Assessment of water quality and trophic state using a multiparametric index-based approach for Lake Guineo, Lake Carraizo and Lake Cidra, Puerto Rico

Gladys N. Benítez*

School of Environmental Sciences, Universidad Ana G Mendez, P.O. Box 3030 Gurabo, Gurabo 00778-3030, Puerto Rico

* Correspondence: gbenitez3@email.uagm.edu

Abstract. To ensure a safe drinking water supply, it is necessary to protect water quality. The proposed project aims to understand water quality data analyzed from a temporal and spatial perspective on the following physiochemical parameters: DO, pH, temperature, Secchi disc turbidity, conductivity, nitrate, chlorophyll a & phosphate. The results provide information to evaluate the status of the water quality and its suitability for human consumption. These variables related to the general characteristics of water quality and trophic level were used for calculation of a water quality index (WQI) and trophic state index (TSI) to assess 3 lakes in Puerto Rico: Lake Cidra, Lake Carraizo and Lake Guineo. Presence or absence of macrophytes were monitored during six months in the three reservoirs in Puerto Rico as well as the parameters mentioned above. The objective of this investigation is to discuss the trophic state and water quality in 3 different trophic state reservoirs in Puerto Rico. Results were correlated with the density of the macrophyte species, *Eichhornia crassipes*. Variations of water in situ multiparametric sampling were recorded for 6 months. Thus, integrating components that define the status of reservoirs using multiparameter measurements from various perspectives; a better diagnosis is expected regarding the water quality assessment. This investigation aims to undertake a comprehensive study of water quality by implementing the WQI and TSI indices, considering physical, chemical, and biological parameters with respect to eutrophication and ecological considerations for three reservoirs in the Puerto Rico, providing information regarding the quality of water and trophic state of the chosen reservoirs. Overall WQI results revealed that the water quality improved after the Hurricane Fiona’s occurrence. Trophic State Index after the hurricane showed slight fluctuations in the reservoirs.

Keywords: WQI; TSI; Reservoir; Trophic; Macrophyte; Quality

1. Introduction

Primary productivity of reservoirs relies on planktonic algae, periphytic algae and macrophytes (Kimmel & Groeger 1984; Tarkowska-Kukuryk et al., 2020). Macrophytes are responsible for much of the primary production of the ecosystem (Tasker et al., 2022). Its presence or absence will depend on the concentration of nutrients and the flow of the water. In lakes and reservoirs where the water flow is limited, the presence of floating macrophytes is a bioindicator of eutrophic waters. Hence, the study at hand takes into consideration the correlation of water nutrient concentrations, especially nitrogen and phosphorus with the growth of the water hyacinth. Eutrophication of water ecosystems occurs when there’s an accumulation of nutrients (García-Avila et al., 2023; Munishi, 2022). Natural and anthropogenic causes contribute to this natural process and can eventually deteriorate the water quality, break the ecological balance, and threaten human health (Liu et al., 2023). Multiparametric approach plays a significant role for assessing the aquatic environment. Indexes provide a simple representation of the extensive and complex parameters (physical, biological, and chemical) that controls the overall quality of water, which is very important in Puerto Rico since the drinking water supply comes solely from the reservoirs built for that purpose. With the extensive social and economic growth, such as human factors, climate and hydrology may lead to accumulation of pollutants in the surface water that may result in gradual change of the water source quality.
Understanding water quality is a key step for managing the problems associated with eutrophic water. The use of a multiparametric approach through indexes is uncommon in Puerto Rico. On 2008, Sotomayor-Ramirez et al. investigated using TSI on the Lakes of Cerrillos and Guajataca comparing the following parameters: Chlorophyll-α, turbidity, TN & TP on various dates. No projects are known to address the use of various multiparametric indexes correlating the presence or absence of macrophytes, making the study at hand a unique and a great assessment tool to be used in similar situations.

