into four ecohydrological units and 144 water samples were examined from October 2015 to March 2017. The Malaysian Water Quality Index (WQI. The ENOS is a climate variability event that originates in the equatorial Pacific Ocean (Martínez et al., 2022), and which affects several regions of South America by producing intensive rainfall and extended droughts (Hao et al., 2018). According to Blanco et al. (2003), a climate variability phenomenon such as El Niño and La Niña causes major effects on the physical-chemical and biological characteristics of the water sources and on the hydrology of water basins. This event causes variables such as precipitation and temperature to fluctuate above or below the average, bringing about serious biological, social and economic consequences (Ohman et al., 2017). Colombia's location in a geographic area with highly variable conditions is influenced by phenomenon such as the ENSO (Loaiza et al., 2020)Colombia and their primary relations to the El Nino Southern Oscillation (ENSO.

Colombia is one of the countries with the greatest water resources (Gallo et al., 2021)this practice generates a high impact on water quality due to the accumulation of waste during its process. In this study water quality was evaluated in five natural stream beds corresponding to four streams with gold mining operations and one in the Cauca River, taking samples before the water inlet and after the outlet in each operation in the streams of Dios Te Dé, Tamboral, Piedra Imán, and Lorenzo affected by artisanal gold mining labor, which drain into the Salvajina Reservoir on the Cauca River in the municipality of Suárez Cauca, Colombia. Characterization of water bodies in the streams was carried out applying contamination indices of Colombia. The IDEAM protocol was used as guide to monitor the water currents. Samples were taken in 15 stations in the natural stream beds with operations and a sampling station on the Cauca River after the reservoir in these lotic ecosystems, during three periods; two from 2018 and one from 2019. The range of the contamination indices according to the environmental variables were considered. Results show that the contaminants associated with TSS, TUR, and Hg are high in the sampling stations in the output of the operations and the sampling stations of the streams with influence on the operations (T3, T4, I2, I3, D2, and D5. Yet, Colombian environmental authorities have determined that water sources face a deterioration of their physical properties such as smell, color and temperature, among others, because of discharges and inadequate treatment of wastewater (Giraldo, 2017), in this country the Cauca River is the second most important river after the Magdalena River (Villamizar & Brown, 2016), given that its water is used for agricultural, recreational, industrial and other activities (Galvis et al., 2018). However, the quality of this water source is getting deteriorated due to discharges of industrial, domestic and agricultural wastewater (Serna et al., 2015). Valle del Cauca department contributes to the progressive deterioration of the water quality of the Cauca River, and sites where high volumes of discharges and dumping of wastewater take place have been identified in 33 municipalities, including Buga, the municipality where the stations of this study are located (Villamizar & Brown, 2016).

Wastewater discharges into this basin lead to one of the most important problems for water quality, which is the reduction of DO (Landazábal, 2017). On the other hand, Callejas (2002) assesses water quality of the Cauca River basin, finding critical values of DO in some stations located in Valle del Cauca such as Mediacanoa, Yotoco, among others. Regarding the physical-chemical parameters of water and the ENSO, Blanco et al. (2003) stated that lower precipitation levels were found at the Pescador River (Valle del Cauca) during El Niño, and higher increases of precipitation during La Niña. Additionally, they noted that higher concentrations of nitrates were found during La Niña events, theorizing that the nitrates may have increased because of nitrification, causing a reduction in DO.

In Colombia, no specific studies were found on the influence of ENSO on the water quality of the Cauca River basin (Valle del Cauca); nonetheless, the influence of ENSO on the Pacific coastal areas has been studied (Blanco et al., 2003). In this regard, Carrillo (2012) has performed a similar study along the coast of Ecuador, finding that the DO is lower when El Niño is present. Ávila et al. (2014)asociados a la variabilidad climática o al cambio climático, se ha convertido en el principal problema ambiental del siglo XXI al hacer más vulnerables las sociedades humanas. En el trópico, la variabilidad climática interactúa con el cambio climático, haciendo difícil distinguir entre sus respectivos impactos dada la fuerte influencia de la primera en las condiciones normales del clima. El objetivo de la investigación consistió en analizar la oferta hídrica mensual en la cuenca del río Cali durante la ocurrencia de eventos extremos asociados al ENOS (El Niño Oscilación del Sur assess the influence of the ENSO on the water supply of the Cali River, finding that water availability increased by 65% due to La Niña, and decreased by 40% due to El Niño. Bearing in mind these considerations, the purpose of this study is to contribute to the description and analysis of the influence of the ENSO and its intensities on the spatial-temporal variability of DO concentration from 1985 to 2015 at two stations on the Cauca River, and to assess the impact that ENSO has on the water quality of this critical section of the Cauca River.

2. Materials and methods

Area of the Study

The Cauca River originates in the department of Cauca in the Macizo Colombiano region, and merges into the Magdalena River in the department of Bolívar. It is 1,350 km long and it flows through altitudes between 900 and 4,000 meters above sea level. This study was focused on the Yotoco (EYOC) and Mediacanoa (EMED) monitoring stations, located in the municipality of Buga, in the central area of the department of Valle del Cauca (Colombia). EYOC is approximately located at latitude of 03° 51’02.4”, longitude of 76°22’26.0” and at an altitude of 860 meters above sea level, and EMED is located at latitude of 03°53’27.7”, longitude of 76°20’56.5” and altitude of 927 meters above sea level. Both stations are on the left bank of the Cauca River, and the distance between them is 9.09 km (Figure 1).

Database

The DO data were obtained by the environmental laboratory of the regional environmental authority, Corporación Autónoma Regional del Valle del Cauca (CVC, per its Spanish acronym) from 1985 to 2015. In general, in each year the samplings were performed at different time intervals, therefore, the months in which the water samples were taken changed considerably year after year. In both stations, an average of four samples were taken per year. In EMED in 2003, 2004 and 2005 only 2 samples were taken per year (minimum number), while in 1991, 8 samples were taken (maximum number). In EYOC in 1993, no sampling was recorded, in this station the minimum number of samplings was 1 in 1992, while the maximum was 7 in 1985 and 1991. It should be noted that in the two seasons the months in which the samplings were most frequently taken were February and September. On the other hand, January was the month with fewer samples.

CVC measured DO using the azide modification test, following the protocols of Standard Methods 23rd. 2017. This is a method frequently used by environmental authorities in different countries in order to identify the presence of contamination or bacteria, especially when monitoring the quality of waters with high content of nitrites, effluents, natural waters and wastewaters (Ramos, 2020). However, this method is inefficient when water samples have high concentrations of suspended solids, easily oxidizable organic substances in strongly alkaline solutions (IDEAM, 2020)effective, and efficient from both the volunteer and event organising committee perspectives. Using a Strategic Human Resource Management (SHRM.

Oceanic Niño Index (ONI)

The Oceanic Niño Index (ONI) is a measurement of the conditions of the ENSO in its warm (El Niño) and cold (La Niña) phases in the central equatorial Pacific. This index is used to identify the ENSO taking into consideration the sea surface temperature (SST) (Moya, 2020). During some periods the ENSO phases described above do not occur; such periods are called the Neutral phase (Groch et al., 2020).

In order to identify the presence of El Niño or La Niña and their different intensities over the studied years, data was taken from the report named "Update of the Meteorological Component of the Institutional Model of Colombian Institute of Hydrology, Meteorology and Environmental Studies (IDEAM, for the Spanish original) on the Climate Effect of El Niño and La Niña in Colombia" (Montealegre, 2014), whereby the El Niño anomaly is determined as above SST + 1.03°C, whereas La Niña is determined as below – 0.79°C (NOAA Climate Prediction Center, 2019). The records for the years on which no data was found in the IDEAM report were taken from the reports published by the National Oceanic and Atmospheric Administration Office (NOAA) of El Niño 3 region (NOAA, 2016). The classification used in this study is displayed on Table 1.

