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Variation of Water Pollution Index due to anthropogenic activity pressure in Lake Tondano

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Abstract
Lake Tondano is the largest lake in North Sulawesi with an area of approximately 44–48 km², and plays an important role as a source of irrigation water, electricity, floating net fisheries, tourism, and raw water for the community. Increasing anthropogenic activities in the surrounding area, including settlements, restaurants, duck farms, agriculture, and fish farming, can reduce water quality through organic loads, nutrients, and microbiological contamination. This study aims to analyze water quality in six representative locations of human activity and assess the Water Pollution Index (WIP) based on the water quality standards of Government Regulation No. 22 of 2021. Sampling and analysis included in-situ measurements (temperature, pH, DO, conductivity, clarity, TDS) and laboratory analysis (BOD, Total Coliform). Sub-indexes for each parameter were converted and calculated using standard weights to determine the WIP. The measurement results showed a water temperature variation of 26.8–31°C and a pH variation of 8.03–9.07, relatively safe for biota. The highest TDS was in fish ponds (261 mg/L), the highest BOD was in residential areas (3.56 mg/L), and Total Coliform exceeded the quality standard in most locations (1,600 MPN/100 mL), indicating organic and microbiological pollution. The IPA calculation based on the quality standard class showed: all locations were categorized as Very Heavy (IPA > 70) for Class I; Severe–Very Heavy for Class II; Moderate for Class III; and Moderate–Severe for Class IV. Residential areas and fish ponds exert the greatest pressure on water quality, primarily through BOD and Total Coliform. This study confirms that anthropogenic activities significantly affect the water quality of Lake Tondano. Domestic and aquaculture waste management, routine monitoring, and zoning and pollution mitigation strategies are needed to maintain ecosystem sustainability and public health.

Keywords: Lake Tondano, water quality, Water Pollution Index, anthropogenic activity, total coliform

Introduction

Lakes are freshwater ecosystems that are crucial for human life and environmental sustainability, serving as water sources, fisheries, irrigation, transportation, and tourism (Anwar, 2024) [1]. However, increasing anthropogenic activities, such as settlements, agriculture, aquaculture, and tourism, often negatively impact water quality through increased nutrient and organic waste loads, and microbiological contamination (Dapas *et al*., 2021) [2].

Lake Tondano, with an area of approximately 44–48 km², is the largest lake in North Sulawesi and plays a vital role as a source of irrigation water for over 3,000 hectares of rice fields, floating net fisheries, tourism, and a raw water supply for the surrounding community (Putri *et al*., 2023) [7]. Ecological pressures are increasing due to dense settlements, the growth of restaurants, duck farms, and intensive agricultural activities in the surrounding area (Hidayat *et al*., 2022) [4].

Several previous studies have indicated eutrophication and bacterial contamination in Lake Tondano's waters (Kusuma *et al*., 2021) [5]. However, comparative studies of water quality based on variations in human activity around the lake are still limited. Therefore, this study was conducted to analyze water quality at six different locations representing dominant anthropogenic activities and compare them to the water quality standards stipulated in Government Regulation No. 22 of 2021.

Therefore, this study aimed to analyze water quality based on various anthropogenic activity zones in Lake Tondano and assess the Water Pollution Index at six locations representing anthropogenic activity pressures.

Methods

The research was conducted at Lake Tondano, Minahasa Regency, North Sulawesi, from November to December 2024. Sampling points were determined based on the dominant anthropogenic activities around the lake, namely residential areas, restaurants, duck farms, hot springs, agriculture, and fish ponds/floating nets. The locations were chosen to represent a variety of human activities that could potentially impact water quality, such as domestic waste, agricultural nutrients, and livestock waste (Rahmawati, 2023).

Water samples were collected using sterile HDPE bottles or glass bottles according to the parameters being analyzed. The procedure involved sampling water at a depth of 0.5–1 meter. For biological parameters (BOD, Coliform), samples were stored in a cooler box at 4°C before being analyzed in the laboratory (Dapas *et al*., 2021) [2].