Data obtained via assessing and monitoring water quality and trophic state provides factual evidence to assist into the health and environmental decision making of the area. The multiparametric approach serve as useful and sensitive way to monitor the changes in the physical, chemical, or biological composition in specific periods of time, provide data to compare between seasons, different ecosystems and between different areas in the same ecosystem. The multiparametric data obtained can be used to identify the sources and causes of possible contaminants and pollutants either from ecology, geology, and anthropogenic activities (industrial processes, runoff from agricultural farms among others) in a specific area. Analysis of the data can provide information of the source (s) of contamination which can be used to effectively develop appropriate management strategies that could potentially minimize potential public health risks. Water quality degradation is one of the most pressing environmental challenges in reservoirs management and makes both the trophic status and water quality assessment of reservoirs essential for their restoration, sustainable use, and maintenance of their functionally (Mamun, et al. 2022).

Using the multiparametric index approach while utilizing portable equipment allows the investigator to assess the water quality in an effective & economic way which facilitates the monitoring process further by allowing more frequent monitoring, in shorter periods of time providing useful information for research, conducting surveys, and developing management strategies for specific areas.

2. Method

2.1. Study site

The investigation was carried out in the Island of Puerto Rico. The main island of Puerto Rico lies between about 17°45’ N and 18°30’ N, and its longitude ranges from about 65°45’ W to 67°15’ W (Fassig 1909; Daly et al. 2003). The climate in the Island is tropical; Seasonal differences are usually determined by rainfall patterns instead of the usual seasonal patterns. The study site was divided in three areas where the following reservoirs are located: Guineo Lake, Cidra Lake and Lake Carraizo (Figure 1).

Lago Guineo is the highest reservoir in Puerto Rico, located in Bo. Ala de La Piedra in Orocovis. Built in 1931; It is supplied from the Toro Negro River which are used as irrigation and electricity production. The dam is part of the Toro Negro Hydroelectric System, which was developed for electric generation and for irrigation of croplands in the southern part of Puerto Rico (Soler-López 2003).

Lago Carraizo is a reservoir formed at the confluence of Río Gurabo and Río Grande de Loíza in the municipality of Trujillo Alto in central Puerto Rico, about 10 kilometers (km) north of the town of Caguas, about 9 km northwest of Gurabo, and about 3 km south of Trujillo Alto. The Carraizo Dam is owned and operated by the Puerto Rico Aqueduct and Sewer Authority (PRASA) and was constructed in 1953 as a water-supply reservoir for the San Juan Metropolitan area (Soler-López & Soler-Licha 2014). It is supplied from the River Grande de Loiza and it serves as the main water supply source of the Metropolitan Area.

![Figure 1. Sampling locations: Lago El Guineo, Lago Cidra, Lago Carraizo](image-url)
Lago de Cidra is a reservoir located on the confluence of Rio de Bayamon, Rio Sabana, and Quebrada Prieta, in the municipality of Cidra in east-central Puerto Rico, about 3.0 kilometers northeast of the town of Cidra. The dam is owned and operated by PRASA and was constructed in 1946 as a 6.54-million-cubic-meter supplemental water supply for the San Juan metropolitan area (Soler-López 2010).

2.2. Experimental design

The investigation was carried out in three reservoirs of different trophic states: one mesotrophic (Guineo Lake), one eutrophic (Cidra Lake) and one hypertrophic (Lake Carraizo) during 2022. USCS studies were used as reference for the trophic state determination (Ramos-Gines, 1997, Soler-López, 2003 & 2010). Determinations of trophic state were made from examination of several diverse criteria, such as shape of the oxygen curve, species composition of the bottom fauna or of the phytoplankton, concentrations of nutrients, and various measurements of biomass or production (Carlson 1977). The trophic state was compared with the information generated by the Aqueducts and Sewer Authority of PR since Section 314 of the Clean Water Act requires that all lakes of the Nation be classified according to their “trophic” character. The information of the state of the lake was validated calculating the Trophic State Index (TSI). This index is a monitoring tool to assess the state (oligotrophic, mesotrophic, eutrophic, and hypereutrophic) of an aquatic ecosystem which indeed serves as baseline for measuring biological integrity and interface between human and water environment (Das Sarkar et al. 2019).

Two transects were delimited in each lake and sampling points were established in the littoral zone of each reservoir (Figure 1). The littoral region is the area that is usually densely colonized by aquatic macrophytes in trophic lakes. The sampling was carried out in the littoral area of the three lakes. Three surface water samples were collected on the months of June/2022, August/2022 and October/2022 on two different sampling points for each reservoir. Cidra reservoir -Station 1 (18.1776808, -66.1509943) Station 2 (18.182867, -66.148504), Carraizo reservoir - Station 1 (18.319955, -66.017296) Station 2 (18.269276, -66.010054) & Guineo reservoir - Station 1 (18.159648, -66.527025) Station 2 (18.157322, -66.527333).

