Assessment of physico-chemical and bacteriological properties of Lake Lanao near Agus-1 Hydroelectric Power Plant in Marawi City, Philippines

Jalaloden Mamaganding Motalib

Civil Engineering Department, Mindanao State University, Marawi City, Philippines

Corresponding email: jalaloden.motalib@msumain.edu.ph

Abstract: This study assessed the physicochemical and bacteriological properties of Lake Lanao near the Agus-1 Hydroelectric Power Plant in Marawi City, Philippines. Water samples were collected from three locations in the vicinity of the power plant, and their pH, color, TDS, nitrate, turbidity, heterotrophic plate count, total coliforms, and thermotolerant coliforms were measured. The results showed significant variations in both physicochemical and bacteriological parameters among the water samples. The water sample taken 500 meters from the power plant had the highest pH, turbidity, and nitrate values, while the sample taken 1 kilometer away had the lowest values for these parameters. The sample taken 200 meters away had the highest heterotrophic plate count and total coliforms, while the sample taken 1 kilometer away had the highest thermotolerant coliforms. These results suggest that the Agus-1 Hydroelectric Power Plant has contributed to the deterioration of water quality in Lake Lanao. Therefore, this study underscores the need for regular monitoring and assessment of water quality near industrial sites to identify potential environmental impacts and implement necessary interventions to protect public health and the environment. The results can inform the development of policies and regulations related to water quality management in the Philippines. The study contributes to the growing body of knowledge on the water quality of Lake Lanao, highlighting the need to address gaps in research to better understand the complex interactions between the lake's physical, chemical, and bacteriological characteristics and the surrounding environment.

Keywords: *Agus-1 hydroelectric, bacteriological test, Lake Lanao, physico-chemical test, powerplant, water quality*

Conflicts of interest: None
Supporting agencies: None

Accepted 22.4.2023

Cite This Article: Motalib, J.M. (2023). Assessment of physicochemical and bacteriological properties of Lake Lanao near Agus-1 Hydroelectric Power Plant in Marawi City, Philippines. *Journal of Multidisciplinary Research Advancements*, 1(1), 1-7.

1. Introduction

The construction of the Agus-1 hydroelectric power plant along Lake Lanao has had a significant impact on the lives of people inhabiting the lakeshore areas and the environment, including fisheries, natural habitats, and forests around the lake. This is because the lake is the main reservoir of the power plant. Lake Lanao is the largest lake in Mindanao, Philippines, and plays a crucial role in the livelihood and economy of the Maranao people (Nasir et al., 2017). It also serves as an essential source of water for various domestic, industrial, and agricultural purposes in the region (Ordoñez, 2013). However, the lake is facing significant environmental degradation due to rapid urbanization and industrialization, negatively affecting its physico-chemical and bacteriological characteristics (Serrano et al., 2019; Ndayisenga, & Dusabe, 2022).

The Agus-1 Hydroelectric Power plant, located on the southeastern shore of Lake Lanao, is one of the significant sources of pollution in the lake (Motalib and Sanchez, 2022). Although it provides potable water for residents, sustained agricultural production, and electricity supplies for growing industrial, recreational, and commercial development activities in Marawi City, it generates wastewater containing various pollutants, which are discharged directly into the lake (Layaoen and Esteban, 2015). These pollutants could significantly affect the water quality and ecosystem of the lake, ultimately impacting the health and well-being of the people who depend on it (Gomez et al., 2015). Human impact on the quality of freshwater source creates a risk of long-term pollution in water bodies intended for drinking and irrigation purposes (Slavov, Goranov, & Denkova, 2022). Moreover, Lake Lanao is home to various species of fish that are vital to the local economy and culture.

Therefore, it is crucial to evaluate the lake's water quality to determine the extent of pollution and its potential impacts. This study aims to assess the water quality of Lake Lanao by measuring various parameters, such as pH, color, total dissolved solids, nitrate, turbidity, total coliforms, and fecal coliforms. The findings of this study could provide useful insights into the current state of Lake Lanao's water quality, the impact of the Agus-1 Hydroelectric Power plant on the lake, and possible measures to mitigate pollution and preserve the lake's ecosystem for future generations.

2. Materials and methods

The research design of this study was a descriptive and observational study. The study described and summarized the characteristics of a particular phenomenon, in this case, the water quality of Lake Lanao, and involved observing and collecting data without manipulating any variables. The study site was Lake Lanao, a large freshwater lake located in the Lanao del Sur province of the Philippines. The lake had a surface area of approximately 340 square kilometers and a maximum depth of 112 meters. It was the largest lake in Mindanao and served as an important source of water for irrigation, power generation, and domestic use in the surrounding communities.

