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Nutrient and Coliform Levels in the Surface Waters of a Protected Upland Lake in Ormoc City Philippines

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ABSTRACT

Lake Danao in Ormoc City, Philippines, is a legally protected freshwater ecosystem classified as a Class A water body by the government. However, its ecosystem services and biological stability are continuously threatened by untreated runoff from human activities in the upland regions surrounding the lake. A study was thus conducted to evaluate the water quality of Lake Danao using water quality indices and microbiological assessments. Water samples were collected in five sampling stations from April 2021 to June 2022. Results ranged between 0 and 20.53 mg/L for nitrates, 0 and 1.06 mg/L for nitrites, 0.07 and 2.5 mg/L for phosphates, 2.86 and 7.73 mg/L for dissolved oxygen, and 2.83 and 1,600 MPN/100 mL for total coliform. On average, the readings of these parameters were above the Philippines' Department of Environment and Natural Resources maximum allowable limits for Class A waters. In addition, fecal coliform (0-849.67 MPN/100 mL, $\bar{x}$=40.17 MPN/100 mL) consistently exceeded the limit. Mean readings in fecal coliform and phosphate levels were drawing near Class B levels. The results may impose possible threats to human health, as high levels of coliform suggest that the lake is already an unsafe source of potable water. In addition, fluctuations across sampling periods were observed for all parameters measured, except for total and fecal coliforms. Lastly, heavy precipitation resulted in a very low N/P ratio (<1) which suggests that the possible source of the phosphate is anthropogenic, and runoff from the surrounding land has carried significant concentrations of phosphates and coliform into the water body. The nutrient pollution index shows that Lake Danao is "moderately polluted," while its trophic state index states that it is "mesotrophic." It is recommended that strategies in runoff treatment should be advanced, be it by nature-based solutions, such as ensuring thick vegetation cover along the buffer zone, or via man-made interventions like no-till farming. Regular monitoring of the lake water quality should therefore be continued, particularly for nutrients and coliform, to ensure the maintenance, protection, and responsible use of the protected upland lake.

1. INTRODUCTION

Lakes are one of the most important sources of fresh water, though they account for only about 0.3% of the total surface waterbody sources. Lake waters are used by humans for drinking, aquaculture, and recreational activities (Vasistha and Ganguly, 2020). Unfortunately, the conditions of lakes and other water bodies have been in constant deterioration due to increased anthropogenic activities, such as agriculture, industry, and urbanization. Water contamination and scarcity are the utmost concerns because they pose threats to public health and food security, impair ecosystem services, and hinder economic growth (UNESCO, 2021).

Eutrophication happens when excess nutrients like nitrates and phosphates cause too much plant and algae growth, reducing dissolved oxygen (DO) and harming aquatic life (Schindler, 2006; Isiuku and

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Enyoh, 2020). A major source of these nutrients is agricultural runoff from fertilizers and livestock waste (USEPA, 2002). A study of Al-Afify et al. (2023) on Burullus Lake in Egypt showed severe eutrophication and extreme environmental stress due to runoffs from several drains containing agricultural, industrial, and domestic effluents. The lake's nutrient loading behavior was greatly reduced due to the presence of high traces of nitrates in the form of ammonia (1,221 µg/L) exceeding Canadian guidelines and orthophosphates (436 µg/L) that were approximately twice as high as they were during the summer season. The high levels of nutrient contaminants in the lake affected its primary productivity and deteriorated the water quality. To improve water quality, the locals surrounding the lake have shifted to various programs and activities, such as improved farming methods, dredging and deepening the inlet link, and investigating several drainage water management options.

Total coliform (TC) and fecal coliform (FC) counts are indicators of pollution as well as the water supply's sanitary condition. TC includes bacteria that are usually found in water and soil that have been contaminated by human or animal waste. These bacteria are less likely to cause illness, but their presence, especially in large numbers, is an indication that the water supply may be susceptible to contamination by pathogens. On the other hand, FC bacteria are gram-negative, non-spore-forming rods that are found in the intestines and feces of humans and other warm-blooded animals. Thus, the presence of FC in water sources may indicate contamination of the waterbody by human and/or animal feces. Most strains of FC bacteria are pathogenic, with *Escherichia coli* as the most predominant (USEPA, 1995). Niyoyitungiye et al. (2020) assessed the presence of coliform bacteria in Lake Tanganyika in Burundi, as its water is used by nearby residents for cooking, drinking, and washing. Results showed that FC is low, but TC is high; thus, to be considered safe for drinking and bathing purposes, the lake water requires treatment prior to use.

Different physicochemical parameters were used by García-Avila et al. (2023) to assess a high Andean lake's trophic state and water quality. Results from several eutrophication and trophic state indices from nutrient concentrations, dissolved oxygen levels, and biological productivity indicated that the lake had a high level of eutrophication attributed to excessive accumulation of nutrients in the water. The results showed that the lake is in a hypereutrophic state, indicating a high concentration of nitrates, which ranges from 1 to 5 mg/L in the summer season with concentrations between 0.8 and 2.7 mg/L in winter, and phosphates of 2.89 mg/L and 1.84 mg/L in summer and winter, respectively. Anthropogenic causes were identified as the main sources of eutrophication, including tourism and agriculture, suggesting means be considered to mitigate human activity in the area and control pollution in the lake.

Lake Danao in Ormoc City, Leyte, Philippines, is a protected upland area with a total surface area of 139.83 hectares (de la Cruz et al., 2024). The lake was classified as Class A freshwater according to the Philippine Water Quality Guidelines, which designate it as a water source suitable for public water supply, requiring conventional treatment to meet drinking water standards (DENR, 2016). At present, it is primarily used for recreation and tourism, but locals also rely on it for food (fish, mussels, and prawns) and agricultural water (Romero et al., 2023).