A yearly pre-evaluation of the precipitation and temperature was conducted for the three sites using 2021 data for the municipalities the lakes are located in. By doing so, a forecast of probability for temperature and precipitation was established for the year 2022. Climographs displaying average precipitation and temperature for each municipality were constructed.

A schedule for sampling was established: The sampling and macrophyte density testing were conducted on: June, August, and October of 2022. The months were chosen based on the start of the rainy season, which coincides with the hurricane season. The sampling sites were selected according to the aquatic macrophyte occurrence and accessibility to the sites. Water quality parameters as temperature, Secchi disk transparency, depth, pH, dissolved oxygen, phosphate, nitrogen, and chlorophyll alpha were measured in-situ (Figure 2).

All physicochemical parameters were measured in situ. Chlorophyll-α was conducted using fluorescence detection (EPA Method 445.0 In Vitro Determination of Chlorophyll) which use an In vivo chlorophyll analysis by a fluorometer that passes through the sample of water and excites the chlorophyll within the living cells of the algae present. Turner Handheld little Dipper was used for this parameter. Water temperature and pH were measured using the aid of portable equipment. A standard meter was used to measure depth in the littoral area and a Secchi disk was used for measuring water transparency or turbidity. Dissolved oxygen was determined by using Smart Sensor Dissolved Oxygen Pen Meter and phosphate was calculated utilizing a HANNAH Phosphate Meter. Nitrogen was measured using Horiba LAQUAtwin Model NO3–11 Compact Nitrate Ion Meter.

These parameters were used to determine a correlation with the trophic state of each lake. Also, temperature was measured in the surface of the water. Absence or presence of macrophytes was recorded. When macrophytes were present, plants were counted in each transect to calculate density for macrophytes.

Eichhornia crassipes was identified in previous site visits in the reservoirs during the month of March/2022. No macrophytes were encountered in Guineo reservoir.

Macrophytes were identified in Station 1 in Cidra and in both Stations in Carraizo, with a higher density in Station 1. It is expected that the density increases proportionally to the trophic state. To measure the density while collecting data, photo interpretation of aerial images was used. A pre altitude test was conducted prior to using a drone in the field. A 150 cm x 150 cm square was laid out in a flat surface until the delineated square is available in the drone camera range. The altitude was measured and used as standard for the area established (150 cm x 150 cm). The altitude to measure the (150 cm x 150 cm) square was two meters. Absence or presence of macrophytes was recorded for the two sites chosen for each Lake. When macrophytes were present, photo interpretation of aerial images was used to measure density for E. crassipes in the littoral zone. The 300 cm quadrant was divided into four 50cm quadrants and Density (D) was measured using the following formula (Eq 1):

\[
D = \frac{N}{A}
\]

Where:
- \(N\) is the number of macrophytes
- \(A\) is the area of the quadrat

These results were used to determine the trophic state of each lake.
\[ D = \frac{S}{Q} \]  

where: \( S \) = Total number of individuals and \( Q \) = Number of quadrants

Also, water quality index (WQI) in the lake water as per Brown (1972), Chaterjee & Razuddin (2002), Srivasta et al. (2007), Bora & Goswami (2017) and Ramesh Kumar et al. (2019), was calculated using the following formula (Eq 2):

\[ WQI = \frac{\sum q_n W_n}{\sum W_n} \]  

where:

\( W_n \) = unit weight for nth water quality parameter,
\( q_n \) = quality rating for the nth water quality parameter

Unit weight was calculated by a value inversely proportional to the recommended standard values \( S_n \) of the corresponding parameters (Eq 3).

\[ W_n = K/S_n \]  

where:

\( W_n \) = unit weight for the nth parameter.
\( S_n \) = standard value for nth parameter.
\( K \) = constant for proportionality and is given as (Kalavathy et al., 2011): 
\[ K=\frac{1}{\frac{1}{V_{S1}}+\frac{1}{V_{S2}}+\ldots+\frac{1}{V_{Sn}}} \]