Statistical Analysis

Based on the records on DO, the ENSO phases and their intensities, statistical analyses were performed at the spatial and temporal levels. Additionally, an analysis was performed on the correlation of the intensities of the ENSO phases and the DO concentration at the two stations; the temporal study was performed for one-year periods, five-year periods and ten-year periods. The indicators used were the arithmetic mean, median, range, standard deviation and coefficient of variation. Box plots were also prepared, and trend graphs were constructed with the annual classification of the intensities of the ENSO phases and the simple moving average of three observations of the OD. The results of the descriptive analysis were compared to Colombian regulations (DO > 4.0 mg/l).

The spatial study consisted in comparing the behavior of DO at the EYOC and EMED. DO concentration at the two stations in the presence of ENSO phases and their intensities were assessed and compared. The same descriptive indicators of the temporal variation analysis were used, as well as box plots and histograms. In terms of statistical inference, initially the assumptions of homogeneity of the DO variances were tested using the Levene test, and the assumption of normality was tested with the Lilliefors (Kolmogorov Smirnov) and Shapiro Wilk tests. Because the above assumptions were not fulfilled in many of the studied situations, non-parametric tests were also performed. To compare DO concentration at the studied stations, the Mann Whitney U Test was used.

At each studied station, the comparison of DO concentration according to the ENSO phases and the intensities of La Niña and El Niño, the Kruskal Wallis test was used. Afterwards, for the comparisons that displayed statistical differences, a post hoc test was conducted using the Mann Whitney U Test. It should be noted that for the comparisons of the ENSO phases with statistical differences, confidence intervals (CI) were calculated to find which of them has the highest median levels of DO. In order to explain the degree and type of association between the intensities of the ENSO phases and DO at each of the studied stations, the Spearman correlation coefficient was calculated. The intervals were defined with a confidence level of 95%, and hypothesis testing was carried out using a significance level of 5%. Data processing for this study was run in the RStudio 4.2.2 software package. The maps were developed using the ArcGIS 10.6 software package.

3. Results

Temporal variation of dissolved oxygen

The annual analysis showed that the highest medians of DO at EMED were reported in 1999 and 2011, with levels of 3.6 mg/l and 2.9 mg/l, respectively. At EYOC, the highest medians were reported in 1999 and 2008, with levels of 3.0 mg/l. The lowest medians were of 0.7 mg/l in 1992 y 2012 at EYOC, whereas at EMED it was of 0.7 mg/l in 2015. Large variations of DO were found annual, with coefficients of variation greater than 30%, except at EMED in 1987 (Table S1). This illustrates the magnitude of the challenges faced in this important body of surface water, because the DO levels were far below the admissible level, which hinders the optimal development of the aquatic ecosystems and the environmental health of the Cauca River.

Concerning ENSO, summarizing the 30 years covered by the study, 93.3% of the years had a Niño or Niña event, and only 6.7% were neutral years. This situation clearly illustrates the climate variability phenomenon in the region. At EYOC, downward trends were found between 2000 and 2003 and between 2009 and 2010, during which a moderate and weak Niña, and moderate and weak Niño took place. However, upward trends were observed between 1987 and 1989, 1998 and 2000, 2002 and 2009, and 2012 and 2014, periods in which a moderate Niño was followed by a strong Niña, a strong Niño was followed by a moderate Niña, a moderate Niño was followed by a strong Niña, and a moderate Niña was followed by a strong Niño, respectively. Only two records, of 4.3 mg/l in 1999 and 4.2 mg/l in 2006, were in compliance with Colombian regulations (Figure 2).

At EMED, the moving averages displayed an upward trend of DO during periods of a strong Niña (1988 to 1989 and 2010 to 2012), as well as between 1998 and 2000, 2004 and 2009, and 2009 and 2012, when a strong Niño was followed by a moderate Niña, a weak Niño was followed by a strong Niña, and a weak Niño was followed by a moderate Niña, respectively. However, downward trends were found between 1991 and 1993 in periods of a moderate Niño followed by a weak Niño, and from 2000 to 2003, during which a moderate Niña, weak Niña and moderate Niño were reported. The only records that complied with the standard set by the Colombian government were 4.1 mg/l, and 4.6 mg/l in 1985, and 2011, respectively (Figure 3).

In the ten-year-periods analysis, no major changes were found in the DO medians at the two studied stations, and a slightly improving trend was observed. These results may reflect the fact that in this section of the river water quality is poor, because the medians are very low (1.3 mg/l - 1.6 mg/l). Additionally, the coefficients of variation indicated wide variability in DO concentrations (Table 2). In the three ten-year periods, 50% of the DO records at the EYOC and EMED stations were lower than or equal to 1.3 mg/l and 1.5 mg/l, respectively. In general, at both stations the dispersion of 50% of the DO records between quartile one and three increased over time. It was also found that the values higher than or equal to quartile three displayed greater dispersion than the values lower than or equal to quartile one. On the other hand, at both stations a slight increase of DO was found over the ten-year periods (Figure 4).

In the analysis of five-year periods, it was found that between 2001 and 2005 both stations reported the lowest medians concentration of DO, 1.1 mg/l at EMED and 0.8 mg/l at EYOC. The highest medians concentrations of DO at EMED were found between 1996 and 2000, with a value of 1.8 mg/l. At EYOC, the highest median was reported in the period from 2006 to 2010, with a value of 1.6 mg/l. Very high coefficients of variation were found: at EMED they were between 40% and 63.2%, and at EYOC they were between 46.2% and 68.8%, indicating wide variability of DO at both stations (Table S2). On the other hand, the lowest DO concentrations with lower dispersion were found in the five-year periods 1991-1995 and 2001-2005, which were slightly lower than those found at EYOC. In contrast, the highest DO concentrations, though with greater dispersion, were found in the five-year periods of 1995-2000, 2006-2010 and 2011-2015 (Figure 5).

Spatial variation of dissolved oxygen

The details of the different test results on normality, homogeneity of variances, multiple comparisons (post hoc tests) and the shapes of the distribution graphs, for each studied situation, are included in the Supplementary data.

Variation of dissolved oxygen by monitoring station

At both stations, failure to comply with the Colombian government's provisions regarding adequate DO concentrations in water bodies was evident, because 71.1% and 73.2% of DO records were below 2 mg/l, a situation that is highly concerning in environmental terms, because less than 2% of the DO recorded levels complied with the regulation (Figure 6). On the other hand, the variability of DO at both stations was very large (coefficients of variation greater than 50%), which indicates the heterogeneity of the studied levels (Table S3). Additionally, it was found that there were no statistical differences in the DO concentrations at the two studied stations (p = 0.1164).

Variation of dissolved oxygen according to the ENSO phases.

Considering the El Niño, La Niña and Neutral phases, it was found that the lowest medians concentrations of DO were reported during El Niño, 1.3 and 1.22 at EMED and EYOC, respectively. The coefficients of variation indicate that the variability of DO found at the studied stations was very high during the El Niño, its counterpart La Niña and Neutral phases (Table 3). In analyzing the levels of DO and the ENSO phases at EMED, it was found that during El Niño, DO levels were lower than those recorded during La Niña. In both phases, high variability in DO levels was found. However, at EYOC it was not found that El Niño was associated with lower DO levels than La Niña, but in both phases the variability was very high (Figure 7).

When DO concentrations are compared during El Niño, La Niña and Neutral at EMED, statistical differences were found ($p = 0.002556$). Specifically, these differences were identified between El Niño and La Niña ($p = 0.0005993$), however, the CI (0.24 mg/l; 0.80 mg/l) showed that the differences between the medians found DO levels produced when La Niña and El Niño occurred are not considerable. These minimal differences may be due to the fact that during La Niña there are precipitations higher, which implies greater flow volumes that may dilute the pollutants, which would allow DO levels to rise, the opposite occurs during El Niño, when there is less precipitation, and consequently less dilution of pollutants; on the other hand, in the EYOC no statistical differences were found between El Niño, La Niña and Neutral ($p = 0.2036$).

