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Nutrient Concentration, Water Brightness, Chlorophyll-a, and Phytoplankton Abundance as Indicators for Determining the Trophic Status of Lake Toba, North Sumatera - Indonesia

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Water quality, Phytoplankton abundance, Trophic status, Lake Toba

Abstract

The purpose of this study was to investigate the water quality and phytoplankton abundance in Lake Toba to determine its trophic status. This research was conducted from January to March 2024 at four stations in Lake Toba. Water samples were taken using a UWITEC water sampler and a plankton net and brought to the laboratory for analysis. The study measured physical and chemical water quality and phytoplankton abundance. The results showed a brightness ranging between 5.8 and 6.3 meters, chlorophyll-a content <10 μg/L, total nitrogen <750 μg/L, and phosphorus ranging from 20 μg/L to 30 μg/L. Based on these parameters, the nutrient quality of Lake Toba was classified as mesotrophic. Phytoplankton abundance ranged from 22,514 to 33,475 individuals/L, with 33 genera identified across nine classes: Bacillariophyceae, Chlorophyceae, Cyanophyceae, Coscinodiscophyceae, Dinophyceae, Euglenida, Fragilariophyceae, Mediophyceae, and Zygnemophyceae. The diversity index (H') was 2.631 - 2.723, the uniformity index (E) was 0.828 - 0.872, and the percentage of blue-green algae was 14.75 - 20.85. Zygnemophyceae was the most dominant phytoplankton class, with *Staurastrum sp.* being the most prevalent species. In conclusion, Lake Toba's waters are categorized as mesotrophic based on the chemical parameters and as eutrophic based on phytoplankton abundance, indicating potential nutrient enrichment issues that warrant further investigation.

INTRODUCTION

Lake monitoring has become an important part of lake management due to the increasing human population and the threat of pollution from various activities. Lake Toba is located in the northern part of the volcanic Barisan Mountains and crosses Sumatra Island from northwest to southeast. The lake is surrounded by sheer cliffs 400 - 1,200 m high. Based on topographic features and volcanic eruptions around the lake, some geologists and volcanologists consider it a caldera or giant cauldron (ILEC, 2024).

Maintaining the long-term economic and environmental value of Lake Toba

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depends on addressing water quality degradation. The acceleration of water quality degradation since the mid-1990s has been driven by excessive nutrient additions resulting in algae blooms, large fish kills, and health concerns. As one of the world's deepest volcanic tectonic lakes, water quality management in Lake Toba is further constrained by an 80-year residence time (i.e., the time required to replace water) and inhomogeneous mixing that results in compartmentalized lake water (World Bank Group, 2019).

The water quality of Lake Toba is a major key to the sustainability of all activities in the lake. Monitoring water quality parameters and phytoplankton abundance is important in determining the trophic status of the lake as an indicator of the state of the environment and the load it can accommodate. Determining the trophic status of the lake by PermenLH No 28 of 2009 (Table 1) describes each range for the parameters total Nitrogen (μg/l), total P (μg/l), Chlorophyll a (μg/l) and water brightness (m).

Estimating trophic status based on phytoplankton abundance is guided by Landner and Reuther (2005). Oligotrophic waters are waters of low fertility with phytoplankton abundance ranging from 0 - 2000 ind/l, Mesotrophic waters are waters of medium fertility with phytoplankton abundance ranging from 2000 – 15.000 ind/l, Eutrophic waters are waters of high fertility with phytoplankton abundance ranging from > 15.000 ind/l. Phytoplankton. Most primary producers in waterbodies perform photosynthesis which is the basis of the food chain for marine life and river waters. Phytoplankton is also one of the parameters indicating the fertility level of a water body (Sunarto, 2008; Yuliana *et al*., 2012).

Changes in water quality can be seen from the abundance and composition of phytoplankton in these waters (Wijaya and Hariyati, 2011). Phytoplankton is a biological parameter that can be used as an indicator to evaluate the quality and fertility of a water body (bioindicator) (Yuliana *et al*., 2012). Polluted waters cause changes in the structure of the plankton community, especially in abundance and species diversity. Changes in abundance and number of species can be used as indicators of water fertility in the region, as a result of changes in environmental conditions (Fajrina *et al.*, 2013).