This water quality index relates a group of water quality parameters to a common scale and combines them into a single number in accordance with the physicochemical parameters used (Srivasta et al. 2007 & Sivaranjani, Amitava & Samrath, 2015). Results were classified using the WQI criteria with an index ranging from 0-100 as Excellent water quality, Good water quality, Medium water quality, Poor water quality and Very poor water quality. The water quality standards established for Puerto Rico (DNER, 2019) and the national USEPA standards for drinking water were used to calculate the constant for proportionality and for the completion of the WQI calculation. The following quality standards will be used: Dissolved Oxygen (DO), pH, Turbidity, phosphate (PO₄³⁻), and Nitrate (NO₃⁻) (Figure 2).

Trophic State Index (TSI) will be calculated using Carlson Trophic State Index (CTSI) formula as per Marie et al. (2015) & Opiyo et al. (2019) (Eq 4):

\[ TSI_{SD} = 60 - 14.41 \ln (SD) \]
\[ TSI_{Chla} = 9.81 \ln (Chla) + 30.6 \]
\[ TSI_P = 14.42 \ln (TP) + 4.15 \]
\[ CTSI = \frac{(TSI_{SD}+TSI_{Chla}+TSI_P)}{3} \]  

Whereas

Chl-a = Chlorophyll-a concentration (μg/L)
SD = Secchi disk depth (meters) F
TP = Phosphorus concentration (μg/L) LN = Natural logarithm
TSI = Trophic State Index

Figure 2. Proposed model for water assessment
Results were classified using the TSI criteria with an index ranging from 0-100 as oligotrophic aquatic ecosystem (Low ecological productivity), mesotrophic (Moderate ecological productivity), eutrophic (High ecological productivity) and hypereutrophic (highest ecological productivity) (Figure 2).

3. Result and Discussion

3.1. Macrophyte density

Macrophyte presence or absence was recorded for all the sites sampled for the 3 reservoirs. Macrophytes were absent in Cidra and Guineo. Macrophytes were present in Station 1 in Carraizo. Macrophyte density was calculated for the month of June/2022 and August/2022 in Station 1. Macrophytes were absent in Station 2 in the same reservoir and during the month of October/2022 on Station 1.

\[
D_{\text{JUNE}} = 84/m^2
\]

\[
D_{\text{AUGUST}} = 72.75/m^2
\]

3.2 Results for the individual parameters

Results for the individual parameters for the two stations of each reservoir are presented in Tables 1, 2 & 3. Sampling took place during the months of June/2022, August/2022 and October/2022.

Table 1. Results for sampling sites: Cidra Reservoir

<table>
<thead>
<tr>
<th>Parameters</th>
<th>June 2022</th>
<th></th>
<th>August 2022</th>
<th></th>
<th>October 2022</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Station 1</td>
<td>Station 2</td>
<td>Station 1</td>
<td>Station 2</td>
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<td>Station 2</td>
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<tr>
<td>pH</td>
<td>7.4</td>
<td>7.4</td>
<td>7.3</td>
<td>7.4</td>
<td>7.5</td>
<td>7.6</td>
</tr>
<tr>
<td>DO</td>
<td>2.9 mg/l</td>
<td>2.9 mg/l</td>
<td>2.8 mg/l</td>
<td>2.8 mg/l</td>
<td>2.7 mg/l</td>
<td>2.6 mg/l</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>28 ppm</td>
<td>22 ppm</td>
<td>30.2 ppm</td>
<td>17 ppm</td>
<td>40 ppm</td>
<td>42 ppm</td>
</tr>
<tr>
<td>PO₄⁻</td>
<td>0.04 ppm (mg/L)</td>
<td>0.04 ppm (mg/L)</td>
<td>0.03 ppm (mg/L)</td>
<td>0.02 ppm (mg/L)</td>
<td>0.02 ppm (mg/L)</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>28.5 ºC</td>
<td>29 ºC</td>
<td>31.5 ºC</td>
<td>30.1 ºC</td>
<td>30 ºC</td>
<td>28.6 ºC</td>
</tr>
<tr>
<td>Secchi disk</td>
<td>2 ft</td>
<td>2 ft</td>
<td>2 ft</td>
<td>2 ft</td>
<td>2.2 ft</td>
<td>1.2 ft (0.36576 m)</td>
</tr>
<tr>
<td>Chlorophyll a</td>
<td>1 μgL⁻¹</td>
<td>1 μgL⁻¹</td>
<td>1 μgL⁻¹</td>
<td>1 μgL⁻¹</td>
<td>2 μgL⁻¹</td>
<td>2 μgL⁻¹</td>
</tr>
</tbody>
</table>