Spatial variation of dissolved oxygen according to the intensity of the ENSO phases

The analysis carried out based on the intensities of ENSO phases indicated that at EMED the highest medians DO concentrations were found during a moderate Niña 1.95 and strong Niña 1.9, whereas the lowest median concentration was found during a moderate Niño 1.2 (Table 4). At EYOC, the greatest and lowest median concentrations were found during a moderate Niña 1,47 and during a moderate Niño 0.9 (Table 5). The indicators shown in Tables 4 and 5 again reflect the poor water quality in terms of DO concentration depending on the intensities of the ENSO phases, as well as wide heterogeneity of DO in the studied situations. At EMED, maximum concentrations of DO greater than 4.0 mg/l were found in the intensities weak and strong of La Niña (Table 4), whereas at EYOC they were found during a weak Niño and a moderate Niña (Table 5).

50% of the DO observations obtained during the different intensities of La Niña at EMED were lower than or equal to 1.95 mg/l. However, at EYOC, during the different intensities of La Niña, 50% of the observations of DO were at or below 1.55 mg/l. On the other hand, at the studied stations during the different intensities of El Niño, 50% of the observations were at or below 1.41 mg/l. At both stations, during the Neutral phase, 50% of the measurements recorded were lower than or equal to 1.94 mg/l (Figure 8). All the above analyses lead to believe that the intensities of El Niño and La Niña influence the hydro-climatic conditions, because each intensity is associated with a specific range of temperatures, which could produce alterations in the hydrological behavior of the basins.

At both stations, when DO concentrations according to the intensities of ENSO phases were compared, at EYOC no statistical differences were found in DO concentration during the different intensities of La Niña ($p = 0.4023$); however, during the different intensities of El Niño, it was assumed that there were statistical differences in DO levels, because a value of $p = 0.0507$ was found. Consequently, a post hoc test was conducted to confirm the above hypothesis; at EMED it was found that there were no statistical differences between the intensities of La Niña ($p = 0.5832$) and El Niño ($p = 0.3633$).

At EYOC, the post hoc test showed that the intensities that had statistical differences in terms of DO concentrations were moderate and weak Niño ($p = 0.02143$), strong and moderate Niño ($p=0.05995$), although the latter is not as conclusive. The CI obtained for the difference of the medians of DO during a weak Niño and moderate Niño was (0.045mg/l; 0.830mg/l), the result showed that the differences obtained are not considerable; however, it did show that there was a slight tendency for the highest median concentrations of DO, which was recorded during a weak Niño.

Relationship between dissolved oxygen and the intensity of the ENSO phases

At the studied stations no linear correlation was found between DO concentration and the intensities of El Niño, while something similar occurred with the intensities of La Niña and the DO levels (Table 6). The above results may suggest other types of correlation between these variables, or could suggest that an increase or reduction of DO might be associated with other natural and/or anthropogenic factors.

4. Discussion

This study shows very low DO concentrations at the EYOC and at EMED stations, far below the levels established by Colombian regulations (> 4 mg/l), which generates a critical situation for the aquatic ecosystems (Mori, 2020), these results are consistent with other studies by Landazabal (2017). The main cause may be the discharges of untreated domestic and industrial wastewater, since anthropogenic activities carried out in the department of Valle del Cauca contribute significantly to the deterioration of water, because industries and over 30 municipalities discharge their wastewater into this basin or its affluents. As a result, along its water course it carries sediments, organic matter and innumerable particles that reduce DO (Villamizar & Brown, 2016).

On the other hand, the periods that show a rising trend of DO might be explained by the influence of biological factors that have positive effects on this parameter. In this regard, Duclaud and Bowen (2008) assess the increase of DO that is produced mainly by a process known as re-aeration, in which the oxygen available in the atmosphere comes into contact with water, as well as the photosynthesis process (Rondón, 2020). Instead, in periods during which a downward trend in DO was observed, the cause might be the intervention of anthropic factors. In fact, Muñoz et al. (2015) state that the reduction of DO is mainly due to discharges of untreated domestic and industrial wastewater.

Another aspect that could explain the reduction of DO is the inadequate operation of some wastewater treatment plants (PTAR, for the Spanish original) in Cali city or neighboring municipalities, such as the PTAR-Cañaveralejo , which was built in 2003, and does not totally fulfill their purpose, since these plants are unable to treat water when DO is less than 3 mg/l (Moreno, 2014) a circumstance that worsens the water quality in terms of the parameter studied at EYOC and EMED.

In the municipality of Yotoco, which is in the area of the study, agricultural and river quarrying activities take place (Landazábal, 2017), which add to the deterioration of water quality in this section of the Cauca River. On the one hand, Pérez y Aguilar (2012) describe that agricultural activities affect water quality due to the use of agrochemicals, and on the other hand, Betancourt and Solaque (2019) point out that quarrying produces sediments that alter the physical characteristics of water. In this same area, felling of forests and overuse of soil generate torrential flows in the Mediacanoa River, which merges into the Cauca River (Corporación Autónoma Regional del Valle del Cauca-CVC, 2017) and leads to a reduction of DO (Villamizar & Brown, 2016). These situations could explain why no statistical differences are found in DO concentration at the spatial level.

Another cause that could explain the low DO levels at the studied stations are high volumes of wastewater discharges into the Cauca River and which are generated and produced by an old landfill site called “Basurero de Navarro”. This dump was not subject to any environmental regulation before, during or after its period of operation, which produced seepage of high volumes of leachate downstream from this basin (Florez et al., 2008). It is important to note that this landfill is located along the old riverbed of the Cauca River, specifically at 3.5 km from Cali in the rural district of Navarro, located at an altitude of 990 meters above sea level.

Only in a handful of periods did DO concentrations reach levels equal to or better than the allowed level; these records are specifically found during cycles of La Niña, and only one during a period of a weak Niño. A reason that could explain this trend is the increase in water flows due to heavy rainfall in the river basin, which ultimately promotes the re-aeration process (Carrillo, 2013). At the studied stations, between 1895 and 2015 it was found that DO shows great variability depending on the ENSO phase, a behavior that makes it more difficult to determine whether DO increases or decreases with the presence of La Niña or El Niño. This behavior may be due to the reasons explained by Flórez et al. (2008), who indicate that the variations of DO over space and time at a given water source may be associated with factors such as rainfall levels, water flows, re-oxygenation capacity, altitude and speed, as well as the time of day when samples are taken.

Upward trends of DO generally take place when any intensity of El Niño is followed by a moderate or strong Niña, a situation that could be explained by the variation of temperature. According to Muñoz et al. (2015), precipitation levels and temperature changes may influence DO concentration, thus during rainy seasons DO is higher compared to dry seasons. Regarding the periods in which a downward trend in DO is found, Aristizábal (2010) describe that the reduction in DO takes place mainly during El Niño periods, which produce changes in atmospheric variables such as higher temperature, which acts inversely to DO. This situation was identified in this study between 2009 and 2010 at the EYOC, and between 1991 and 1993 at the EMED.

At both stations a slight increase in DO is observed in the third five-year period, for some consecutive years. This could be explained by the presence of La Niña, since in several months in 1999 and 2000, heavy rainfall levels were reported in most of the Andean region (Aristizábal, 2010). During the 2006 to 2015 ten-year period, DO displayed substantial variability, a situation that could have been triggered by changes in precipitation patterns, such as the drought that took place in 2009, which brought about a reduction in the flow volumes of the affluents of the Cauca River (Enciso et al., 2016). Also, extreme precipitation events in 2011, caused by a strong Niña, which led to surges in water levels and extensive flooding in the upper valley of the Cauca River (Enciso et al., 2016).