An algal bloom is another term for an algal explosion. An algal bloom is an event or condition where a water body, swamp, experiences a large plankton population explosion. The occurrence of algal blooms is the presence of excess nutrients contained in the water. The disposal of waste containing a lot of phosphate into waters such as domestic waste can also be an additional factor to algae blooms. Increasing phosphate levels in a water body will trigger rapid growth and development of algae. The overwhelming number of algae can result in mortalities in a variety of Aquatic life. These mortalities can occur due to exposure to toxins that come from the excretion of algae. Algal blooms will certainly produce a lot of toxins as well. If allowed to drag on, this will certainly cause mortalities to various types of aquatic organisms.

The parameters of total nitrogen, total phosphate, chlorophyll a, water brightness, and phytoplankton abundance can clearly describe the trophic status of a water body as a reference for determining future policy. The purpose of this research is to make a study for water quality parameters and determine the trophic status of Lake Toba. This is to complete the Lake Toba water quality data series and update the trophic status. The result can be a recommendation to the government and stakeholders in making policies related to the management and utilization of Lake Toba.

METHODOLOGY
Ethical Approval

There is no animal used in this research. Ethical approval for handling animals is not required. The samples refer to water from Lake Toba.

Place and Time

Sampling was carried out at 4 sampling stations namely Pangambatan,

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Lontung, Pangambatan areas located in the Samosir district of Lake Toba and Sirungkungon located in Toba district, North Sumatra, Indonesia. The study was conducted from January to March 2024. Sampling and testing of water quality was carried out every month while sampling and testing of phytoplankton was carried out in March 2024.

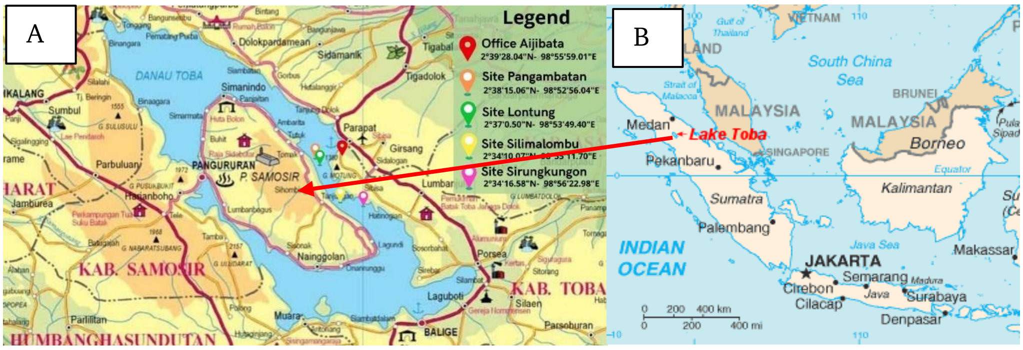

Figure 1. Sampling location (a); Lake Toba area (b).

Research Materials

In situ measurements were carried out for chlorophyll-a and water brightness parameters. Chlorophyll-a testing was performed using the Aquafluor Turner Designs fluorometer (Sunnyvale, CA, USA) to measure chlorophyll/turbidity. Water brightness was measured using a white/black Secchi disk plate from Regal Springs Indonesia equipment. Data recording was done in the field, ensuring accurate and immediate capture of measurements before collecting phytoplankton and water samples.

Water samples were collected using a 5-liter UWITEC water sampler and kept cool in a cool box during transport. Phytoplankton was collected using a HYDRO-BIOS KIEL plankton net with a 55 μm mesh size. Phytoplankton samples were transported to the laboratory with the addition of 2 ml of 1% Lugol solution per 30 ml extracted sample and sent to Shafera Enviro Laboratory in Medan, North Sumatra, Indonesia, for analysis. Phosphorus analysis was carried out using a Phosphate cell test, and nitrogen analysis was performed using a Nitrogen cell test from Merck KGaA, Germany.

Table 1. Parameters and equipment.