This study was conducted to assess the current water quality of Lake Danao, an under-researched upland lake in the region, using water quality indices and microbiological assessment, which focused on addressing the critical intersection of nutrient enrichment and microbial contamination. Its first spatiotemporal assessment of both nutrient concentrations and coliform levels provides a clearer view of the lake's ecological health, particularly in relation to human impacts such as settlements and agriculture. Specifically, nutrients (phosphates, nitrates, and nitrites) and DO were measured *in situ*, while the levels of TC and FC bacteria were estimated using the Multiple-Tube Fermentation Technique. The data was analyzed to check for variations between sampling stations and sampling periods using statistical methods. Then, nutrient pollution and trophic state indices were calculated and used to categorize the status of the lake waters.

2. METHODOLOGY

2.1 Study site

The study was conducted in Lake Danao Natural Park (LDNP) in Ormoc City, Leyte, located in the eastern central region of the Philippines. The lake is classified as Class A, which means that the lake waters can be a source of water supply after completing treatment required by the Philippine National Standards for Drinking Water (PNDSW). During the sampling period, the temperature of the area ranged from 27.3-29.4°C and the precipitation ranged from 150.8-558.6 mm (PAGASA, 2022). The whole area of the lake and sampling stations are shown in Figure 1, the description of each sampling station is listed in Table 1, and the monthly precipitation data of the sampling periods are in Table 2.

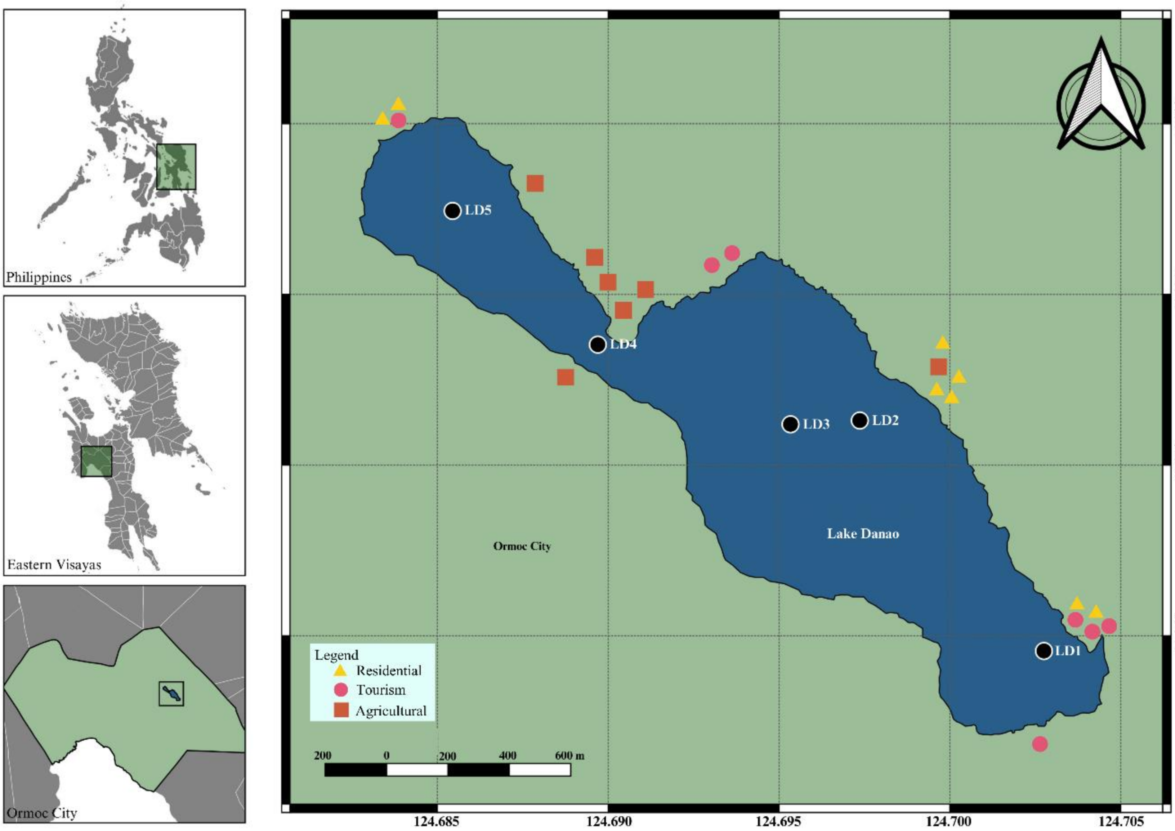

Figure 1. Map of Lake Danao, Ormoc City showing the five sampling stations (LD1-LD5).

Table 1. Site description and geographical coordinates of Lake Danao sampling stations

Stations	Mean depth (m)	Geographical coordinates	Characteristics
LD1	33.35	N 11°03’52.4” E 124°42’09.0”	*Inawasan area* (where water flows out of the lake), recreational establishments and residential areas are concentrated.
LD2	69.47	N 11°04’16.7” E 124°41’50.5”	Below the primary school and community, patches of agricultural land were observed nearby.
LD3	71.57	N 11°04’16.3” E 124°41’43.2”	Least disturbed by humans.
LD4	18.81	N 11°04’24.7” E 124°41’22.9”	Most agricultural areas are located nearby.
LD5	23.20	N 11°04’38.8” E 124°41’07.6”	Newly opened recreational cottages, and near some agricultural land.

Table 2. Average precipitation in Lake Danao from April 2021-June 2022.

Sampling periods	Months	Average precipitation (mm)[a]
SP1	Apr-Jun 2021	204.40
SP2	Jul-Sep 2021	190.27
SP3	Jan-Mar 2022	340.83
SP4	Apr-Jun 2022	330.27

[a]PAGASA (2022)

2.2 Sample collection and in situ physicochemical parameter measurements

The method on the collection of water samples was adapted from the Environmental Management Bureau Ambient Water Quality Monitoring Manual Volume 1 (DENR-EMB, 2008). Bimonthly collection (every 2nd and 4th week of the month) of water samples in triplicate was done from April 2021 to June 2022, in the morning between 9 am and noon. No sampling was conducted in the months of Sep to Dec 2021 due to logistical concerns and Typhoon Odette. Pre-sterilized and acid-washed 150 mL glass bottles were used to collect water samples in the five sampling stations in triplicate, both for nutrient and coliform analyses.