Physical and chemical parameters were measured in situ in the field using portable instruments such as pH meters, DO meters, TDS/conductivity meters, digital thermometers, and Secchi disks for water clarity (Sutrisno *et al*., 2022) [10]. The samples were then tested in the laboratory. For BOD, samples were incubated for 5 days (BOD5) according to APHA (2020). Meanwhile, Total Coliform was measured using the Most Probable Number (MPN) method or Membrane Filtration (Kusuma *et al*., 2021) [5].

Descriptive data analysis techniques, in which the average value of each parameter was calculated and displayed in a table, allowed for comparison between locations and water quality standards according to Government Regulation No. 22 of 2021 (Rahmawati, 2021) [8]. The parameters analyzed included physical (temperature, TDS, conductivity, clarity), chemical (pH), and biological (DO, BOD, Total Coliform).
Sub-Index Calculation (Qi): Each parameter was converted into a sub-index to be standardized against the quality standards:

$$Q_i = \frac{Parameter\ Values}{Quality\ standards} \times 100$$

For DO, the formula is reversed if the value is below the quality standard:

$$Q_{i_{DO}} = \frac{uality\ standards}{DO\ Values} \times 100$$

Water Pollution Index Calculation
The IPA is calculated as the weighted sum of the sub-indices for each parameter:

$$IPA = \sum (Q_i \times W_i)$$

Parameter weights (Wi): pH 15%, TDS 15%, DO 25%, BOD 25%, Total Coliform 20% (Dapas *et al*., 2021; Anwar, 2024) [1, 2]. Water quality categories: Light: Water quality <30, Moderate: 30 ≤ Water quality <50, Heavy: 50 ≤ Water quality <70, and Very Heavy: Water quality ≥70.

A comparative analysis between locations, namely water quality comparisons between six locations, was conducted to assess the impact of specific anthropogenic activities on water quality.

Results and Discussion

Table 1 shows that water temperatures range from 26.8–31°C, with fish farms having the highest temperatures. This is consistent with the tropical water conditions of Lake Tondano (Rahmawati *et al*., 2021) [8]. Water conductivity varies from 261–483 µS/cm, with the highest being in agricultural areas. Water transparency or clarity varies from 4–107 cm. The highest TDS levels are found in fish farms (261 ppm) and agricultural areas (240 ppm), but are still below the maximum quality standard of 1,000 ppm. This indicates the accumulation of dissolved ions from human activities (Santoso *et al*., 2023) [9]. The pH tends to be alkaline in some locations, particularly restaurants (9.07) and fish farms (9.04), but remains within safe limits according to Government Regulation No. 22 of 2021 (1–6). Average DO was quite good, with all locations above the minimum limit of 1 mg/L, although some locations, such as duck farms, showed lower values than fish ponds (Dapas *et al*., 2021) [2]. BOD showed the lowest value in fish ponds (1.37 mg/L), indicating a relatively low organic load. Meanwhile, in residential areas, it was higher (3.56 mg/L) due to domestic activities. Total coliform exceeded the quality standard in several locations (1,600 MPN/100 mL), particularly in residential areas, restaurants, duck farms, hot springs, and fish ponds, indicating fecal bacterial contamination and a potential public health risk.

Table 1: Results of Water Quality Measurements at Six Locations of Lake Tondano

No.	Parameter	Settlement (1)	Restaurant (2)	Duck Farm (3)	Hot water (4)	Agriculture (5)	Fish Pond (6)	Quality standards (PP No. 22/2021)			
								Class I	Class II	Class III	Class IV
1.	Temperature(°C)	28.93	28.6	28.91	27.7	26.8	31	Dev 3	Dev 3	Dev 3	Dev 3
2.	TDS (mg/L)	161	131	131	157	240	261	1,000	1,000	1,000	2,000
3.	Conductivity (µS/cm)	266	263	263	290	483	261	-	-	-	-
4.	Transparency (cm)	107	89	87	79	35	70	10	4	2.5	-
5.	pH	8.13	9.07	8.05	8.03	8.03	9.04	6–9	6–9	6–9	6–9
6.	DO (mg/L)	5.0	5.4	4.8	5.2	5.94	6.31	6	4	3	1
7.	BOD (mg/L)	3.56	1.99	2.38	1.99	2.07	1.37	2	3	6	12
8.	Coliform (MPN/100 mL)	1,600	1,600	1,600	1,600	430	1,600	1,000	5,000	10,000	10,000

*** Description:** Quality standards are based on Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Management (Government Regulation of the Republic of Indonesia, 2021).