Testing	Equipment	Unit
Chlorophyll-a	Aquafluor Turner designs	μg/I
Water brightness	Secchi disk plate	Meter
Water samples collected	UWITEC water sampler	Liter
Phytoplankton	HYDRO-BIOS KIEL	-
Phosphate cell test	Merck KGaA Germany	mg/I
Nitrogen cell test	Merck KGaA Germany	mg/I

Research Design

The research design was a quantitative descriptive approach with the data collection in situ from the sampling location using purposive sampling and sample transport and testing on Laboratory Regal Springs Indonesia in Ajibata, North Sumatra, Indonesia, and Shafera Enviro Laboratory in Medan, North Sumatra, Indonesia.

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Table 2. Parameters and equipment.

Trophic States	Average total Nitrogen (N) levels (mg/l)	Average total Phosphat (P) levels (mg/l)	Average total Chlorophyll-a levels (µg/l)	Average Brightness (m)
Oligotrophic	≤ 650	< 10	< 2.0	≥ 10
Mesotrophic	≤ 750	< 30	< 5.0	≥ 4
Eutrophic	≤ 1900	< 100	< 15	≥ 2.5
Hypereutrophic	> 1900	≥ 100	≥ 200	< 2.5

Source: KLH (2009).

Work Procedure

Water sampling at 4 stations was collected using a UWITEC water sampler with a volume of 5 liters from a depth of 2 m 3 times per sampling location. Water samples were stored in a cool box and transported to the Regal Springs Indonesia water quality laboratory located in Ajibata, Toba Regency, North Sumatra, Indonesia. Samples were tested for total nitrogen and total phosphate Phytoplankton was collected using a plankton net with a mesh size of 0.55 µm.

The extracted sample was added with 1 % Lugol solution and brought to the Shafera laboratory for Phytoplankton analysis. The test results were transferred into an Excel file to be analyzed and compared with the reference standard for each parameter.

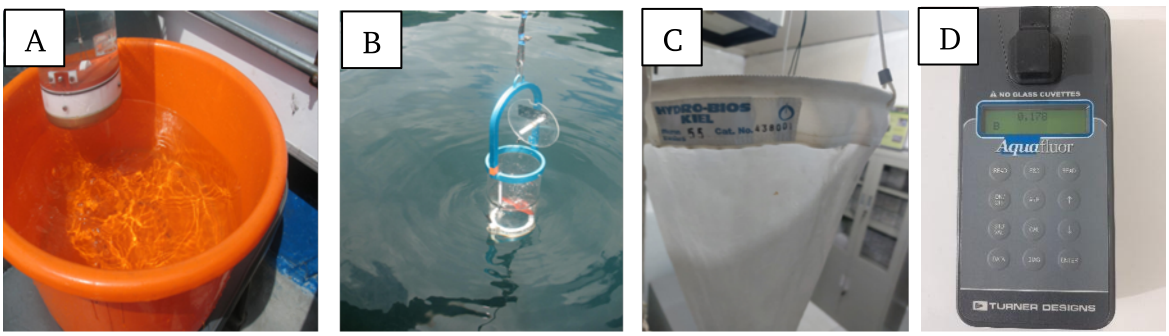

Figure 2. Sampling water and phytoplankton; a. sampling water sampler; b. water sampler; c. phytoplankton net; d. Aquafluor.

Data Analysis

Data that has been obtained is analyzed with MS. Excel 2017. The method used in this data analysis is a descriptive statistical test by measuring data centers such as mean value, standard deviation, etc.

RESULTS AND DISCUSSIONS

Table 3. Water quality testing results based on sampling location.

Parameters	January				February				March				Average Water Quality	StD
	LTG	NGB	SLM	RKG	LTG	NGB	SLM	RKG	LTG	NGB	SLM	RKG		
Water Brightness (m)	5.75	5.85	5.75	5.75	6.05	6.65	6.25	6.35	5.95	6.05	5.75	6.05	6.02	0.284
Phosphat (P) levels (mg/l)	0.02	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.007
Chlorofil-a levels (µg/l)	0.29	0.30	0.16	0.19	0.23	0.24	0.23	0.33	0.14	0.15	0.22	0.08	0.21	0.071
Nitrogen (N) levels (mg/l)	1.00	0.10	0.60	1.30	1.00	0.10	0.60	1.30	1.00	1.20	0.20	0.60	0.75	0.448

The results of the water brightness test (Table 3) show that the average water quality of the four sampling stations' monthly measurements was lowest in January and best in February. Water brightness is in the range of 5.75 m to 6.65 m with an average

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value of 5.78 m in January, 6.33 m in February, and 5.95 m in March. Based on the trophic status criteria that refer to the Minister of Environment Regulation No. 28 of 2009 concerning the capacity to accommodate the pollution load of lakes and/or reservoirs, the water brightness parameter meets the criteria for mesotrophic status.