DO levels were measured in situ using a Hanna portable multiparameter (HI7698194). Meanwhile, the nutrient content of the water samples was analyzed using nitrate (Hanna HI977288), nitrite (Hanna HI97707), and phosphate (Hanna HI97713) photometers. The protocol suggested by the manufacturers of the photometers and the multi-parameter was used in the analysis. Distilled water was used as the negative control. Water transparency was measured in terms of Secchi disk depth.

2.3 Total coliform and fecal coliform analysis

The multiple-tube fermentation technique was used to estimate total coliform (TC) and fecal coliform (FC) levels using a ‘333’ tube series with lactose broth. This three-step method gives results as the Most Probable Number (MPN), following the American Public Health Association’s guidelines (APHA, 1998). It includes three phases: a presumptive test using lactose tryptose broth, a confirmed test with brilliant green bile broth for TC, and a completed test using *E. coli* broth for FC. Peptone water was used as a diluent to support bacterial growth for easier detection.

2.4 Data analysis

The Kruskal-Wallis nonparametric test followed by the Mann-Whitney test were conducted to test significant differences ($p<0.05$) of some water parameters (nutrients, coliform levels, and DO) at sampling stations during select sampling periods. The nitrate-to-phosphate ratio (N/P) was calculated as an indicator of the extent of algal or phytoplankton production in water bodies. N/P is usually assumed to be equal to the Redfield ratio of 16N:1P; however, deviations to this value have been observed depending on both phytoplankton species and study sites. A higher ratio indicates that P is limiting, and a lower ratio means that N is limiting (Spalinger and Bouwens, 2003; Isiuku and Enyoh, 2020).

Nutrient pollution index (NPI) was also computed using Eq. 1., where MATN/P is the maximum allowable value based on DENR (2016) guidelines. The following are the classifications based on NPI values: < 1-no pollution; 1 ≤ 3-moderately polluted; > 3 ≤ 6-considerably polluted; and > 6-very highly polluted (Isiuku and Enyoh, 2020).

$$\mathrm{NPI} = \frac{\mathrm{TP}}{\mathrm{MATN}} + \frac{\mathrm{TP}}{\mathrm{MATP}} \tag{1}$$

To determine the lake’s trophic state classification as the basis of primary productivity, a numerical trophic state index (TSI) model developed by Carlson (1977) was used. Carlson’s TSI was calculated using Secchi disk transparency (SDT), total phosphorus (TP), total nitrogen (TN), and existing mathematical model computations (Equation 2-4). Mean values from the three variables were taken to determine the overall trophic state classification.

$$\mathrm{TSI\ (SDT)} = 10\left[6 - \left(\frac{\ln \mathrm{SDT}}{\ln 2}\right)\right] \tag{2}$$

$$\mathrm{TSI\ (TP)} = 10\left[6 - \left(\frac{\ln \frac{80.32}{\mathrm{TP}}}{\ln 2}\right)\right] \tag{3}$$

$$\mathrm{TSI\ (TN)} = 54.45 + 14.43\ (\ln \mathrm{TN}) \tag{4}$$

3. RESULTS

3.1 Spatial variation of water quality parameters

Figure 2 shows that nutrients and DO levels did not vary among the five sampling stations in Lake Danao. However, significant variations were observed between sampling stations in terms of TC and FC. The estimated average values for TC counts ranged from 2.83 to >1,600 MPN/100 mL, with some sampling stations showing values above the Class A standard water limit (1,000 MPN/100 mL) set by the DENR (2016). LD4 and LD5 showed high average TC levels, 431.00 MPN/100 mL and 523.12 MPN/100 mL, respectively, as compared to the other stations. For the FC counts, all measured values in the five sampling stations are above the maximum permissible limit (<1.1 MPN/100 mL) for Class A water. LD3 had the least mean FC estimate of 4.78 MPN/100 mL, significantly lower than the other four sampling stations.