Water quality data from the Mawalelong River estuary was used as a comparison (Table 2). Table 2 shows that the water hyacinth area has lower clarity than the residential area, indicating sediment and nutrient accumulation (Manampiring *et al*., 2022) [6]. TDS and pH are relatively stable, but DO tends to be lower, which can impact the condition of aquatic biota (Santoso *et al*., 2023) [9]. Total coliform levels are higher in the water hyacinth area than in the residential area, likely related to aquatic vegetation degradation and waste accumulation (Dapas *et al*., 2021) [2].

Table 2: Water Quality at the Mawalelong River Estuary Location

Parameter	Location		Quality standards (Lamp. VI PP 22/2021)			
	Residential area	Water hyacinth area	Class I	Class II	Class III	Class IV
pH	7.61	6.95	6-9	6-9	6-9	6-9
TDS (mg/L)	341	336	1,000	1,000	1,000	1,000
DO (mg/L)	2	2.3	6	4	3	1
Transparency (cm)	1.1	0.87	10	4	2.5	-
Temperature (^{0}C)	30.1	29.9	Dev 3	Dev 3	Dev 3	Dev 3
BOD (mg/L)	0.7	2	2	3	6	12
Total Coliform (MPN/100 mL)	350	540	1,000	5,000	10,000	10,000

Source: Research Analysis Results, 2025

Water Pollution Index (WIP) for the six locations

The main parameters relevant to the WIP are: pH, TDS, DO, BOD, and Total Coliform. Temperature, conductivity, and water clarity are not typically included directly in standard WIP calculations, but can be analyzed descriptively. The WIP (Water Pollution Index) category is a water quality classification criterion based on WIP values. This standard is used to assess the level of pollution and its potential impact on ecosystems and human health. Here is a summary:

IPA Category	IPA Value Range	Description / Impact
Light	IPA < 30	Water quality is still good; little or no contamination. Safe for biota and public use.
Currently	30 ≤ IPA < 50	Pollution is beginning to be visible; there is stress on the ecosystem, but it is still tolerable.
Heavy	50 ≤ IPA < 70	Significant pollution; water quality is declining. May have a significant impact on humans and aquatic biota.
Very heavy	IPA ≥ 70	High pollution; high risk to biota and human use. Requires immediate mitigation.

Step 1: Determine Parameter Weights

Parameter	Bobot (%)
pH	15
TDS	15
DO	25
BOD	25
Coliform	20

Weight converted to decimal: 15% → 0.15, etc.

Step 2: Calculating the Sub-Index (Qi)

Calculating the Residential Location Sub-Index

1. **pH:** 8.13 → Qi = (8.13 / 9) × 100 = 90.3
2. **TDS:** 161 → Qi = (161 / 1000) × 100 = 16.1
3. **DO:** 5.0 → Qi = (6 / 5.0) × 100 = 120
4. **BOD:** 3.56 → Qi = (3.56 / 2) × 100 = 178.0
5. **Coliform:** 1,600 → Qi = (1,600 / 1,000) × 100 = 160

Step 3: Calculating IPA (Weighted Sum)

IPA = (90.3 X 0.15) + (16.1 X 0.15) + (120 X 0.25) + (178 X 0.25) + (160 x 0.20)

IPA = 13.55 + 2.42 + 30 + 44.5 + 32 = 122.5

Category: Very Heavy (IPA ≥ 70)

Step 4: IPA Calculation based on the Quality Standards of Appendix VI of PP 22/2021 Class I

Location	pH Qi	TDS Qi	DO Qi	BOD Qi	Coliform Qi	IPA	Category
Residential Areas	90.3	16.1	120.0	178.0	160.0	122.5	Very heavy
Restaurants	100.8	13.1	111.1	99.5	160.0	101.7	Very heavy
Duck Farms	89.4	13.1	125.0	119.0	160.0	108.4	Very heavy
Hot Springs	89.2	15.7	115.4	99.5	160.0	101.5	Very heavy
Agriculture	89.2	24.0	101.0	103.5	43.0	76.7	Very heavy
Fish Ponds	100.4	26.1	95.1	68.5	160.0	91.9	Very heavy

Note: Q_{iDO} is reversed if the value is below the quality standard, according to the IPA calculation standards.