Table 4. Average of sampling.

Sampling Location	Average of Testing Results			
	Water Brightness (m)	Chlorophyll-a (µg/l)	Phosphate (mg/l)	Nitrogen (mg/l)
Lontung	5.92	0.22	0.03	1.00
Pangambatan	6.18	0.23	0.02	0.47
Silimalombu	5.92	0.20	0.03	0.47
Sirungkungon	6.05	0.20	0.02	1.07

The results of testing the Chlorophyll-a (Table 4) show the average value is below 2 µg/l which means it meets the criteria for oligotrophic status. Low chlorophyll-a concentrations in oligotrophic lakes lead to nutrient limitation, high dissolved oxygen levels, reduced predation pressure, and better overall water quality, which collectively support a diverse and healthy aquatic ecosystem. The total Phosphate (Table 3) shows a value of 0.02 mg/l to 0.03 mg/l or equivalent with 20 µ/l and 30 µ/l which meets the criteria for mesotrophic status.

The total Nitrogen (Table 4) parameter shows an average value of 0.75 mg/l which meets the criteria for mesotrophic status. Phosphate levels in mesotrophic lakes are moderate. This supports a moderate growth of algae and other photosynthetic organisms, leading to moderate chlorophyll-a levels and water clarity. Overall, moderate phosphate concentrations support a healthy and diverse aquatic ecosystem in mesotrophic lakes (Trowbridge, 2009). Phytoplankton abundance ranges from 22,514 to 33,475 Individuals/L.

The nutrient levels in these lakes foster a diverse range of aquatic life, including salmonid fish species, as well as a variety of macrophytes and macroinvertebrates. Regular monitoring of phosphate and phosphorus levels, along with other water quality parameters, is crucial to ensure the lake conditions remain balanced and to prevent excessive nutrient inputs that could lead to eutrophication (Pujiastuti *et al.,* 2021).