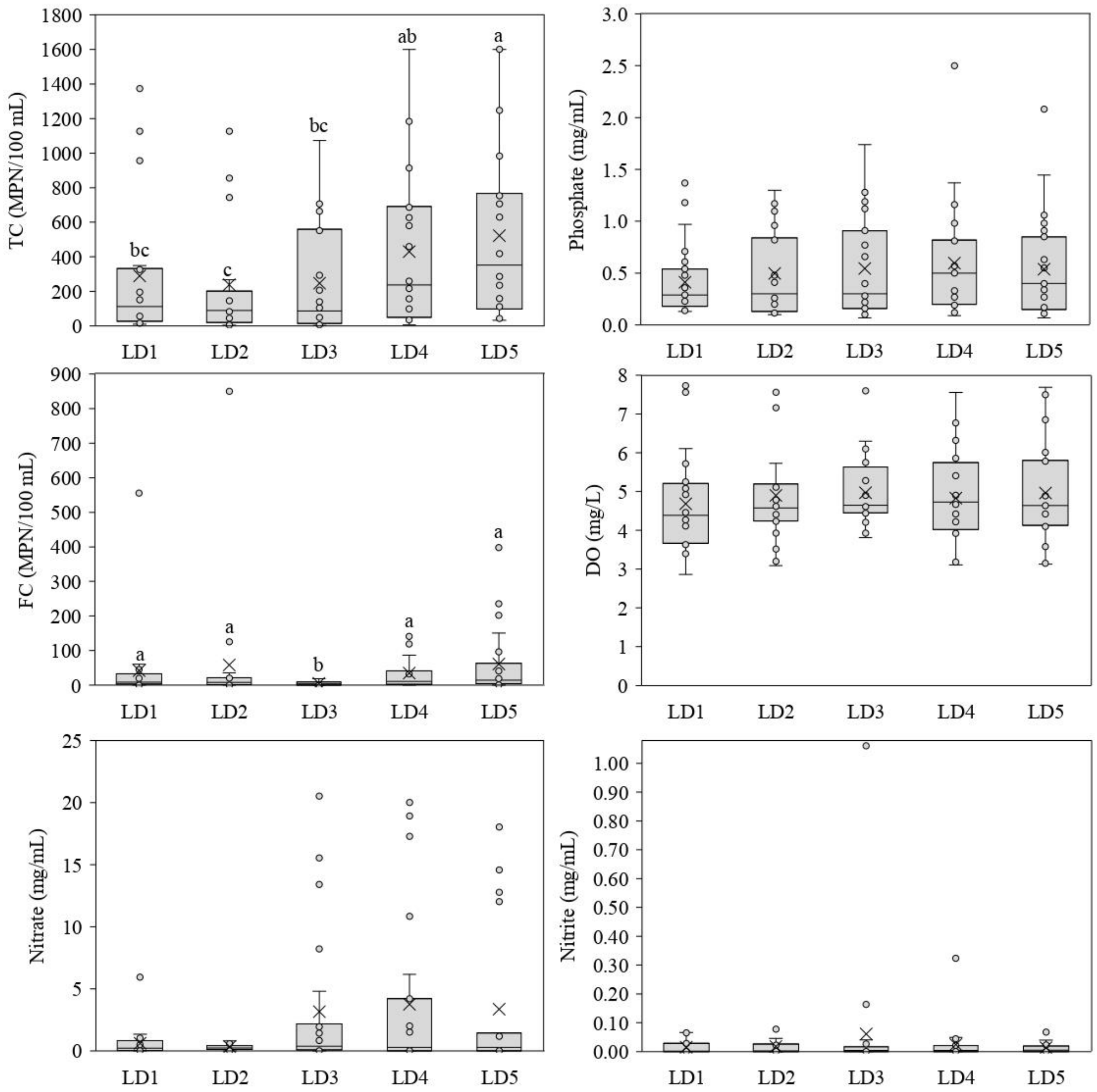

Figure 2. Box plot of coliform levels (TC: total coliform, FC: fecal coliform), nutrients (phosphate, nitrate, and nitrite), and dissolved oxygen (DO) based on sampling stations in Lake Danao, Ormoc City (n=23). Groups with different letters are significantly different ($p<0.05$) by Kruskal-Wallis and Mann-Whitney tests. LD-Sampling stations.

Figure 3(a) shows the calculated N/P values for each sampling station, with the mean values for LD3, LD4, and LD5 close to the Redfield ratio of 16N:1P. In LD1 and LD2, the N/P values were <<16, which means that N is limited in these locations.

3.2. Temporal variation of water quality parameters

There are no pronounced seasons in the Eastern Visayas Region. The sampling periods were divided based on the monthly precipitation data (Table 2). SP3 and SP4 recorded higher amounts of precipitation as compared to SP1 and SP2, a factor that may have significantly contributed to the amount of nutrients, DO, and coliform detected in the lake waters. Significant variations in water quality parameters were observed in terms of the sampling period, as shown in Figure 4.

High TC levels were observed in SP4 (17,632.7 MPN/100 mL), while SP1 and SP2 recorded the lowest levels (4,536.60 MPN/100 mL and 5,924.47 MPN/100 mL, respectively). Based on the guidelines of the DENR (2016), the waters of Lake Danao were contaminated with FC in all sampling periods. The highest FC levels (2,344.8 MPN/100 mL) were recorded in SP4, while SP2 had the lowest (94.4 MPN/100 mL).

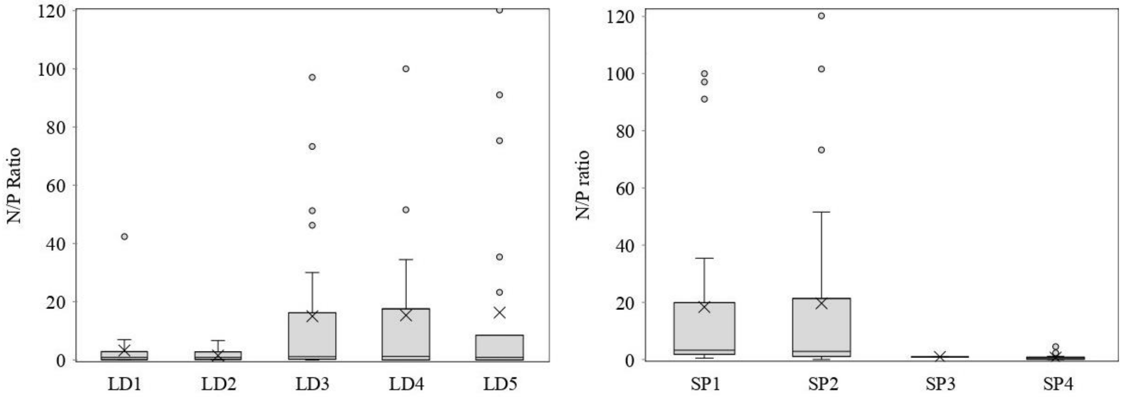

Figure 3. Nitrate to phosphate ratio (mean±stdev) of Lake Danao, Ormoc City based on (left) sampling stations (n=23) and (right) sampling periods (SP1: Apr-Jun 2021, SP2: Jul-Sep 2021, SP3: Jan-Mar 2022, SP4: Apr-Jun 2022) in Lake Danao, Ormoc City (n=30). N/R 0-16: nitrate is limiting; N/R above 16: phosphate is limiting (Spalinger and Bouwens, 2003; Isiuku and Enyoh, 2020). LD-Sampling stations. SP-Sampling periods.