Based on the above, during the studied period, upward trends in DO, mainly during La Niña, could be explained by the low temperatures that occur during this phase. In this regard, Sierra (cited by Baque-Mite et al., 2016)provincia de Los Ríos, Ecuador. Se evaluaron parámetros físicos, químicos y microbiológicos del agua en nueve estaciones de bombeo del EPMAPAQ, en épocas lluviosa y seca. Se compararon los resultados obtenidos con los valores de referencia establecidos en las normativas (Acuerdo ministerial Nº 097 Norma INEN 1108, TULSMA, EPA y OMS describes that when low temperatures occur, DO increases. Similarly, Fitzcarrald (2015) assessed the oceanographic conditions of ENSO and found that the increase in DO is produced by the low temperatures associated with La Niña.

Carrillo (2012) describes that DO concentration is lower during warm periods, especially during El Niño. As for Mol et al. (2000) freshwater swamps and a rainforest creek in Suriname, South America. The mean rainfall in the period August to February in 22 El Niño years was 76.6% of the mean rainfall in the same months of non-El Niño years. In the period 1900-1999, three out of four years in which an extreme drought (rainfall less then 60% of the mean value, they assess the effects caused by El Niño on fresh and brackish waters in Suriname, also finding a reduction in DO during an El Niño phase in 1997 and 1998. Similarly, Aguayo et al. (2019) study the contribution of fresh water to Chile’s coastal system during dry seasons caused by El Niño, finding low DO levels during this phase. A similar behavior of DO was found at the studied stations, given that the study covering the period from 1985 to 2015 found a downward trend in this parameter during different intensities of El Niño.

Regarding the intensity of the ENSO phases, Valencia (1987) assesses the variability of DO in coastal waters of the province of Guayas (Ecuador), finding low DO concentrations during a moderate Niño. This result is similar to the findings of this study, because at EYOC lower median concentrations of DO were found during a moderate Niño. This could be explained by the behavior of temperature, precipitation, and other atmospheric variables during these intensities. However, no relationship was found between DO concentration and the intensities of the ENSO, which would indicate that it is important to engage in further research of this type with the analysis of different factors that may be involved in determining water quality.

5. Conclusions

The phenomena associated with changes in precipitation were permanent during the studied period, alternating between Niña and Niño events in different intensities, which would imply that mankind will have to coexist with climate variability and develop adaptation strategies, in this case related to the management of water resources and water quality. When La Niña is present, the DO concentrations tend to be higher than during El Niño or neutral years, although the identified differences between ENSO phases are not considerable. This indicates that water resource management conditions may change depending on the climate phenomena occurred at the time or that may arise in the future.

The water quality of the Cauca River during the study period, specifically at the EYOC and EMED, showed very poor conditions, given that only a very low percentage of measurements complied with Colombian regulations, in addition to the great variability of these in the different periods, which has produced innumerable negative consequences in social, economic and environmental terms. For Colombia, quality water from this source is of outmost importance since it contributes to the sustainability of many regions. Consequently, it would be well worth carrying out new research to conduct similar analyses apart from those included on this study, but also including a greater number of parameters to measure water quality and the incorporation of more monitoring stations along the Cauca River.

The concentration of DO does not differ from one station to another because the anthropic activities carried out in the study area are not generating sustainable development. The existing imbalance between social, economic and environmental aspects has led to a constant deterioration in water quality of this important water network. The river's natural self-purification is not capable of assimilating wastewater discharges and dealing with the physical, chemical and biological phenomena, such as water velocity, flow, the presence of aerobic bacteria and aquatic plants since they pose limitations for the recovery of river's health due to the high pollutant loads.

6. References

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Figure 1. *Location of the EYOC and EMED monitoring on the Cauca River in the department of Valle del Cauca, Colombia.*

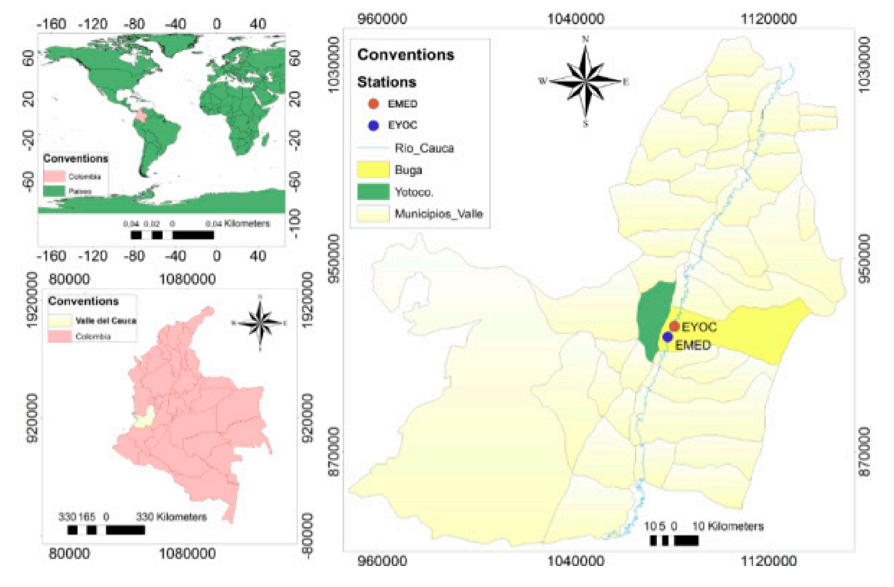


Figure 2. *Temporal variation of DO from 1985 to 2015 at the EYOC.*

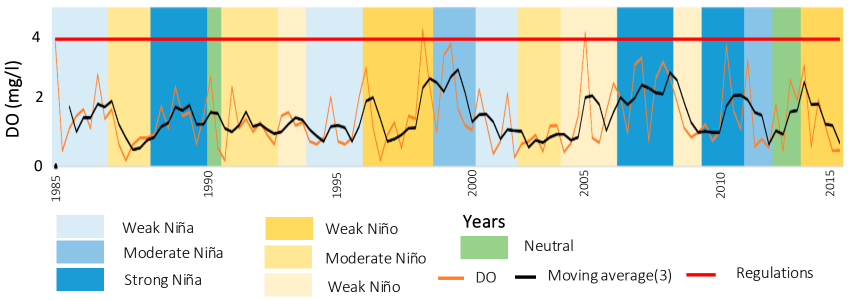
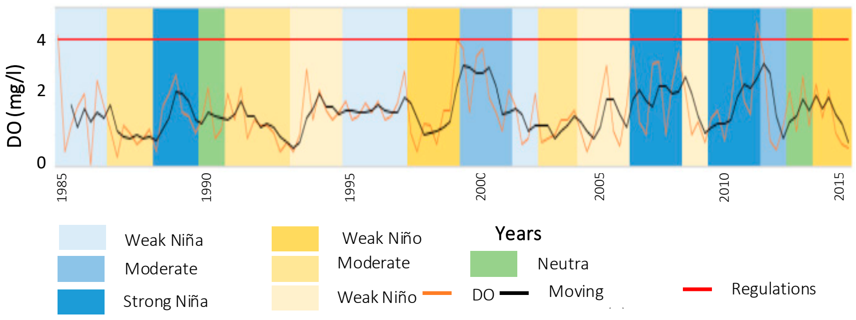