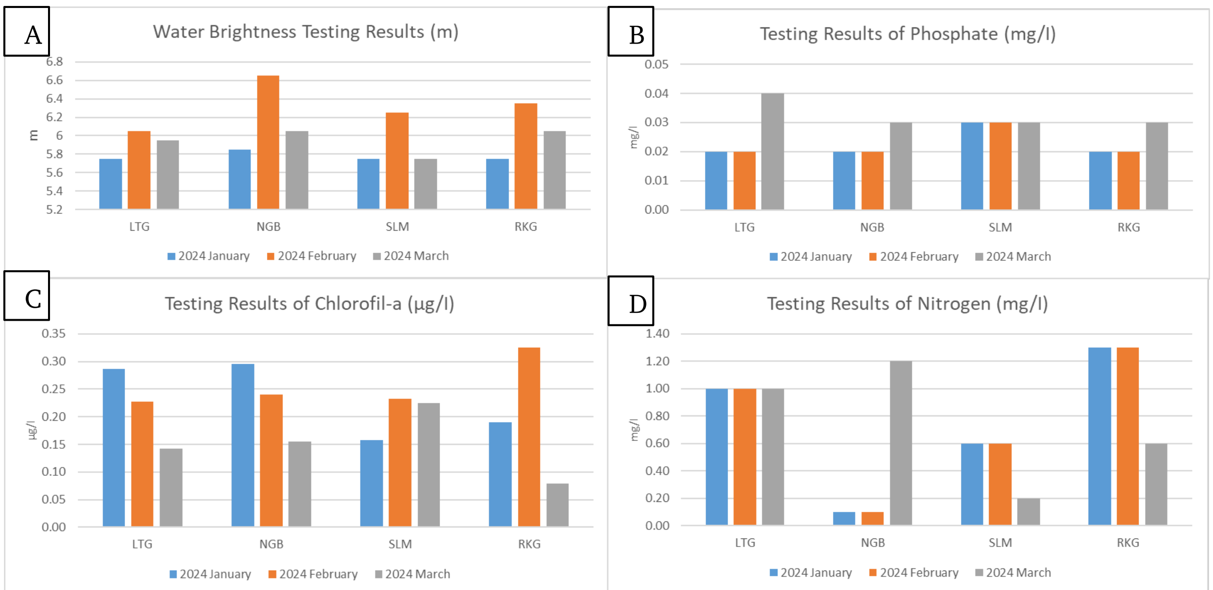

Figure 3. Diagram water testing, a. Water brightness testing result; b. Phosphate testing result; c. Chlorophyll-a testing result; d. Nitrogen testing result.

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The highest abundance was found in the Sirungkungon location with 25 taxa followed by the Silimalombu, Pangambatan, and Lontung locations. Phytoplankton composition consists of 33 genera and 9 classes namely Bacillariophyceae, Chlorophyceae, Cyanophyceae, Coscinodiscophyceae, Dinophyceae, Euglenida, Fragilariophyceae, Mediophyceae, Zygnemophyceae.

The diversity index (H') is 2.631 - 2723, the uniformity index (E) is 0.828 - 0.872 and the percentage of blue-green algae is 14.75 - 20.85. Zygnemophyceae is the dominant phytoplankton class based on abundance and is dominated by *Staurastrum* sp. Based on the level of phytoplankton abundance, Lake Toba waters are categorized as a eutrophic lake with an abundance of > 15.000 ind/l.

Table 4. Phytoplankton test results.

Taxa	Project			
	Lontung	Pangambatan	Silimalombu	Sirungkungon
Phytoplankton				
Class: Bacilliariophyeeae				
Fam: Aulacoseiraceae				
Aulacoseira sp.	1204	662	963	783
Fam: Naviculacea				
Navicula sp.	662	1686	722	1385
Fam: Nitzchiaceae				
Nitzhia sp.	1385	2227	2830	3010
Fam: Surirellaceae				
Surirella sp.	120	-	241	-
Fam: Rhophalodiaceae				
Rhopalodia sp.	421	-	-	241
Fam: Rhizosoleniaceae				
Guinardia sp.	1565	662	-	602
Fam: Fragillariaceae				
Fragillaria sp.	1264	421	-	722
Synedra sp.	-	783	963	2167
Fam: Pinnulariaceae				
Pinnularia sp.	181	602	181	783
Fam: Cymbellaceae				
Cymbella sp.	-	-	120	-
Class: Chlorophyceae				
Fam: Selenastraceae				
Selemastrum sp.	-	-	181	-
Fam: Scenedesmaceae				
Coelastrum sp.	-	301	181	-
Fam: Hydrodictyaceae				
Pediastrum sp.	963	1084	1806	1264
Fam: Chorellaceae				
Gleotila sp.	1144	963	963	963
Fam: Oocystaceae				
Oocystis sp.	722	1385	1264	3492
Fam: Sphaerocystidaceae				
Sphaerocystis sp.	181	-	-	181
Class: Cyanophyceae				
Fam: Oscilatoriaceae				
Oscilatoria sp.	241	301	542	783
Anabaena sp.	602	241	482	241

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Fam: Spirulinaceae				
Spirulina sp.	-	301	-	-

Taxa	Project			
	Lontung	Pangambatan	Silimalombu	Sirungkungon
Fam: Chroococcaceae				
Chlorococcum sp.	421	-	-	-
Chroococcus sp.	722	301	722	542
Gloeocapsa sp.	-	-	783	181
Fam: Merismopediaceae				
Merismopedia sp.	1084	722	662	542
Fam: Microcystaceae				
Microsystis sp.	1625	3010	2167	2528
Fam: Gloeotrichiaceae				
Gloeotrihia sp.	-	-	-	120
Class Coseinodiscophyceae				
Fam: Coscinodiscaceae				
Cosdinodiscus sp.	-	-	542	-
Fam: Rhizosoleniaceae				
Rhizosolenia sp.	-	482	-	-
Class: Dinophyceae				
Fam: Ceratideae				
Ceratium sp.	301	-	181	783
Class: Euglenida				
Fam: Phacaceae				
Phacus sp.	-	361	602	602
Class: Cyanophyceae				
Fam: Oscilatoriaceae				
Oscilatoria sp.	241	301	542	783
Anabaena sp.	602	241	482	241
Fam: Spirulinaceae				
Spirulina sp.	-	301	-	-
Fam: Chroococcaceae				
Chlorococcum sp.	421	-	-	-
Chroococcus sp.	722	301	722	542
Gloeocapsa sp.	-	-	783	181
Fam: Merismopediaceae				
Merismopedia sp.	1084	722	662	542
Fam: Microcystaceae				
Microsystis sp.	1625	3010	2167	2528
Fam: Gloeotrichiaceae				
Gloeotrihia sp.	-	-	-	120
Class Coseinodiscophyceae				
Fam: Coscinodiscaceae				
Cosdinodiscus sp.	-	-	542	-
Fam: Rhizosoleniaceae				
Rhizosolenia sp.	-	482	-	-