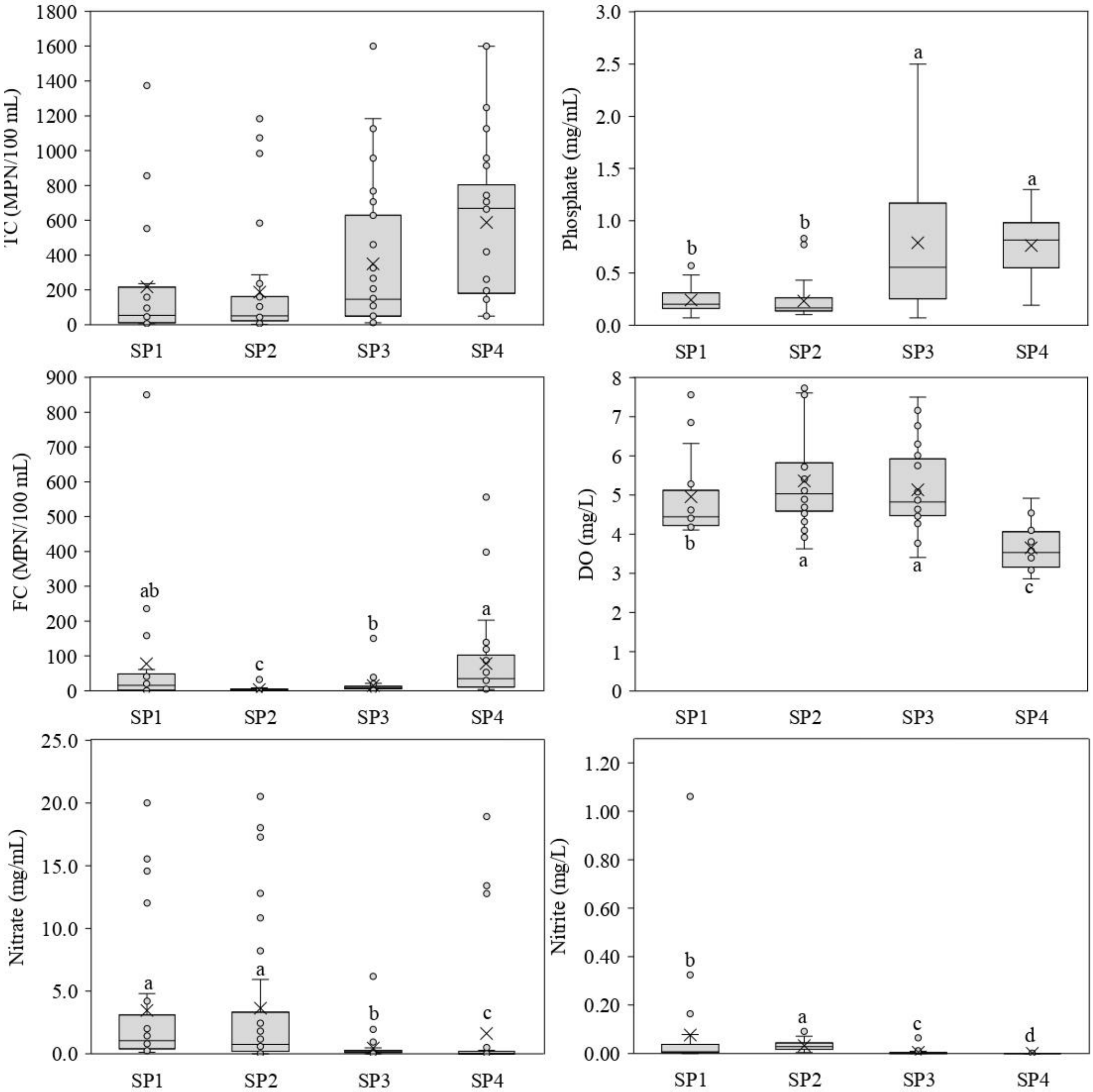

Figure 4. Box plot of coliform levels (TC: total coliform, FC: fecal coliform), nutrients (phosphate, nitrate, and nitrite), and dissolved oxygen (DO) based on sampling periods (SP1: Apr-Jun 2021, SP2: Jul-Sep 2021, SP3: Jan-Mar 2022, SP4: Apr-Jun 2022) in Lake Danao, Ormoc City (n=25). Groups with different letters are significantly different (p<0.05) by Kruskal-Wallis and Mann-Whitney tests. SP-Sampling periods.

For nitrates, high levels (3.33 mg/L) were measured in SP1 and SP2, then decreased to 0.44 mg/L and 1.61 mg/L in SP3 and SP4, respectively. Similarly for nitrites, high levels (0.052 mg/L) in SP1 and SP2 were observed, followed by significantly lower levels (0.003 mg/L) in SP3 and SP4. An opposite trend was observed for phosphates. Phosphates were below the maximum allowable limit set by DENR Water Quality Standard for Class A and B waters during SP1 and SP2 (0.24 mg/L) but increased to above the allowable limit in SP3 and SP4 (0.80 mg/L). The maximum allowable limits for Class A waters for nitrate, nitrite, and phosphate are 7 mg/L, 1 mg/L, and 0.5 mg/L, respectively.

The observations on the fluctuation in nutrient levels are consistent with the computed N/P in Figure 4(b). In SP1 and SP2, the N/P values are relatively close to the observed Redfield ratio, but in SP3 and SP4, the N/P values were <1 due to the very high amounts of P available, with limited N. The increasing amount of phosphate also affected the DO levels (Figure 4), with SP4 having significantly lower values (3.6 mg/mL) than the other three earlier sampling periods.