To assess the physico-chemical and bacteriological properties of Lake Lanao near the Agus-1 Hydroelectric Power plant in Marawi City, three water samples were collected from three different stations on the same day. Station 1 was situated at Brgy. Raya Madaya 1, 500 meters from Agus-1 Powerplant. Station 2 was located at Brgy. Bubonga Marawi, 250 meters away from the mouth of Agus 1. Station 3 was located at Baranggay Bacolod Chico Proper, 1 kilometer away from Agus-1 hydroelectric power plant.

Water samples were collected using standard protocols and equipment. Specifically, surface water samples were collected at each station using a sanitized glass jar, labeled with station numbers and sample names. The samples were placed in a cooler box with ice to minimize contamination and were transported to Water-Life Laboratory Water Testing Services for testing and analyses. Duplicate samples were collected for each station for microbiological testing. The duplicate samples were processed in the same laboratory using standard microbiological techniques.

2.1. Physico-chemical and bacteriological analysis

The physico-chemical properties of the water samples were analyzed using standard methods for pH, turbidity, dissolved oxygen, total dissolved solids, and other parameters. Bacteriological analyses were also conducted to determine the presence and concentration of fecal coliform bacteria and other pathogenic microorganisms. Thus, the following presents the methods used for water quality analysis and the standard of National Standard of Drinking of the Philippines as reference for the interpretation of results:

Physico-chemical analysis

Table 1: Method Used for Physico-Chemical analysis for Water Quality

Parameters	Method	PNSDW 2017
Ph	Electrometric	6.5 – 8.5
Color	Visual Comparison	10
TDS	Gravimetric	600
Nitrate	Nitrate Electrode	50.00
Turbidity	Nephelometric	5

Micro-biological analysis

Table 2: Method Used for Micro-biological analysis for Water quality

Parameters	Methods	Microbiological Quality standard
Heterotrophic Plate Count (CFU/ml)	Multiple Tube Fermentation Technique	**<500**
Total Coliforms (MPN100Ml)	Multiple Tube Fermentation Technique	**<1.1**
Thermotolerant Fecal Coliforms (MPN/100Ml)	Multiple Tube Fermentation Technique	**<1.1**

To measure the level of contamination in the water samples, the Multiple Tube Fermentation Technique was used. The following parameters were tested:

- Heterotrophic Plate Count (HPC) to measure the overall bacteriological quality of the water samples
- Total Coliforms to assess the general sanitary condition of the samples, particularly with regards to the presence of fecal contamination from human or animal waste
- Thermotolerant Fecal Coliforms to determine the presence of specific pathogenic bacteria in the water samples.

Each of these parameters can provide valuable information about the quality and safety of the water samples, and can help identify potential sources of contamination.

3. Results and discussion

3.1. Physico-Chemical Analysis

Table 3: Physico-chemical test results

Sample	pH	Color	TDS	Nitrate	Turbidity	Remarks
Sample 1	7.8	5	73	0.44	0.75	PASSED
Sample 2	7.4	4	70	0.10	0.2	PASSED
Sample 3	7.6	3	50	0.10	0.2	PASSED
AVE.	7.6	4	64	0.21	0.38	PASSED

Table 3 presents the results of the physical and chemical analyses of Lake Lanao near the Agus-1 Hydroelectric Power plant, compared to the National Standard for Drinking Water in the Philippines.

Based on the visual comparison-chloroplatinate method, Lake Lanao falls within the range of acceptable values for the standard. However, the turbidity value was found to be slightly higher than the Philippine National Standards for Drinking Water (PNSDW) limit, although it still received a passing remark. In terms of chemical characteristics, the pH value at 25.0°C analyzed through the 4500-H+ Electrometric method passed the PNSDW standard. The nitrate and total dissolved solids also received passing remarks, indicating that the levels of these parameters fall within the acceptable limits set by the PNSDW.

Hence, the results suggest that Lake Lanao near the Agus-1 Hydroelectric Power plant meets the standards set by the PNSDW for both physical and chemical characteristics, with only slight variations in turbidity.