Figure 3. *Temporal variation of DO from 1985 to 2015 at the EMED.*



https://doi.org/10.24050/reia.v21i41.1714

Figure 4. *Behavior of DO by ten-year period at the EMED and EYOC.*

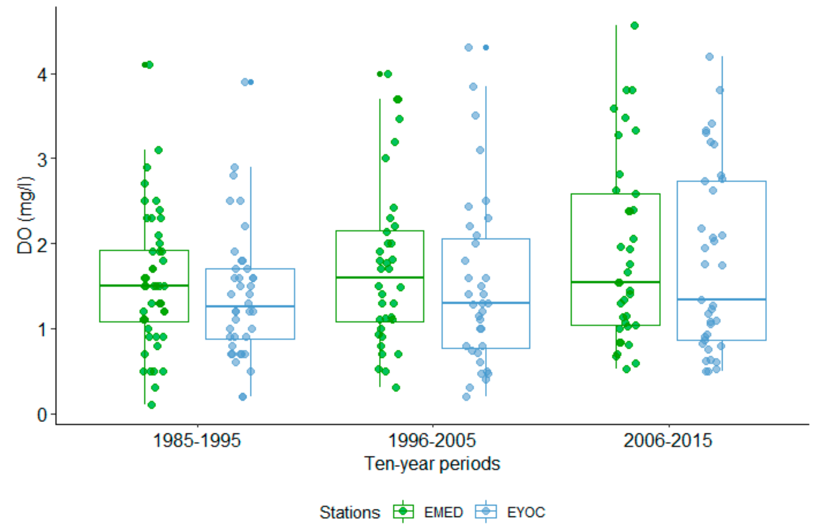


Figure 5. *Behavior of DO by five-year period at the EMED and EYOC.*

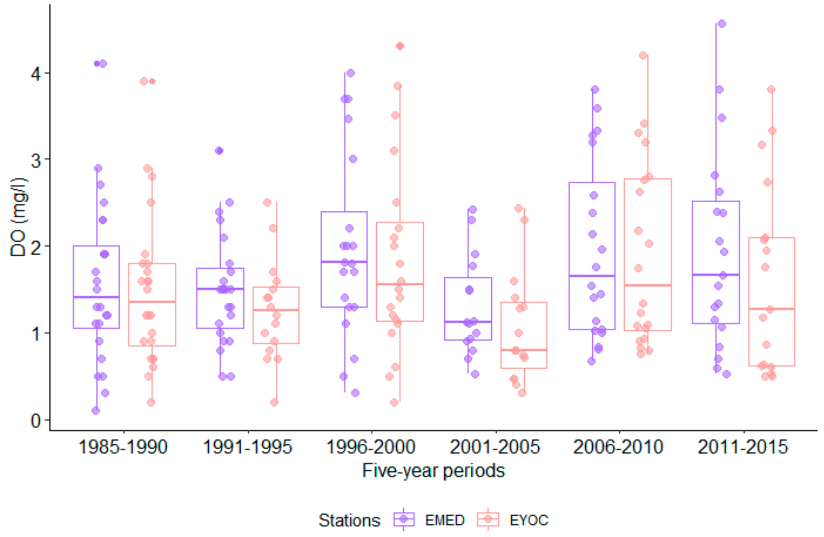


Figure 6. *Distribution of DO at the EYOC and EMED from 1985 to 2015.*

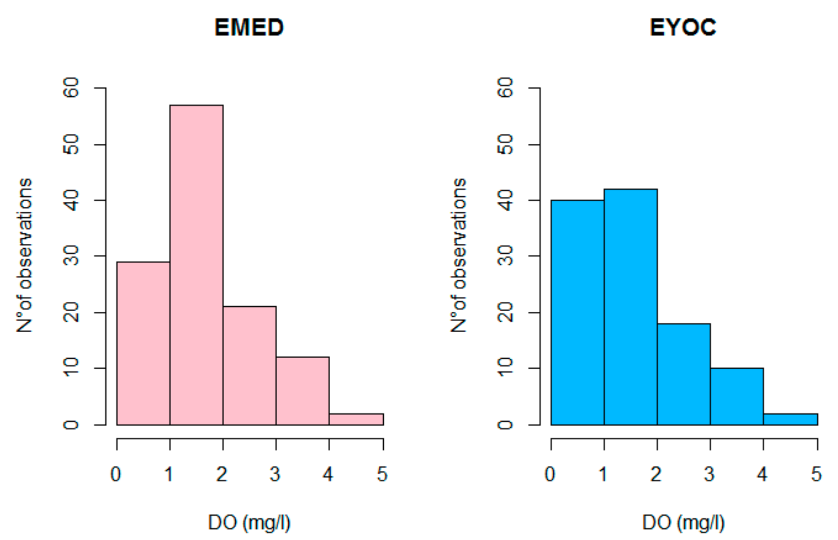
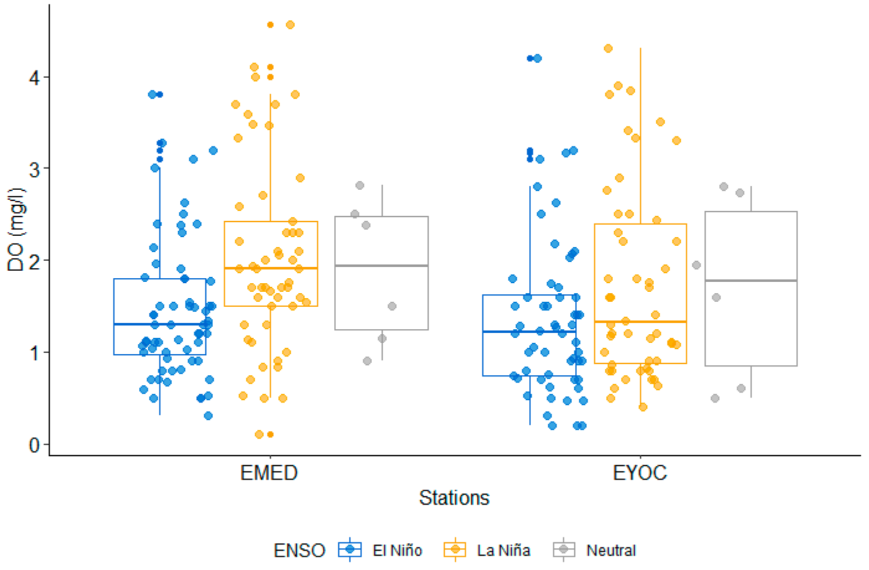


Figure 7. *Behavior of DO depending on the ENSO phases.*



https://doi.org/10.24050/reia.v21i41.1714

Figure 8. *Behavior of DO according to the intensities of the ENSO phases at the EMED and EYOC Table 1. Classification of the intensity of the ENSO phases using the ONI index*

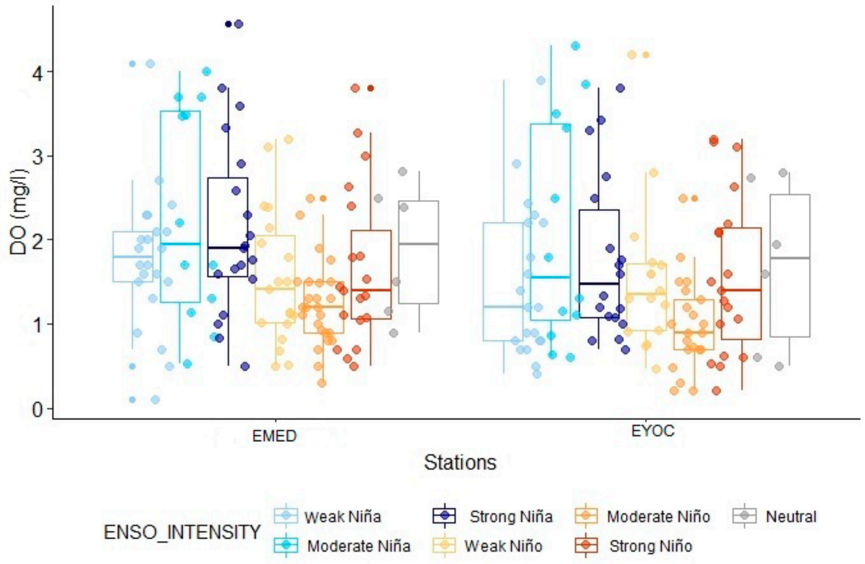


Table 1. *Classification of the intensity of the ENSO phases using the ONI index*