Interpretation of the Class I Quality Standards, Appendix VI of Government Regulation 22/2021: The Water Pollution Index (IPA) values at all sampling locations in Lake Tondano fall into the "Very Heavy" category, indicating severe water pollution throughout the lake. High BOD and total coliform values indicate significant organic and microbiological contamination, particularly from residential areas, duck farms, and restaurants. Although pH and TDS remain within safe limits, and DO levels are generally adequate, the accumulation of anthropogenic activity poses serious risks to the aquatic ecosystem and public health. Waste management, zoning arrangements, and pollution mitigation strategies are essential to maintain water quality and the sustainability of the Lake Tondano ecosystem.

IPA calculations based on the Class II Quality Standards, Appendix VI of Government Regulation 22/2021

Location	pH Qi	TDS Qi	DO Qi	BOD Qi	Coliform Qi	IPA	Category
Residential Areas	90.3	16.1	100.0	118.7	32.0	77.0	Very heavy
Restaurants	100.8	13.1	100.0	66.3	32.0	65.1	Heavy
Duck Farms	89.4	13.1	100.0	79.3	32.0	66.6	Heavy
Hot Springs	89.2	15.7	100.0	66.3	32.0	63.7	Heavy
Agriculture	89.2	24.0	100.0	69.0	8.6	61.0	Heavy
Fish Ponds	100.4	26.1	100.0	45.7	32.0	61.8	Heavy

Interpretation of the Class II Quality Standards for Appendix VI of Government Regulation 22/2021:

- Pollution in Lake Tondano is influenced by anthropogenic activities: residential areas pose the highest pressure, followed by livestock and restaurants.
- Although DO and pH remain within safe limits, the high BOD and the presence of coliforms indicate a risk of ecosystem degradation and a potential public health hazard.
- Measures are needed to manage domestic and livestock waste, zone lake use, and routine monitoring of the wastewater treatment plant (WTP) to prevent further deterioration.

WTP calculation based on the Class III Quality Standards for Appendix VI of Government Regulation 22/2021

Location	pH Qi	TDS Qi	DO Qi	BOD Qi	Coliform Qi	IPA	Category
Residential Areas	90.3	16.1	100.0	59.3	16.0	59.0	Medium
Restaurants	100.8	13.1	100.0	33.2	16.0	53.6	Medium
Duck Farms	89.4	13.1	100.0	39.7	16.0	53.5	Medium
Hot Springs	89.2	15.7	100.0	33.2	16.0	52.2	Medium
Agriculture	89.2	24.0	100.0	34.5	4.3	51.5	Medium
Fish Ponds	100.4	26.1	100.0	22.8	16.0	52.9	Category

Interpretation of Class III Quality Standards for Appendix VI of PP 22/2021:

a. Pollution Category

- All locations show IPA in the Moderate category (51.5–59.0).
- This indicates that pollution is still controllable, but still poses ecological pressure on the lake waters.

b. Parameter Contribution

- pH and DO are in good condition (Qi ~90–100), so they are not major contributors to pollution.
- BOD is the main parameter contributing to pollution, especially at residential locations (59.3) and duck farms (39.7), indicating organic loads from domestic and livestock waste.
- Total Coliform is relatively low compared to previous calculations (16.0), indicating lower microbiological pressure, but still a potential health risk.
- TDS is low to moderate (16.1–26.1), so the influence of dissolved materials on water quality is relatively small.

c. Interpretation of Anthropogenic Activity Pressure

- Residential locations have the highest IPA (59.0), indicating that domestic waste remains a major factor in water quality degradation.
- Activities such as restaurants, duck farms, hot springs, agriculture, and fish ponds exert moderate pressure on water quality, through a combination of organic load and light biological contamination.