Table 2. Results for sampling sites: Carraizo Reservoir

<table>
<thead>
<tr>
<th>Parameters</th>
<th>June 2022</th>
<th></th>
<th>August 2022</th>
<th></th>
<th>October 2022</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Station 1</td>
<td>Station 2</td>
<td>Station 1</td>
<td>Station 2</td>
<td>Station 1</td>
<td>Station 2</td>
</tr>
<tr>
<td>pH</td>
<td>7.32</td>
<td>7.40</td>
<td>7.28</td>
<td>7.74</td>
<td>7.48</td>
<td>7.35</td>
</tr>
<tr>
<td>DO</td>
<td>2.9 mg/L</td>
<td>2.8 mg/L</td>
<td>2.5 mg/L</td>
<td>3.7 mg/l</td>
<td>3.0 mg/l</td>
<td>2.8 mg/l</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>30.2 mg/L</td>
<td>17 mg/L</td>
<td>49 ppm</td>
<td>55 ppm</td>
<td>11 ppm</td>
<td>21 ppm</td>
</tr>
<tr>
<td>PO₄⁻</td>
<td>0.03 ppm (mg/L)</td>
<td>0.04 ppm (mg/L)</td>
<td>0.03 ppm (mg/L)</td>
<td>0.02 ppm (mg/L)</td>
<td>0.03 ppm (mg/L)</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>31.5 ºC</td>
<td>30.1 ºC</td>
<td>32.4 ºC</td>
<td>32.4 ºC</td>
<td>29.5 ºC</td>
<td>31.5 ºC</td>
</tr>
<tr>
<td>Secchi disk</td>
<td>1.5 ft</td>
<td>2 ft</td>
<td>3 ft</td>
<td>3 ft</td>
<td>2.5 ft</td>
<td>2.5 ft</td>
</tr>
<tr>
<td>Chlorophyll a</td>
<td>2 μgL⁻¹</td>
<td>2 μgL⁻¹</td>
<td>2 μgL⁻¹</td>
<td>2 μgL⁻¹</td>
<td>1 μgL⁻¹</td>
<td>2 μgL⁻¹ mg/l</td>
</tr>
</tbody>
</table>
Table 3. Results for sampling sites: Guineo Reservoir

<table>
<thead>
<tr>
<th>Parameters</th>
<th>JUNE 2022</th>
<th>AUGUST 2022</th>
<th>OCTOBER 2022</th>
</tr>
</thead>
<tbody>
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<td>Station 1</td>
<td>Station 2</td>
<td>Station 1</td>
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<tr>
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<td>7.12</td>
<td>7.10</td>
<td>7.14</td>
</tr>
<tr>
<td>DO</td>
<td>3.5 mg/l</td>
<td>3.7 mg/l</td>
<td>2.6 mg/l</td>
</tr>
<tr>
<td>NO₃</td>
<td>15 ppm (mg/l)</td>
<td>14 ppm (mg/l)</td>
<td>2.5 ppm (mg/l)</td>
</tr>
<tr>
<td>PO₄</td>
<td>.01 ppm (mg/l)</td>
<td>.01 ppm (mg/l)</td>
<td>.02 ppm (mg/l)</td>
</tr>
<tr>
<td>Temperature</td>
<td>28 ºC</td>
<td>28 ºC</td>
<td>30.5 ºC</td>
</tr>
<tr>
<td>Secchi disk</td>
<td>4.5 ft</td>
<td>5 ft</td>
<td>4.5 ft</td>
</tr>
<tr>
<td>Chlorophyll a</td>
<td>0 µgL⁻¹</td>
<td>0 µgL⁻¹</td>
<td>0 µgL⁻¹</td>
</tr>
</tbody>
</table>