Intensity	SST of El Niño	SST of La Niña
Weak	1.03°C to 1.48 °C	-0.79°C to -1.06 °C
Moderate	1.49°C to 1.94 °C	-1.07°C to -1.33 °C
Strong	>1.94 °C	< -1.33 °C

Table 2. *Descriptive statistics of DO by ten-year periods at the EYOC and EMED.*

Descriptive Statistics	1985-1995		1996-2005		2006-2015	
	EMED	EYOC	EMED	EYOC	EMED	EYOC
Arithmetic mean	1.5	1.4	1.7	1.9	1.9	1.8
Median	1.5	1.3	1.5	1.3	1.6	1.4
Minimum-Maximum	0.1-4.1	0.2-3.9	0.3-4	0.3-4	0.5-4.6	0.5-4.2
Standard deviation	0.8	0.8	1.0	1.1	1.1	1.1
Coefficient of variation (%)	53.3	57.1	58.8	57.9	57.9	61.1
No. of observations	48	40	35	35	38	37

Table 3. *Descriptive statistics of DO at the EYOC and EMED according to the ENSO phases.*

Descriptive statistics	EMED			EYOC		
	El Niño	La Niña	Neutral	El Niño	La Niña	Neutral
Arithmetic mean	1.46	2.02	1.88	1.35	1.73	1.70
Median	1.30	1.90	1.94	1.22	1.32	1.78
Minimum	0.3	0.1	0.9	0.2	0.4	0.5
Maximum	3.8	4.56	2.82	4.2	4.3	2.8
Standard deviation	0.77	1.04	0.79	0.84	1.06	1.0
Coefficient of variation%	52.73	51.48	42.02	62.22	61.27	58.82
No. of observations	63	53	6	56	50	6

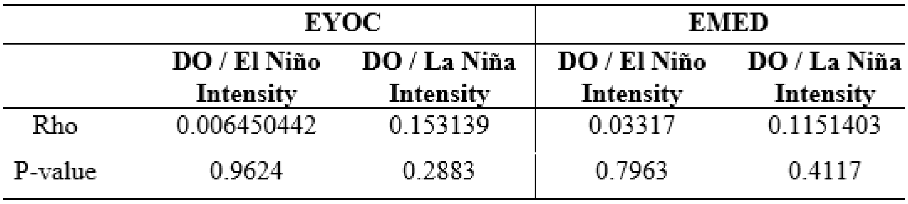
Table 4. *Descriptive statistics of DO at the EMED according to the intensity of the ENSO phases.*

Descriptive statistics	EMED					
	Weak Niña	Moderate Niña	Strong Niña	Weak Niño	Moderate Niño	Strong Niño
Arithmetic mean	1.77	2.31	2.14	1.54	1.24	1.65
Median	1.8	1.95	1.9	1.41	1.20	1.4
Minimum	0.1	0.53	0.5	0.5	0.3	0.5
Maximum	4.1	4	4.56	3.2	2.5	3.8
Standard deviation	0.83	1.28	1.08	0.81	0.51	0.95
Coefficient of variation%	46.89	55.41	50.46	52.59	41.13	57.57
No. of observations	22	12	19	19	25	19

Table 5. *Descriptive indicators of DO at the EYOC according to the intensity of the ENSO phases.*

Descriptive statistics	EYOC					
	Weak Niña	Moderate Niña	Strong Niña	Weak Niño	Moderate Niño	Strong Niño
Arithmetic mean	1.48	2.08	1.78	1.54	0.99	1.57
Median	1.2	1.55	1.47	1.35	0.9	1.4
Minimum	0.4	0.6	0.7	0.47	0.2	0.2
Maximum	3.9	4.3	3.81	4.2	2.5	3.2
Standard deviation	0.92	1.35	0.97	0.91	0.55	0.95
Coefficient of variation%	62.16	64.90	54.49	59.09	55.55	60.50
No. of observations	20	12	18	16	21	19

Table 6. *Correlation between DO and the intensity of the ENSO phases*



	EYOC		EMED	
	DO / El Niño Intensity	**DO / La Niña Intensity**	**DO / El Niño Intensity**	**DO / La Niña Intensity**
Rho	0.006450442	0.153139	0.03317	0.1151403
P-value	0.9624	0.2883	0.7963	0.4117

Supplementary data

Table S1. *Descriptive indicators of DO at the EYOC and EMED by year.*

Descriptive statistics							
		Arithmetic mean	Median	Minimum-Maximum	Standard deviation	Coefficient of variation (%)	No. of observations
1985	EMED	1.8	1.9	0.1-4.1	1.4	77.8	7
	EYOC	1.9	1.6	0.5-3.9	1.2	63.2	7
1986	EMED	1.2	1.3	0.3-1.9	0.7	58.3	3
	EYOC	1.3	1.5	0.7-1.8	0.6	46.2	4
1987	EMED	1.0	1	0.7-1.2	0.2	20	4
	EYOC	0.7	0.8	0.2-0.9	0.3	42.8	4
1988	EMED	1.6	1.9	0.5-2.3	0.9	56.3	3
	EYOC	1.4	1.2	1-1.9	0.5	35.7	3
1989	EMED	1.8	1.7	1.1-2.9	0.8	44.4	4
	EYOC	1.6	1.7	0.7-2.5	0.7	43.8	4
1990	EMED	1.6	1.5	0.9-2.5	0.8	50	3
	EYOC	1.7	1.6	0.6-2.8	1.1	64.7	3
1991	EMED	1.6	1.4	0.9-2.5	0.6	37.5	8
	EYOC	1.3	1.2	0.2-2.5	0.7	53.8	7
1992	EMED	0.8	0.8	0.5-1.1	0.3	37.5	3
	EYOC	0.7	0.7	N.E	N.E	N.E	N.E
1993	EMED	1.5	1	0.5-3.1	1.4	93.3	3
	EYOC	N.E	N.E	0.0-0.0	N.E	N.E	0
1994	EMED	1.8	1.7	1.5-2.4	0.4	22.2	4
	EYOC	1.5	1.5	1.3-1.7	0.2	13.3	4
1995	EMED	1.8	1.7	1.5-2.1	0.3	16.6	5
	EYOC	1.2	0.9	0.7-2.2	0.7	58.3	4
1996	EMED	1.4	1.7	0.3-2	0.8	57.1	4
	EYOC	1.7	2.1	0.5-2.2	0.8	47.1	4
1997	EMED	1.5	1.3	0.5-3	1.1	73.3	4
	EYOC	1.4	1.1	0.2-3.1	1.2	85.7	4
1998	EMED	1.4	1.6	0.7-1.8	0.5	35.7	4
	EYOC	1.3	1.5	0.6-1.6	0.5	38.5	4
1999	EMED	3.2	3.6	1.7-4	1.0	31.3	4
	EYOC	2.9	3	1.1-4.3	1.4	48.3	4

Descriptive statistics							
		Arithmetic mean	Median	Minimum-Maximum	Standard deviation	Coefficient of variation (%)	No. of observations
2000	EMED	2.2	2	1.1-3.7	1.1	50	4
	EYOC	2.0	1.6	1.2-3.9	1.2	60	4
2001	EMED	1.6	1.9	0.7-2.4	0.8	50	5
	EYOC	1.5	1.4	0.4-2.4	0.9	60	5
2002	EMED	1.1	1	0.8-1.5	0.3	27.3	4
	EYOC	0.7	0.8	0.3-1.0	0.3	42.9	4

Table S1, *continuation. Descriptive indicators of DO at the EYOC and EMED by year.*