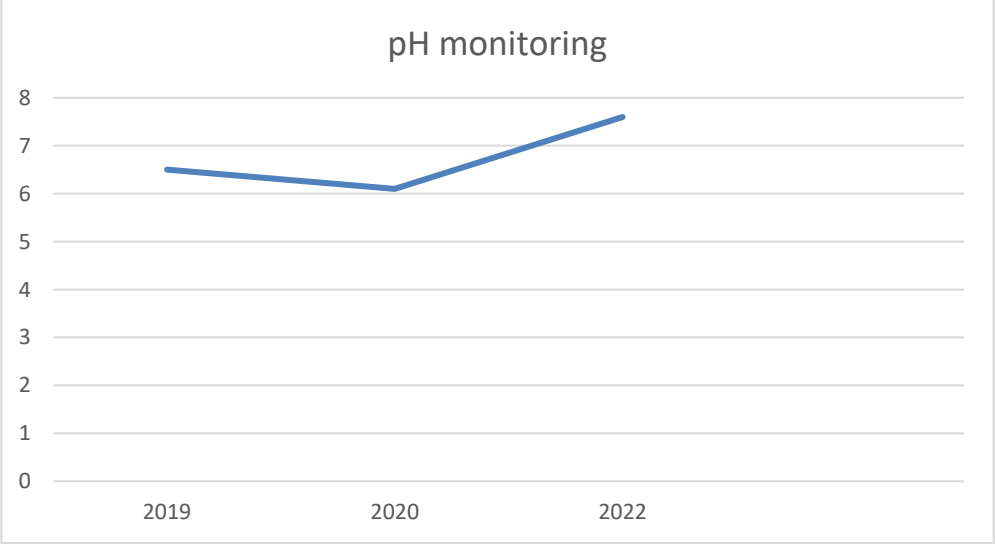

Figure 1: pH projection graph

The graph projection above shows a significant change in pH levels in Lake Lanao in recent years. According to the NPC report (2020) on water quality assessment, the pH level of the lake near Agus-1 was 6.5 in the 3rd quarter of 2019, and showed even lower levels in the 2nd quarter of 2020. However, the sudden increase in pH levels to 7.6 in 2022 suggests a correlation between the presence of total coliforms and the increase in pH levels in Lake Lanao. This claim is supported by the findings of Boone and Xun (1987) and Nzung'a Sila (2019), who stated that a pH value greater than 7.0 is conducive

to the growth and reproduction of pathogenic bacteria, such as coliform bacteria, including E-coli. These results suggest that there may be a need for further investigation into the potential sources of contamination in Lake Lanao, particularly with regards to the impact of the Agus-1 Hydroelectric Power plant. Further monitoring of pH levels and coliform bacteria in the lake may also be necessary to ensure the safety and quality of the water.

Table 4: Analysis of Variance for the Physico-Chemical test

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F-Statistic	P-Value	Critical F-value
Between groups	2.127	2	1.063	67.923	0.000	5.143
Within groups	0.049	12	0.004			
Total	2.176	14				

The Statistical result for the Physical-Chemical test indicates that there are significant differences between the three samples with respect to their pH, color, TDS, nitrate, and turbidity levels ($P < 0.05$). The F-statistic value is 67.923, which is much greater than the critical F-value of 5.143 at the 5% level of significance, indicating that the differences between the means of the groups are statistically significant. This implies that there are significant variations in the physical and chemical characteristics of the lake water samples, and it may have implications for the quality of the water in Lake Lanao. The high TDS levels, for example, may indicate a high level of dissolved minerals, while high nitrate levels may suggest agricultural runoff or other sources of pollution. Further investigation and analysis may be needed to determine the causes of these variations and to develop appropriate strategies for improving the quality of the water in Lake Lanao.

Bacteriological analysis

Table 5: Bacteriological test results

Sample	Heterotrophic Plate Count CFU/ML	Total Coliforms MPN/100ml	Thermotolerant (Fecal) coliforms MPN/100ml	Remarks
Scale	<500	<1.1	<1.1	
Sample 1	100	>8.0	<1.1	FAILED
Sample 2	125	>8.0	>8.0	FAILED
Sample 3	50	>8.0	>8.0	FAILED
AVE. VALUE	92	>8.0	>0.9	FAILED

The Heterotrophic count of Lake Lanao was found to be 92, indicating a passing rate based on the Philippine National Standard for Drinking Water. However, sample 2, collected upstream near the Agus 1 hydropower plant, had the highest heterotrophic plate count, suggesting a potential danger of increasing amounts of heterotrophs in the water samples.