3.3 Nutrient pollution index and trophic state index

NPI considers the effects of nitrate and phosphate on the overall quality of Lake Danao. Figure 5(a) shows the NPI values for the five sampling stations with LD1 classified as "not polluted" and the rest of the other stations as "moderately polluted". Spatial variation in TSI for Lake Danao using three limnological parameters (SDT, TP, and TN) shows significant variation for TN only (Figure 6(a)). Primary productivity in terms of SDT was observed to fluctuate within the oligotrophic range. In terms of TN inputs, TSI was fluctuating from oligotrophic to eutrophic state, while all locations are eutrophic in terms of TP. The average primary productivity for Lake Danao is "mesotrophic" (48.55±1.33 TSI) for LD1 and LD2, which is attributed to moderate nutrient supply as well as dissolved and suspended solid inputs affecting the water clarity. On the other hand, LD3, LD4, and LD5 are "eutrophic" (58.02±1.07 TSI) or have a good supply of nutrients resulting in enhanced production and reduced transparency.

Figure 5(b) shows the calculated NPI values for each sampling period. Lake Danao is "not polluted" when precipitation is low but becomes "moderately polluted" when precipitation is high. TSI calculated for Lake Danao using the same limnological parameters shows monthly variations (Figure 6(b)). Primary productivity in terms of SDT was observed fluctuating within the oligotrophic range, while in terms of TN inputs, TSI fluctuated from ultraoligotrophic to mesotrophic state. Measured high phosphate concentration in the lake water corresponds to increasing trophic state trends and primary productivity. TSI in terms of TP was observed to increase from eutrophic to hypereutrophic. Generally, the lake reservoir's primary productivity can be classified as "mesotrophic" (48.14±2.55 TSI).

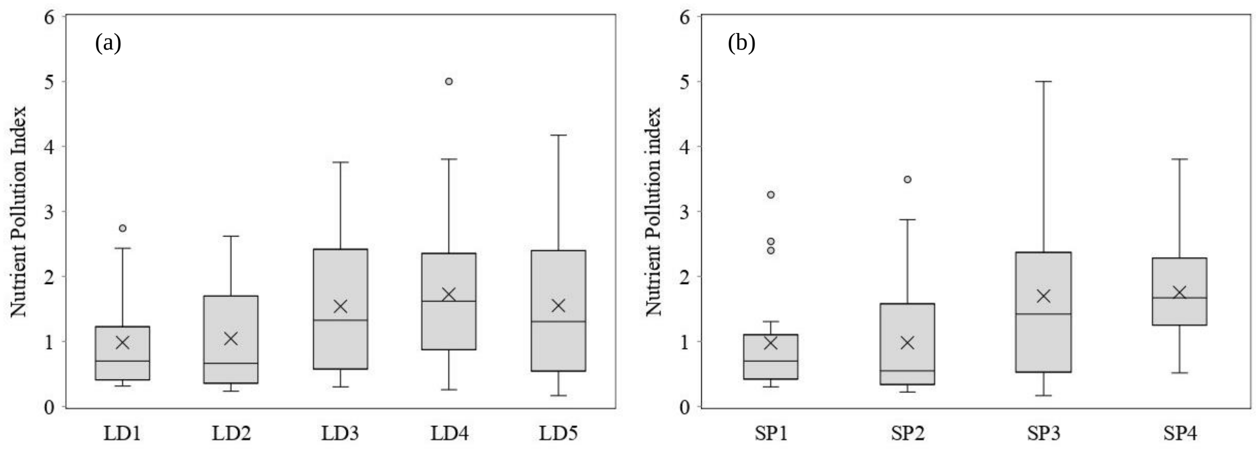

Figure 5. Box plot of nutrient pollution index (mean±stdev) based on (left) sampling stations (n=23) and (right) sampling periods (SP1: Apr-Jun 2021, SP2: Jul-Sep 2021, SP3: Jan-Mar 2022, SP4: Apr-Jun 2022) in Lake Danao, Ormoc City (n=30). NPI values: <1-no pollution; 1≤3-moderately polluted; >3≤6-considerably polluted; and >6-very highly polluted (Isiuku and Enyoh, 2020). LD-Sampling stations. SP-Sampling periods.

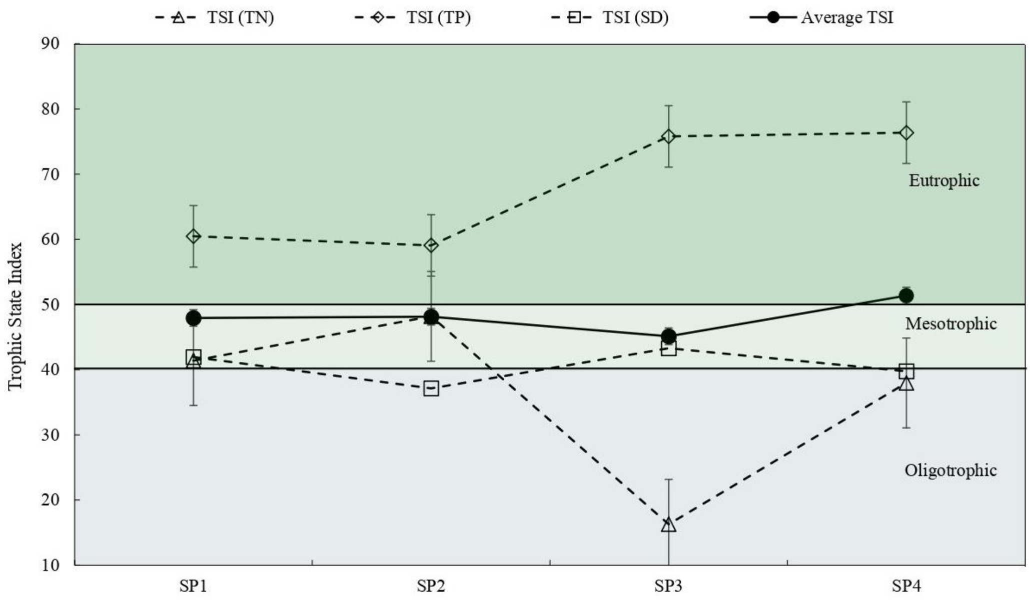

Figure 6. Trophic State Index (mean±stdev) fluctuations using three limnological parameters (TN: Total nitrogen, TP: Total phosphorus, SD: Secchi disk depth) in Lake Danao, Ormoc City (A) sampling stations (n=12) and (B) sampling periods (SP1: Apr-Jun 2021, SP2: Jul-Sep 2021, SP3: Jan-Mar 2022, SP4: Apr-Jun 2022) in Lake Danao, Ormoc City (n=30). SP-Sampling periods.