Descriptive statistics							
		Arithmetic mean	**Median**	**Minimum-Maximum**	**Standard deviation**	**Coefficient of variation (%)**	**No. of observations**
2003	EMED	1,6	1,6	1.5-1.8	0.2	12.5	2
	EYOC	0,9	0,9	0,5-1.3	0.6	66.7	2
2004	EMED	0.8	0.8	0.5-1.1	0.4	50	2
	EYOC	0.9	0.9	0.5-1-3	0.6	66.7	2
2005	EMED	1.6	1.6	1.1-2.1	0.7	43.8	2
	EYOC	1.2	1.2	0.7-1.6	0.6	50	2
2006	EMED	1.7	1.6	0.7-3.2	1.1	64.7	4
	EYOC	1.9	1.3	0.8-4.2	1.6	84.2	4
2007	EMED	2.4	2.4	1.0-3.8	1.3	54.2	4
	EYOC	2.3	2.4	1.1-3.2	0.9	39.1	4
2008	EMED	2.6	3	1-3.6	1.2	46.2	4
	EYOC	2.6	3	0.8-3.4	1.2	46.2	4
2009	EMED	1.4	1.2	0.8-2.4	0.7	50	4
	EYOC	1.7	1.6	0.9-2.8	0.8	47.1	4
2010	EMED	1.5	1.7	0.8-1.9	0.5	33.3	4
	EYOC	1.1	1.1	0.8-1.3	0.2	18.2	4
2011	EMED	3.0	2.9	1.7-4.6	1.4	46.7	4
	EYOC	2.3	1.8	1.2-3.8	1.4	60.9	3
2012	EMED	1.5	1.1	0.5-3.5	1.3	86.7	4
	EYOC	1.4	0.7	0.6-3.3	1.3	92.3	4

Descriptive statistics							
		Arithmetic mean	**Median**	**Minimum-Maximum**	**Standard deviation**	**Coefficient of variation (%)**	**No. of observations**
2013	EMED	2.1	2.4	1.2-2.8	0.9	42.3	3
	EYOC	1.7	2	0.5-2.7	1.1	64.7	3
2014	EMED	2.0	2	1.3-2.6	0.6	30	4
	EYOC	2.0	2.1	0.6-3.2	1.0	50	4
2015	EMED	0.8	0.7	0.6-1.1	0.3	37.5	3
	EYOC	0.8	0.5	0.5-1.3	0.4	50	3

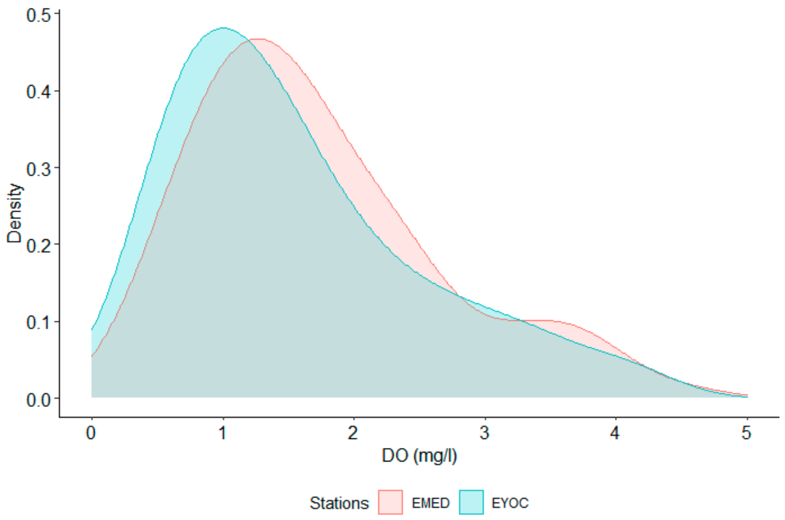
Table S2. *Descriptive indicators of DO at the EYOC and EMED by five-year periods.*

Descriptive statistics							
		Arithmetic mean	**Median**	**Minimum-Maximum**	**Standard deviation**	**Coefficient of variation (%)**	**No. of observations**
1985-1990	**EMED**	**1.5**	**1.3**	**0.1-4.1**	**0.9**	**60**	25
	EYOC	1.5	1.4	0.2-3.9	0.9	60	24
1991-1995	EMED	1.5	1.5	0.5-3.1	0.6	40	23
	EYOC	1.3	1.3	0.2-2.5	0.6	46.2	16
1996-2000	EMED	1.9	1.8	0.3-4	1.1	57.9	20
	EYOC	1.8	1.6	0.2-4.3	1.1	61.1	20
2001-2005	EMED	1.4	1.1	0.5-2.4	0.6	42.9	15
	EYOC	1.1	0.8	0.3-2.4	0.7	63.6	15
2006-2010	EMED	1.9	1.7	0.7-3.8	1.0	52.6	20
	EYOC	1.9	1.5	0.8-4.2	1.1	57.9	20
2011-2015	EMED	1.9	1.6	0.5-4.6	1.2	63.2	18
	EYOC	1.6	1.3	0.5-3.8	1.1	68.8	17

Table S3. *Descriptive indicators of DO at the EYOC and EMED between 1985 and 2015.*

Descriptive statistics	Stations	
	EYOC	EYOC
Arithmetic mean	1.6	1.7
Median	1.3	1.5
Minimum – Maximum	0.2-4.3	0.1-4.6
Standard deviation	1.0	0.9
Coefficient of variation (%)	62.5	52.9
No. of observations	112	121

Figure S1. *Behavior of DO at the EYOC and EMED.*



It was found that the DO concentration at the EMED did not fit a Normal distribution (p = 0.001264); the same was true at the Yotoco station (p = 0.0002582). It was found that the DO concentration variances at the studied stations are equal (p = 0.8654). The graphic representation is displayed in Figure S1.

Figure S2. *Behavior of DO depending on the ENSO phases at the EYOC.*

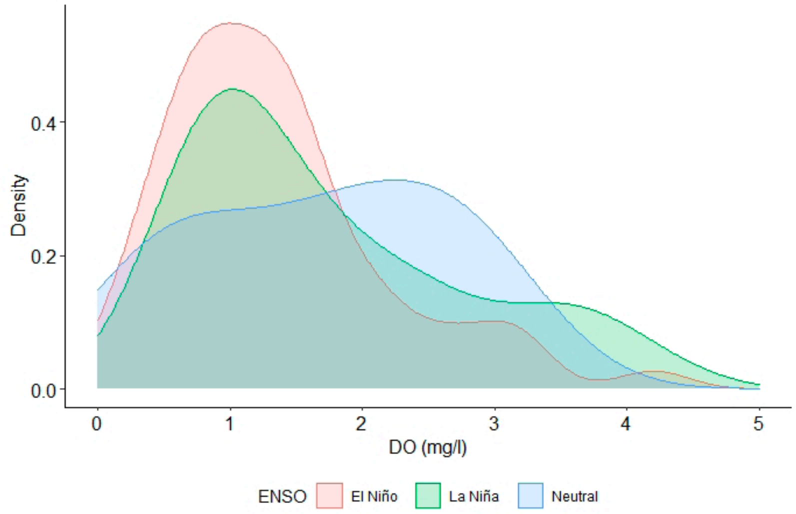
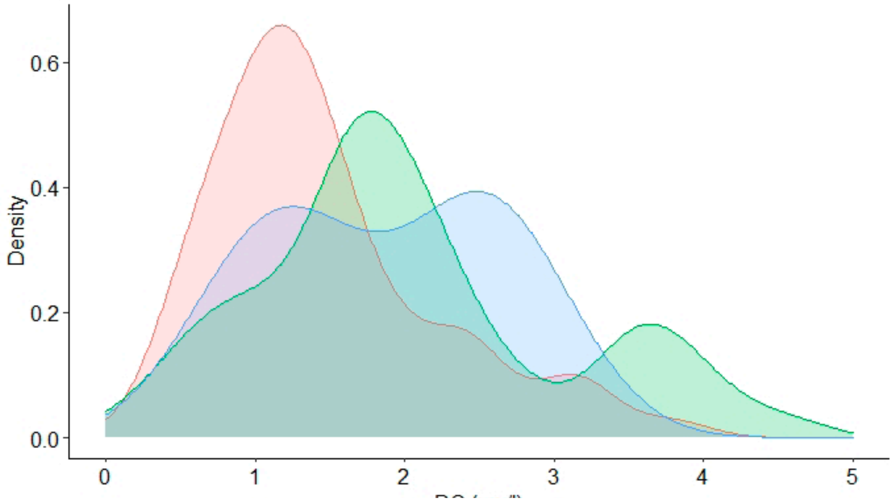


Figure S3. *Behavior of DO depending on ENSO at the EMED.*



At EYOC, when El Niño and La Niña occurred, the DO concentrations did not fit the Normal distribution (p = 0.01554, p = 0.00082), whereas in the Neutral phase they did fit the Normal distribution (p = 0.3162). At EMED, when El Niño and La Niña occurred, the DO concentrations did not fit the Normal distribution (p = 0.0000514, p = 0.02284), whereas in the Neutral phase they did fit the Normal distribution (p = 0.4126). It was found that the DO concentration variances at the studied stations were equal at EYOC (p = 0.2534) and EMED (p = 0.1474). The graphic representation is displayed in Figures S2 and S3.