Taxa	Project			
	Lontung	Pangambatan	Silimalombu	Sirungkungon
Class: Dinophyceae				
Fam: Ceratideae				
Ceratium sp.	301	-	181	783
Class: Euglenida				
Fam: Phacaceae				

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Phacus sp.	-	361	602	602
Class: Fragilariophyceae				
Fam: Tabellariaceae				
Tabellaria sp.	-	-	-	181
Class: Mediophyceae				
Fam: Biddulphiaceae				
Isthmia sp.	-	783	181	532
Class: Zygnemophyceae				
Fam: Desmidiadeae				
Staurastrum sp.	5599	4937	6141	6201
Cosmarium sp.	2107	3131	4636	4636

Table 5. Phytoplankton analysis.

Taxa	Project			
	Lontung	Pangambatan	Silimalombu	Sirungkungon
Number of Taxa	21	22	24	25
Abundance (Ind/L)	22514	25346	28056	33465
Diversity Index (H')	2.647	2.696	2.631	2.723
Uniformity Index €	0.869	0.872	0.828	0.846
Blue Green Algae Percentage (%)	20.85	19.24	19.1	14.75

The presence of Cyanophyceae species, specifically *Oscillatoria* sp., *Anabaena* sp., *Chroococcus* sp., *Merismopedia* sp., and *Microcystis* sp. was observed in all sampling stations. These species are associated with high levels of phosphorus and nitrogen in the lake. The highest percentage of blue-green algae or Cyanophyceae was found at the Lontung station, which had high levels of phosphorus and nitrogen. These species can be harmful and toxic to organisms and their environment. *Anabaena* species, for example, produce the monocyclic heptapeptide toxin called microcystin, which can cause significant mortality in freshwater aquatic organisms. The high intensity of light from January to March, coupled with high temperatures, also contributed to phytoplankton abundance (Hertika and Umi, 2009).

The values of H' in Table 5 illustrate that a higher H' value indicates a greater diversity of aquatic species. Based on the data above, the diversity index ranges from 2.631 to 2.723, indicating an increasing abundance of 22514 to 33465 ind/L. The uniformity index (E) ranges from 0.828 to 0.872, indicating that the species in the community are evenly distributed. The study found that the number of taxa ranges from 21 to 25.

CONCLUSION

Based on the five key water quality parameters (total nitrogen, total phosphate, chlorophyll a, water brightness, and phytoplankton abundance), Lake Toba is currently classified as a lake with a mesotrophic trophic status. Although the chlorophyll values are still relatively low and meet the oligotrophic criteria, the other four key parameters consistently indicate mesotrophic status at the maximum threshold. This situation should concern stakeholders because environmental pressure and exceeding the carrying capacity and environmental capacity of Lake Toba can lead to eutrophication. Eutrophication negatively impacts all activities in Lake Toba and its surroundings.

CONFLICT OF INTEREST

The is no conflict of interest during the writing and publishing of the manuscript.

AUTHOR CONTRIBUTION

The author's contribution to this research is Friska Setiawani Saragih, Juanda, and Agusmanto Sihombing managed the sampling, laboratory work, analysis, and article writing. Hasim Djamil, Shofy Mubarak, Veryl Hasan, and Woro Hastuti Satyantini contributed to the article writing and performed statistical and data analyses

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