4. DISCUSSION

This study reports the spatial and temporal variations of nutrients and coliforms in the waters of Lake Danao, Ormoc City (Philippines), as well as an assessment of the lake's water quality and trophic status based on NPI and TSI values.

Data analysis showed that the water quality parameters measured in different areas of Lake Danao were not significantly different from each other, except for TC and FC. The calculated NPI values of the five sampling stations indicated that the waters in LD1 are "not polluted" but the other stations are "moderately polluted." Then based on the TSI, LD1 and LD2 are "mesotrophic" while LD3, LD4, and LD5 are "eutrophic." Even though tourism activities are abundant in LD1 and LD2, these locations are also near the stream outlet or Inawasan area, where nutrients can be flushed out of the lake quickly (Shaw et al., 2004). LD4 and LD5, on the other hand, are near agricultural lands.

On the other hand, the variability in terms of sampling periods is significant for all parameters, indicating that weather conditions, such as the amount of precipitation, are the main factors affecting the water quality of Lake Danao. The high TC and FC values measured in Lake Danao waters relative to Class A minimum standards are already an indication that the water is unsafe for direct consumption as pathogens may be present in the water. According to Bera (2022), TC and FC bacteria in freshwater ecosystems can drastically increase due to high levels of tourist disturbance coupled with the tourism industry, sewage, and household discharge from nearby residential areas, runoff, and local activities. TC estimates were found to be fluctuating and unpredictable across the five sampling sites since most coliforms are ubiquitous in nature and are cosmopolitan in habitat (Olstadt et al., 2007). Data from stations LD4 and LD5, where farming is common, indicates that runoff from these areas is the main cause of high TC levels, sometimes exceeding the DENR's maximum limit. For LD1, LD2, and LD3, these stations are far from the contamination source, and the bacteria are subjected to sedimentation, predation, dilution, and bacterial death before reaching these stations (Dan and Stone, 1991). In LD1 and LD2, higher water flow towards the stream outlet is likely to reduce TC levels, while minimal human activity at LD3 allows sedimentation to lower TC. However, FC levels were above the limit at all stations. The presence of fecal coliform in concentrations above the tolerable threshold in the lake water constitutes the presence of sewage contamination, which serves as an indicator that a potential health risk exists for individuals exposed to this water. Their presence is associated with pathogens that may cause severe illness, including typhoid fever, viral and bacterial gastroenteritis, and hepatitis when ingested. These bacteria have occurred in the ambient lake water because of the overflow of observed domestic waste and other nonpoint sources of human and animal waste (Staley, 2012).

When precipitation is low (SP1 and SP2), levels of nitrates, nitrites, and DO were high, while TC, FC, and phosphates were low. This coincides with the study of Liu et al. (2024), where rainfall increases nutrient input, particularly nitrogen, through stormwater runoff, which carries organic matter and pollutants into the reservoir. This nutrient influx promotes algal blooms, which, in turn, lower dissolved oxygen (DO) levels. Short-term rainfall periods lead to spikes in nutrient concentrations, while long-term rainfall dilutes the nutrients but still causes higher overall nutrient loads due to increased water volume entering the system (Liu et al., 2024). In all sampling periods, both nitrate and nitrite levels in Lake Danao were below the maximum allowable limit set by the DENR and USEPA. Common sources of nitrate that contaminate lakes include septic systems, animal feedlots, fertilizers, manure, industrial wastewater, sanitary landfills, and garbage dumps (Cooper and Monroe, 2021). The NPI value calculated during these sampling periods also indicates that Lake Danao is “not polluted,” thus the high levels of DO. The N/P values are also relatively close to the usually observed Redfield ratio.

On the other hand, during the sampling periods with high amounts of precipitation (SP3 and SP4), TC, FC, and phosphates were high, while levels of nitrates, nitrites, and DO were low, resulting in low values of N/P ratio. Low levels of nitrates and nitrites in SP3 and SP4 may be due to dilution effects, while the high levels of phosphates in the same sampling periods can be attributed to runoff from nearby residential areas, farmlands, and other anthropogenic activities (Sarpong et al., 2023). Based on the calculated NPI values, the lake became “moderately polluted” during these sampling periods. Similar results were reported by Isiuku and Enyoh (2020) when they compared the levels of nutrients in several water bodies in Nigeria during dry and wet seasons. High levels of P decrease DO, conditions that accelerate the loss of N through denitrification (Downing and McCauley, 1992; Zhang et al., 2018), which may explain the low levels of nitrates and nitrites detected.

Interactions between a lake’s physicochemical characteristics and primary productivity give a clear picture of the whole ecosystem’s food cycle (Dillon and Rigler, 1974; Dodson et al., 2000). Productivity can be quantified and described in terms of its nutrient, clarity, and, to some extent, chlorophyll content (Lewis, 2011). The study on Lake Tana by Sotomayor et al. (2024) reveals significant physicochemical characteristics, including varied physicochemical parameters and nutrient levels, which influence the lake’s overall productivity. High levels of chlorophyll-a indicate elevated primary productivity, predominantly driven by phytoplankton dynamics. The findings highlight the complex interplay between nutrient availability and physical conditions, which are critical for sustaining the lake’s ecosystem services. On the other hand, Liu et al. (2010) applied correlation and multiple regression analysis to their dataset and concluded that Secchi disk depths, phosphates, and nitrates were linked to TSI.