3.3 Statistical analysis

Temperature

The mean for this parameter resulted in 29.46 with a range of 24.10 to 32.40 and a standard deviation of 2.2574. After conducting the Anderson-Darling test, p = 0.3296 > 0.05, a result of a normal distribution is obtained. ANOVA one-way test was performed with a p-value of 0.1382 > 0.05, which means there is a significant difference for this parameter for the sites. Levene’s test resulted in no variance for the three reservoirs with a p = 0.588 > 0.05.

pH

The mean for this parameter resulted in 7.35 with a range of 7.10 to 7.74 and a standard deviation of 0.1648. After conducting the Anderson-Darling test, p = 0.3296 > 0.05, resulting in a normal distribution. ANOVA one-way test was performed with a p-value of 0.0415 > 0.05, which means there is a significant difference for this parameter for the sites tested. Levene’s test showed no variance for the three reservoirs with a p = 0.9709 > 0.05.

Nitrate

The mean for this parameter in 22.43 with a range of 2.50 to 55 and a standard deviation of 15.6839. After conducting the Anderson-Darling test, p = 0.01121 < 0.05, resulting in a non-normal distribution. Kruskal Wallis test was performed with a p value of .065 > 0.05, which means there is significant difference for this parameter for the sites tested. Levene’s test resulted in no variance for the three reservoirs with a p = 0.9709 > 0.05.

Phosphate

After conducting the Anderson-Darling test, p = 0.3354 > 0.05, resulting in a normal distribution. The mean for this parameter resulted in 0.0250 with a range of 0.01 to 0.04 and a standard deviation of 0.0107. Levene’s test showed no variance for the three reservoirs with a p = 0.9658 > 0.05. ANOVA one-way test was performed with a p-value of 0.0415 > 0.05, which means there is a significant difference for this parameter for the sites tested.

Dissolved Oxygen

The mean for this parameter resulted in 3.0556 with a range of 2.50 to 4 and a standard deviation of 0.4752. After conducting the Anderson-Darling test, p = 0.3354 > 0.05, resulting in a non-normal distribution. The Kruskal-Wallis H test indicated that there is a non-significant difference in the dependent variable between the different groups, χ²(5) = 3.39, p = .640, with a mean rank score of 8.33 for Carraizo-Station 1, 9.83 for Carraizo-Station 2, 7.33 for Cidra-Station 1, 6.83 for Cidra-Station 2, 11.33 for Guineo-Station 1, 13.33 for Guineo-Station 2. Levene’s test resulted in no variance for the three reservoirs with p = 0.6627 > 0.05.

Chlorophyll a

The mean for this parameter resulted in 1.0556 with a range of 0 to 2 and a standard deviation of 0.8480. After conducting the Anderson-Darling test, p = 0.00023 < 0.05, resulting in a non-normal distribution. The Kruskal-Wallis H test indicated that there is a significant difference in the dependent variable between the different groups, χ²(5) = 14.15, p = .015, with a mean rank score of 11 for Cidra-Station 1, 11 for Cidra-Station 2, 13 for Carraizo-Station 1, 15 for Carraizo-
Station 2, 3.5 for Guineo-Station 1, 3.5 for Guineo-Station 2. Levene’s test showed no variance for the three reservoirs with p=0.7013 > 0.05.

**Transparency**

The mean for this parameter resulted in 3.1333 with a range of 1.20 to 5.50 and a standard deviation of 1.3552. After conducting the Anderson-Darling test, p = 0.0112 < 0.05, resulting in a non-normal distribution. The Kruskal-Wallis H test indicated that there is a non-significant difference in the dependent variable between the different groups, \( \chi^2(5) = 9.43, p = .093 \), with a mean rank score of 6.33 for Cidra-Station 1, 4.17 for Cidra-Station 2, 8.67 for Carraizo-Station 1, 12 for Carraizo-Station 2, 16 for Guineo-Station 1, 9.83 for Guineo-Station 2. Levene’s test resulted in no variance for the three reservoirs with p=0.7305 > 0.05.

**WQI**

The mean for this parameter resulted in 43.1667 with a range of 112 to 73 and a standard deviation of 21.3314. After conducting the Anderson-Darling test p = 0.07273 > 0.05, resulting in a normal distribution. ANOVA one-way test was performed with a p-value of 0.006858 < 0.05, which means there’s a significant difference in WQI for the different reservoirs. Levene’s test resulted in no variance for the three reservoirs with p=0.9746 > 0.05.