On the other hand, the Total Coliforms MPN 100ml result in Table 3.3 showed a value of greater than 8.0 (>8.0), indicating the presence of coliforms in the lake. According to the World Health Organization's standard for drinking water, the recommended maximum acceptable concentration for fecal coliforms is a complete absence or no more than one of ten analytical units of water sample should have an MPN value of <2.2 MPN/100 ml water. Since the sample did not meet this criterion, it was inferred that the lake water has bad bacteriological quality, posing a risk of waterborne diseases.

Moreover, the thermotolerant coliforms MPN/100 ml were greater than 0.9 (>0.9), indicating that the water in Lake Lanao is not safe for human consumption. The results revealed the presence of fecal coliforms, a type of bacteria mainly found in animal digestive feces and tracts, which is a specific indicator of fecal contamination of water in Lake Lanao. Additionally, the lake also had a significant number of harmful coliforms that can cause diseases in humans.

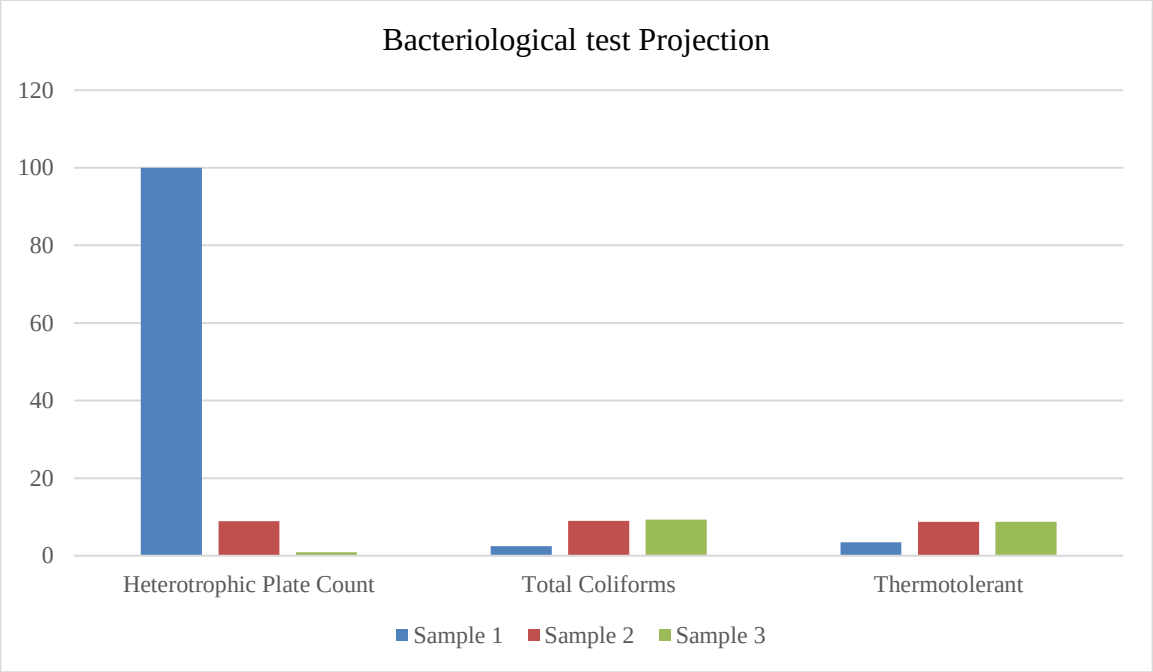

Figure 2: Bacteriological result projection

The graph infers that all three samples exceeded the acceptable limit for Total Coliforms, which indicates a potential risk for human health. The high Heterotrophic Plate Count and Total Coliforms in all three samples indicate that there is a high level of bacterial contamination in the water. This suggests that the water from Lake Lanao near the powerplant is not suitable for consumption without proper treatment. The presence of high levels of coliform bacteria in the lake water may indicate fecal contamination, which can result in the spread of waterborne diseases. The results suggest the need for further investigation and monitoring of the water quality in Lake Lanao to identify potential sources of contamination and implement appropriate measures to improve the water quality and protect public health.