Changes in N/P ratios alter the trophic structure of water bodies (Zhang et al., 2018) as reflected by the component TSI for TN and TP. According to Downing and McCauley (1992), the value of the N/P ratio reflects the source of nutrients. Oligotrophic lakes have high N/P values since the nutrient sources are natural, and undisturbed ecosystems give more N than P. Mesotrophic and eutrophic lakes, meanwhile, have a low N/P ratio since the P-rich nutrient sources include runoff from surrounding residential, urban, and agricultural areas. In general, when the different parameters measured were considered in the computation of TSI, Lake Danao is classified as mesotrophic (Carlson, 1977), which suggests that the lake has an intermediate level of productivity and moderate levels of nutrients. It has relatively clear water, sufficient oxygen levels to sustain diverse aquatic life, and manageable algal growth. This trophic status is generally considered favorable for maintaining biodiversity and ecological stability (Bhateria and Jain, 2016). However, the rising phosphorus levels observed in the study could push the lake toward a eutrophic state, characterized by excessive nutrient enrichment. This transition can lead to increased algal blooms, reduced water clarity, oxygen depletion (particularly in deeper layers), and negative impacts on fish populations, water quality, and overall aquatic health (Liu et al., 2021).

Fink et al. (2018) reported that in the world’s 100 great lakes, P-stimulated eutrophication is high in developing countries and use of inorganic fertilizers is a major contributor. Fertilizers are a possible source of P in Lake Danao since several areas surrounding the lake have been converted into farmland. Animal manure, sewage, and detergents from nearby residential communities are other possible contributors. Phosphates are only moderately soluble and, unlike nitrates, are not very mobile in soil and groundwater. Phosphates tend to remain attached to soil particles, especially in lentic water ecosystems like lakes (Wurtsbaugh et al., 2019), which can explain the steady rise of phosphate levels since Feb 2022. The negative impacts of excess phosphate on lakes and eutrophication have been extensively studied. Unlike nitrates, moderate increases in P can trigger a series of undesirable events, such as algal blooms and low DO, resulting in the death of aquatic organisms (Smith, 2003; Schindler et al., 2006; Bhateria and Jain, 2016). This cascade of events can further lead to significant economic consequences such as loss of fisheries, reduced recreational activities, and increased costs for drinking water treatment due to the need for advanced filtration and removal of algal toxins (Dodds, 2006). In Lake Danao, the DO levels measured during the last sampling period were found to be below the permissible range (5-7 mg/L) set by the DENR for Class A waters.

The results of the water quality analysis proved that stations generally closer to agriculture and residential areas (LD4 and LD5) have relatively higher FC counts and eutrophic water quality status. Similar results were obtained by Tumanda et al. (2021) for Lake Mainit in Mindanao. High levels of FC and TC were observed in the sampling stations near the three populated areas around the lake. High levels of nutrients were also measured in sampling sites near agricultural and residential lands. Thus, management and policy interventions to address these concerns should be focused on these areas (Frei et al., 2021). These include promotion of sustainable agricultural practices and enforcement of wastewater management strategies for residential areas in accordance with the DENR guidelines to minimize coliform contamination and nutrient pollution (Withers et al., 2014). Examples include the establishment of riparian buffer zones with native vegetation around the lake to minimize nutrient runoff, as well as educating the residents of the nearby communities about the importance of proper waste disposal and the impacts of coliform contamination on the lake.

Continuous monitoring of physicochemical parameters, coliform, and heavy metals is also necessary to provide more reliable evidence for adaptive management strategies of Lake Danao in the future. The evidence of contaminants, specifically high levels of fecal coliform, highlights the urgent need for community education on waste management and stricter controls on agricultural runoff, providing actionable and relevant recommendations for policymakers to mitigate pollution and safeguard public health. The results of these recommendations can be used for proper tourism zoning, reclassification of water, and ensuring a shared responsibility among stakeholders, community members, and policymakers for the continuous improvement and maintenance of the lake water and ecosystem services.

In summary, variation across sampling periods was observed to be more significant than across sampling stations, except for TC and FC levels. Discharge from water runoff during periods of high precipitation was identified as a major factor for the increase or decrease of the metrics. The conditions and activities of the surrounding areas of the lake, such as tourism and agricultural activities, are possible sources of contamination. The observed high phosphate levels constitute a threat to Lake Danao's water quality. High levels of this nutrient can result in algal blooms leading to a decrease in DO levels, indicators of eutrophication. For further study, we recommend increasing sampling frequency, adding more sampling points (for better spatial and temporal representation), and expanding the parameters to include heavy metals or emerging pollutants. This more comprehensive assessment would provide valuable insights into the lake's water quality. Finally, conducting three years of continuous monitoring is also recommended to reevaluate the lake's classification and better understand long-term trends and seasonal variations.

5. CONCLUSION

Lake Danao is classified by the Philippine government as a Class A water body; however, this study reports that there are some parameters that are beyond the maximum allowable limits set by the DENR. FC was consistently recorded to be beyond the permissible levels, indicating high amounts of pathogens in the water. This study recommends reviewing the reclassification of Lake Danao from Class A to Class B. Data analysis revealed significant variability in terms of sampling periods for all parameters, except for TC and FC, indicating that weather conditions, such as the amount of precipitation, are the main factor affecting the water quality of Lake Danao. Based on the NPI, most sampling stations in Lake Danao are "moderately polluted," especially when the amount of precipitation is high. Moreover, the calculated TSI value indicates that Lake Danao's trophic status is "mesotrophic," but the high levels of phosphates obtained mean that the lake is also at risk of eutrophication. Early signs of this were observed in some locations. Therefore, regular monitoring of Lake Danao water quality is imperative to ensure the maintenance, protection, and responsible use of the protected upland lake.

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AUTHOR CONTRIBUTIONS

All authors were involved in the conception and design of the study and carried out the material preparation, data collection, and analysis. All authors provided feedback on earlier drafts. Each author has reviewed and approved the final version of the manuscript.

DECLARATION OF COMPETING INTERESTS

The authors affirm that there are no competing interests regarding the research presented in this manuscript. Any sources of funding and relevant relationships have been transparently disclosed, and no financial or personal factors have influenced the study.

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