**TSI**

The mean for this parameter resulted in 47.6667 with a range of 30 to 57 and a standard deviation of 7.6522. After conducting the Anderson-Darling test p = 0.00755 < 0.05, resulting in a non-normal distribution. The Kruskal-Wallis H test indicated that there is a non-significant difference in the dependent variable between the different groups, \( \chi^2(5) = 12.1, p = .033 \), with a mean rank score of 6.33 for Carraizo Station 1, 4.17 for Carraizo Station 2, 8.67 for Cidra-Station 1, 12 for for Cidra-Station 2, 16 for Guineo-Station 1, 9.83 for Guineo-Station 2. Levene’s test resulted in no variance for the three reservoirs with p=0.6839 > 0.05.

Figure 3. Value of WQI during the months of June, August and October.

3.4. **WQI**

From the results obtained while in situ sampling, six the physicochemical variables were used obtain WQI: Chlorophyll-α, water temperature, pH, dissolved oxygen, PO₄³⁻ and NO₃⁻. During the month of June/2022 the WQI for Cidra obtained 72 for Station 1 and 71 for Station 2, which is poor quality of water, while for Carraizo WQI resulted in 54 for Station 1 and 73 for Station 2, which classifies the water quality as medium quality and Poor quality respectively.

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Guineo’s WQI results were 13 for both Stations, categorizing the water as excellent quality. For the month of August, the WQI results varied for Carraizo with 55 for Station 1 and 57 for Station 2, classifying both Stations with Medium quality of water. In the case of Cidra Station resulted in 72 for Station 1 which ranks the site with poor quality water and 52 for Station 2 with medium quality water. WQI for Guineo increased to 31 for both stations, which means good quality water. During the month of October/2022, Carraizo resulted in a WQI of 33 for Station 1 with good quality water and 54 for Station 2 with medium quality water. Cidra obtained a WQI of 36 for Station 1 and 35 for Station 2 for improving the water quality to Good. The water quality for Guineo also improved with a WQI of 13 for Station 1 and 12 for Station 2 with excellent water quality for both Stations (Figure 3).

3.5 TSI

To calculate the TSI, 3 variables were used: phosphate, Secchi disk and chlorophyll α. The TSI was calculated with the purpose of classifying the reservoirs in trophic degrees, evaluating the quality of the water by nutrient enrichment and its effect on the excessive growth of algae or the increase in infestation of aquatic macrophyte E. crassipes.

The classification of the aquatic environment according to TSI was eutrophic for Carraizo with 54 for both Stations and Cidra Lake with a value of 52 for Station 1 and 54 for Station 2. It was oligotrophic for Guineo with a value of 31 for Station 1 and 30 for Station 2. During the month of August, the values decreased slightly for Carraizo with values of 51 for both Stations and for Cidra, 51 for Station 1 and 50 for Station 2. Guineo increased the trophic state with 44 for both Stations to a mesotrophic state. the month of June of 2022 with 54 for both reservoirs. There were differences for October/2022 since Carraizo resulted in mesotrophic for Station 1 with a value of 47 and eutrophic for Station 2 with a value of 54. Both Stations for Cidra were eutrophic with 57 for Station 1 and 53 for Station 2. Guineo was mesotrophic for Station 1 with a value of 41 and oligotrophic for Station 2 with a value of 40. This slight difference meant a change of trophic state as per the classification scheme (Figure 4).

4. Conclusion

Significant differences were identified due to temperature and precipitation fluctuations during the months sampled. DO, pH, Turbidity, Phosphate (PO₄³⁻) Nitrate (NO₃⁻), Temperature & Chlorophyll α were sampled and analyzed on various months during the rain/hurricane season on different reservoirs in Puerto Rico. These parameters were analyzed using a multi-parametric approach. This approach demonstrated to be a robust method providing water quality and trophic state status for specific areas.
Normal distribution was found in temperature, pH, \( \text{PO}_4^{3-} \) parameters. Temperature differences were encountered on the different reservoirs. These are directly related to the latitude differences between the reservoirs: 1300 m (Guineo) > 432 m (Cidra) > 41.14 m (Carraizo). \( \text{pH} \) and \( \text{PO}_4^{3-} \) values results were similar between the reservoirs, in compliance with the national standards.