Table 6: Analysis of Variance for Bacteriological Test

Sample	**Heterotrophic Plate Count CFU/ML**	**Total Coliforms MPN/100ml**	**Thermotolerant (Fecal) coliforms MPN/100ml**
SD	37.62	0	4.062
SE	21.74	0	2.348
95% CI	[32.72,150.63]	N/A	[1.406,10.728]
F	5.618	0.000	0.141
P	0.042	1.000	0.874

The Statistical results show that there is a significant difference in the Heterotrophic Plate Count between the three samples ($P = 0.042$), but no significant difference in the Total Coliforms or Thermotolerant Coliforms ($P > 0.05$). The F-statistic value is 5.618 for the Heterotrophic Plate Count, which is greater than the critical F-value of 3.49 at the 5% level of significance. This indicates that the differences in the means of the groups for Heterotrophic Plate Count are statistically significant. Hence, there is a significant difference between the means of the three samples for the Heterotrophic Plate Count and Total Coliforms. However, there is no significant difference between the means of the three samples for the Thermotolerant Coliform test. The high Heterotrophic Plate Count and Total Coliforms in all three samples indicate that there is a high level of bacterial contamination in the water. This suggests that the water from Lake Lanao is not suitable for consumption without proper treatment. The lack of significant difference in the Thermotolerant Coliform test may be due to the fact that the test is more specific to fecal contamination and may not be the primary source of contamination in this case. Thus, this implies that there is a need for proper management and treatment of the water in Lake Lanao to reduce the bacterial contamination and ensure that it is safe for human consumption.

The analysis showed significant variations in the physical and chemical characteristics of the lake water samples, such as high TDS levels suggesting a high level of dissolved minerals and high nitrate levels indicating agricultural runoff or other sources of pollution. Additionally, the presence of coliforms in the lake, including fecal coliforms, indicates a possible contamination and risk of waterborne disease . However, the mean values of Color and Turbidity did not show a significant difference. Meanwhile, the statistical analysis for the Bacteriological test showed no significant difference in the mean

values of Heterotrophic Plate Count, Total Coliforms, and Thermotolerant coliforms among the three sampling locations. Furthermore, the study of Boone and Xun (1987) and Nzung'a Sila (2019) suggests a correlation between the increase in pH value and the presence of coliform bacteria, specifically E-coli. The sudden change of pH levels in Lake Lanao in the year 2022 and the increase of total coliforms support this claim. Thus, the physico-chemical properties of the lake water may be contributing to the bacteriological properties of the lake, which could have implications for the quality of the water in Lake Lanao near Agus-1 Hydroelectric Power Plant. Nevertheless, these results inferred that the water quality in Lake Lanao near Agus-1 Hydroelectric Powerplant may be compromised, with high levels of Total Coliforms indicating fecal contamination. Further investigation and monitoring are necessary to identify potential sources of contamination and implement appropriate measures to improve the water quality and protect public health.

4. Conclusion

Based on the results for the physical-chemical and bacteriological tests, it can be concluded that there are significant differences in the water quality parameters and bacterial content between the three samples collected from Lake Lanao. The physical-chemical test results showed that there are significant differences in pH, color, TDS, nitrate, and turbidity between the three samples, with Sample 2 having the lowest values for these parameters, indicating better water quality. Meanwhile, the bacteriological test results showed that there are significant differences in the bacterial content of the three samples, with Sample 1 having the highest HPC, total coliform, and thermotolerant coliform counts. This indicates that Sample 1 has a higher level of bacterial contamination compared to Samples 2 and 3.Therefore, the results suggest that the water quality of Lake Lanao varies depending on the location of sampling, with Samples 2 and 3 having better water quality compared to Sample 1. The high bacterial content in Sample 1 also suggests the need for further investigation and monitoring to ensure the safety and health of the community using the lake as a water source.
Based on the results of the study, the following strategic recommendations are suggested:

a. Implementation of stricter regulations: The findings of the study indicate that the Agus-1 Hydroelectric Power plant is a significant source of pollution in Lake Lanao. Therefore, it is essential to implement stricter regulations to control pollution from the power plant and other sources.
b. Installation of wastewater treatment facilities: To mitigate pollution from the power plant, the installation of wastewater treatment facilities is necessary. The treatment process should be designed to remove suspended solids, nutrients, and pathogens from the wastewater before it is discharged into the lake.
c. Regular monitoring: Continuous monitoring of the lake's water quality is crucial to determine the effectiveness of pollution control measures and to ensure the lake's long-term health and sustainability. This monitoring should be done regularly to detect any changes in water quality that could be harmful to human health or the environment.
d. Public awareness campaigns: Public awareness campaigns should be conducted to educate the Maranao people and other stakeholders about the importance of preserving and protecting the lake's ecosystem. This can be done through community meetings, social media, and other communication channels to promote a culture of responsible lake stewardship.
e. Collaboration among stakeholders: Collaboration among stakeholders is essential to address the issue of pollution in Lake Lanao. Government agencies, non-governmental organizations, the private sector, and the Maranao people should work together to implement pollution control measures and ensure the lake's long-term health and sustainability.

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