Figure S4. B*ehavior of DO according to the intensity of La Niña at the EYOC.*

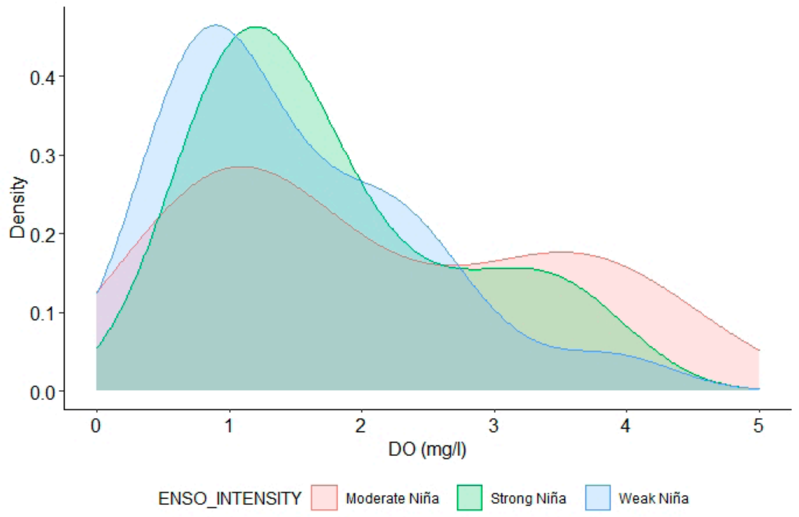


Figure S5. Behavior of DO according to the intensity of El Niño at the EYOC.

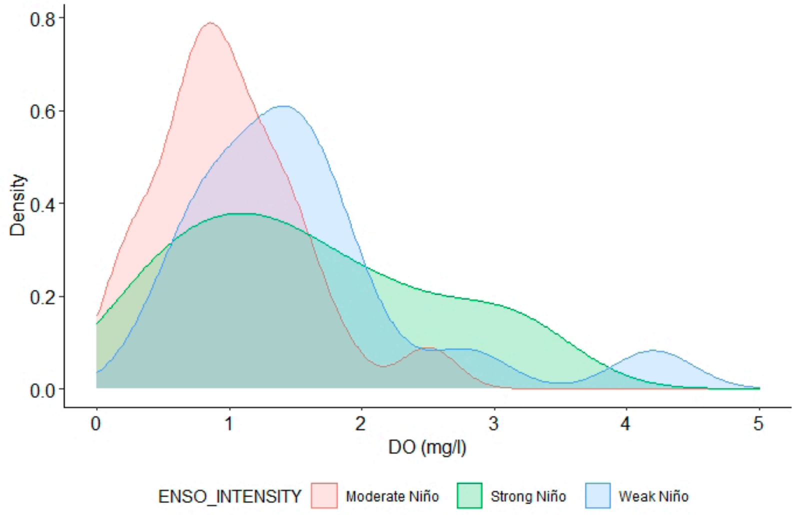


Figure S6. *Behavior of DO according to the intensity of La Niña at the EMED*

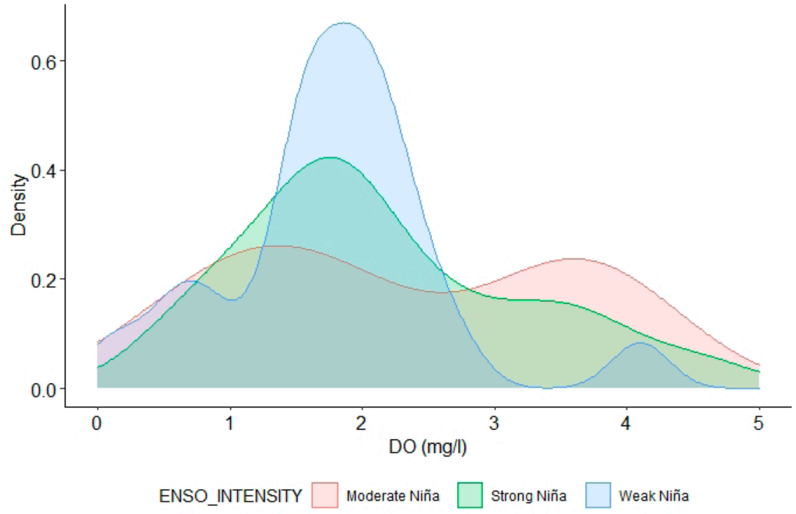
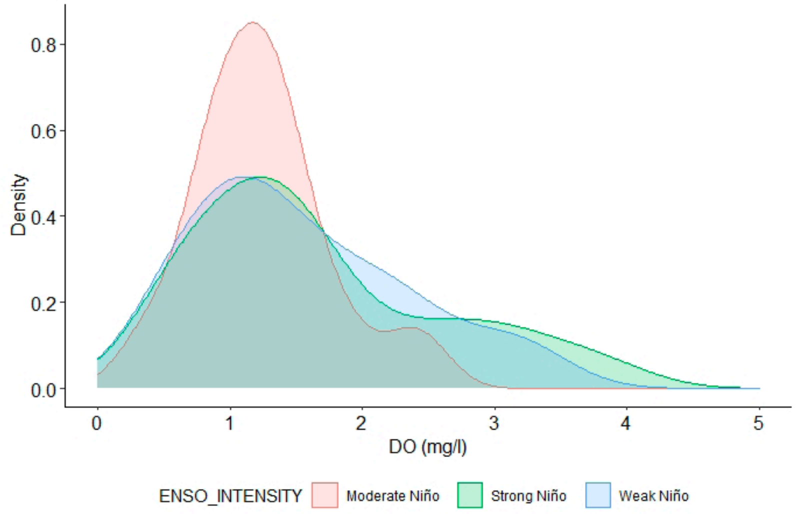


Figure S7. Behavior of DO according to the intensity of El Niño at the EMED



At EMED, it was found that the DO concentration variances were equal when the intensities of El Niño and La Niña occurred, (p = 0.07483) and (p = 0.08411), respectively. At EYOC, it was found that the variances were equal for the intensities of El Niño (p = 0.11) and the intensities of La Niña (p = 0.2263). At EMED, a Normal distribution was found for each of the intensities of El Niño: weak (p = 0.1896); moderate (p = 0.09525) and strong (p = 0.3714) and La Niña: weak (p = 0.1616), moderate (p = 0.3907) and strong (p=0.06679). At EYOC, in the case of the intensities of La Niña, a Normal distribution was not found in a weak Niña (p = 0.03082) and strong Niña (p = 0.02174), whereas a strong Niña did fit a Normal distribution (p = 0.09129). In the case of the intensities of El Niño, a Normal distribution was found in a moderate Niño (p = 0.2608) and strong Niño (p = 0.173); instead, a weak Niño did not fit a Normal distribution (p = 0.008141). The graphic representation is displayed in Figures S4, S5, S6 and S7.