IPA calculation based on Class IV Quality Standards, Appendix VI of Government Regulation 22/2021

Location	pH Qi	TDS Qi	DO Qi	BOD Qi	Coliform Qi	IPA	Category
Residential Areas	90.3	16.1	100.0	29.7	16.0	51.6	Heavy
Restaurants	100.8	13.1	100.0	16.6	16.0	49.4	Currently
Duck Farms	89.4	13.1	100.0	19.8	16.0	48.5	Currently
Hot Springs	89.2	15.7	100.0	16.6	16.0	48.1	Currently
Agriculture	89.2	24.0	100.0	17.3	4.3	47.2	Currently
Fish Ponds	100.4	26.1	100.0	11.4	16.0	50.0	Heavy

Interpretation of Quality Standards for Appendix VI of PP 22/2021 Class IV:

a. Pollution Category

Of the six locations analyzed:

- Residential areas and fish ponds are categorized as Severe (IPA = 51.6 and 50.0).
- Restaurants, Duck Farms, Hot Springs, and Agriculture are categorized as Moderate (IPA = 47.2–49.4).
- This indicates that some locations in Lake Tondano are experiencing significant pollution pressure, while others remain at the control level but require attention.

b. Parameter Contribution to IPA

- pH and DO are within safe limits (Qi ~89–100), thus not negatively contributing to IPA.
- BOD is the main contributor to pollution, particularly in residential areas (29.7) and fish ponds (11.4), indicating organic loads from domestic waste and fishing activities.
- Total Coliform counts were relatively low at all locations (4.3–16.0), indicating lower microbiological pressure, but health risks remain at some locations.
- TDS was low to moderate (16.1–26.1), so its impact on water quality was relatively minor.

c. Interpretation of Anthropogenic Activity Pressure

- Residential locations experienced the highest pressure due to domestic and organic waste.
- Fish farm locations were also categorized as high due to the combined organic load and potential nutrient load from aquaculture activities.
- Restaurants, duck farms, hot springs, and agricultural locations were still categorized as moderate, so water quality in these locations could still be controlled with proper waste management.

Conclsion

Based on the results of the Water Pollution Index (WPI) calculations using the quality standards in Appendix VI of Government Regulation No. 22 of 2021 for Classes I–IV, water quality conditions at six locations in Lake Tondano show varying levels of pollution pressure depending on the quality standard category used. For Class I, all locations are in the Very Severe category, with WPI exceeding 70. High BOD and total coliform values, especially in residential areas, restaurants, and duck farms, indicate significant organic and microbiological contamination. This indicates a high risk to the ecosystem and public health. In Class II, residential areas are in the Very Severe category, while restaurants, duck farms, hot springs, agriculture, and fish farms are in the Severe category. Domestic activities, culinary businesses, and livestock farming place the greatest pressure on water quality. Although DO, pH, and TDS are still within safe limits, high BOD and total coliform values indicate potential ecosystem degradation and health risks that need to be addressed. For Class III, all locations are in the Moderate category (IPA 51.5–59.0), indicating that pollution is still manageable but still poses ecological pressure. BOD is the main parameter contributing to pollution, especially in residential areas and duck farms, while total Coliform is relatively low, indicating that

microbiological pressure is smaller but still poses a health risk. In Class IV, residential areas and fish farms are in the Heavy category, while restaurants, duck farms, hot springs, and agriculture are in the Moderate category. This indicates that some locations experience quite high pollution pressure, mainly due to domestic waste and fish farming, while other locations can still be controlled with proper management. In general, BOD and total Coliform are the parameters that most influence the decline in water quality in Lake Tondano. pH, DO, and TDS are within safe conditions in most locations, so the negative contribution to IPA is relatively small. Anthropogenic activity pressure comes primarily from residential areas, restaurants, livestock, and fish farms, which produce organic loads and biological contamination. Several steps can be taken to maintain and improve the water quality of Lake Tondano, including waste management, water quality monitoring and evaluation, anthropogenic activity mitigation, education and outreach, and zoning-based management strategies. By implementing these measures, it is hoped that Lake Tondano's water quality will be maintained, pollution pressure will be reduced, and ecosystem sustainability and public health will be better assured.

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