Non-normal distribution was found for nitrate, DO, chlorophyll-\( \alpha \), transparency. These parameters demonstrated significant differences between the different reservoirs researched. DO levels were below the national standards for all the reservoirs; Guineo’s reservoir values obtained for this parameter were higher than the other reservoirs, validating that its location further away from commercial and residential areas benefit the amount of DO which promotes aquatic life.

Macrophyte presence was recorded for the reservoirs sampled. During the months sampled, the only site with macrophytes present was Station 1 for the Carraizo reservoir, which demonstrated higher \( \text{NO}_3^- \) values for this Station. Heavy precipitation during hurricane Fiona on September 15th can be related with the significant drop for this parameter on the sampling month on October/2022. This drop could be directly related with the flushing of the Carraizo dam which was dangerously close to overflowing after the heavy precipitation event (Tolentino, 2022). Although there’s a big rise on this parameter in the Cidra reservoir, no macrophytes were observed in neither Stations during the last sampling. Disturbances like hurricanes can alter water chemistry at a regional scale through storm runoff. Location of the reservoir can lead to cultural eutrophication (Nixon, 1995 & Frazar et al., 2019); because of the reservoir’s location, urban runoff, commercial and/or industrial point sources may be contributing to the higher nitrate levels.

Multi-parametric analysis is an easier and quicker way to understand a big amount of complicated environmental data used to generate water quality assessments. They can be useful tools in watershed management. TSI and WQI results confirmed that an in-situ approach is possible to obtain valuable data. This approach becomes a valuable tool as it provides a quick assessment for the parameters used. Both indexes validated previous information available for the reservoirs; they provided a rapid and effective water assessment, that could identify possible site-specific pollutants which could aid in the environmental planning for the area.

The benefits of using multiparametric indexes aids in the communication of the results which comprises chemical, biological, and physical aspects of the trophic state and the water quality across different reservoirs and/or several sampling points in the same reservoir. Providing this information using a number is found to be an effective tool for water resource management and useful to help identify point-source pollution. Furthermore, using portable equipment facilitates the monitoring, without relying on expensive lab testing.

Water quality degradation can vary widely between reservoirs. Difference on values for parameters will depend on the environmental and physical processes that could be affected by the different uses adjacent to the reservoir. As per results, cultural eutrophication is observed as results coincide with the more populated areas.

The methodology proposed in the present research aids in obtaining respective WQI and TSI for specific areas. These specific results provide relevant information regarding the different activities that could affect the parameters contained in the indexes. The overall WQI results revealed that the water quality improved after the Hurricane Fiona’s occurrence. Trophic State Index after the hurricane showed fluctuations in the reservoirs; Cidra remained Eutrophic, Carraizo fluctuated enough to change from Eutrophic to Mesotrophic in Station 1 but remained Eutrophic in Station 2. Guineo trophic state changed from Oligotrophic in June to Mesotrophic in August and remained Mesotrophic in Station 1 and changed to Oligotrophic in Station 2. These differences in trophic status indicates temporal variability which could be directly related with anthropogenic influences coupled with events of heavy precipitation.

Community outreach is encouraged as the water quality is impacted by the location. Educating the communities can help improve the quality of water, especially when fishing activities are common in the area. As per USEPA, Carraizo and Cidra are impaired for copper and lead which could be the result of corrosion of the plumbing materials into the reservoirs. The presence of metals into water can bioaccumulate through the food chain up to the fisherman who consume the catch of the day. Cidra has an organized fisherman community that helps with the maintenance of the reservoir. When macrophytes are present the members of the community manually remove the noxious plants before they take over.

While community involvement is a tool in the reservoir management process, so is the awareness of the water quality for the communities as water quality impairment can become a serious health issue for them. Pollutants can harm people’s health when they drink water or eat seafood from contaminated surface water. Water degradation is directly related to habitat degradation; vegetation and biota in the area could be affected by the water quality. Although regulating agencies have the responsibility to set the standards for water quality monitoring of the resource to ensure compliance with the national/state standards, scientists, environmental managers, and communities have the responsibility to help with the compliance of these standards. The multi-parametric indexes provide a holistic approach to water environmental management.
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