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Study of the succession of Lake Tondano into Land

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Abstract
Lake Tondano, the largest lake in North Sulawesi, is experiencing ecological pressure due to anthropogenic activities such as settlements, agriculture, fisheries, and tourism. This study aims to analyze the Water Pollution Index (WPI) and sedimentation levels in the Mawalelong River Estuary to understand the ecological succession process from the lake to the mainland. Water sampling was conducted at two locations: a residential area and a water hyacinth area, followed by analysis of physical, chemical, and biological parameters. The results show that the Water Pollution Index (WIP) at the two locations is in the 'Very Heavy' category in Class I and Class II' (WIP > 70), the 'Severe' category in Class III (WIP = 50 – 70), the 'Moderate' category in Class IV (WIP = 30 – 50). The average sedimentation rate is 5.35 mL/hour, indicating significant sediment accumulation. This condition accelerates siltation and supports the growth of water hyacinth, accelerating the succession of the lake towards land. Water hyacinth control, reduction of organic pollutant sources, sedimentation control, regular monitoring, and community involvement are recommended to maintain the ecological function of the lake.

Keywords: Lake tondano, water pollution Index, sedimentation, water hyacinth, ecosystem succession

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]. 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 source of raw water for the surrounding community (Putri *et al*., 2023) [5]. Ecological pressures are increasing due to dense settlements, the growth of restaurants, livestock farming, and intensive agricultural activities in the surrounding area (Hidayat *et al*., 2022) [3].

Several previous studies have indicated eutrophication and bacterial contamination in Lake Tondano's waters (Kusuma *et al*., 2021) [4]. However, comparative studies of water quality between areas near residential areas and areas with water hyacinth growth are still limited. Therefore, this study was conducted to analyze the Water Pollution Index based on physical, chemical, and biological parameters as stipulated in Government Regulation No. 22 of 2021 and sedimentation levels at two locations around the Mawalelong River Estuary to understand ecological pressures and the lake's succession process toward land.

Methods

The study was conducted at the Mawalelong River estuary, Lake Tondano, Minahasa Regency, North Sulawesi (10°6'06' – 01°20'25' N; 124°45'04' – 124°58'20' E). The study was conducted in April 2025. Two locations were selected: 1) an area near a residential area, representing direct human activity that generates household waste, and 2) a water hyacinth area, representing an area of floating vegetation with an accumulation of natural organic matter.

Water samples were collected using tools such as HDPE bottles or sterile glass bottles according to the parameters being analyzed. The procedure was as follows: water was collected 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 the field using portable instruments: a pH meter, DO meter, TDS/conductivity meter, digital thermometer, and a Secchi disk for water clarity (Sutrisno *et al*., 2022). BOD: 5-day incubation (BOD5) according to APHA (2020). Total coliform: Most Probable Number (MPN) method or Membrane Filtration (Kusuma *et al*., 2021) [4].

Data analysis techniques included:

1. Descriptive Analysis

- The average value of each parameter is calculated and displayed in a table to compare between locations and water quality standards according to Government Regulation No. 22 of 2021 (Rahmawati, 2021) [6].
- The parameters analyzed include: physical (temperature, TDS, clarity), chemical (pH), and biological (DO, BOD, Total Coliform).

2. Sub-Index Calculation (Qi)

- Each parameter is converted into a sub-index to be standardized against the quality standard:

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

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

$$Q_{i_{DO}} = \frac{Quality\ standards}{DO\ value} \times 100$$

3. Calculation of the Water Pollution Index (WIP)

- WIP is calculated as the weighted sum of the sub-indices for each parameter:

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

- Parameter weight (WIP): pH 15%, TDS 15%, DO 25%, BOD 25%, Total Coliform 20% (Dapas *et al*., 2021; Anwar, 2024) [1, 2].
- **WIP Categories:**
- **Mild:** WIP < 30
- **Moderate:** 30 ≤ WIP < 50
- **Severe:** 50 ≤ WIP < 70
- **Very Severe:** WIP ≥ 70

4. Sedimentation

- **Sediment volume:** Measure directly in the sedimentation tube.
- **Sedimentation rate:** mL/L/hr = Sediment volume / Sample volume / Sedimentation time.

Results and Discussion

a. Water Quality and Water Pollution Index at Two Locations Based on Water Quality Class (PP No. 22/2021)

The water quality and Water Pollution Index (WPI) at the Mawalelong River Estuary, Lake Tondano, Minahasa Regency are shown in Table 1.

Table 1: Water Quality and Water Pollution Index at the Mawalelong River Estuary, Lake Tondano, Minahasa Regency

No	Parameter	Area 1	Area 2	Quality Standards (PP No. 22/2021)				Class I		ClassII		Class III		Class IV	
				Class I	Class II	Class III	Class IV	WPI 1	WPI 2	WPI 1	WPI 2	WPI 1	WPI 2	WPI 1	WPI 2
1	TDS (mg/L)	341	336	1000	1000	1000	1000	34.1	33.6	34.1	33.6	34.1	33.6	34.1	33.6
2	pH	7.61	6.95	9	9	9	9	84.6	77.2	84.6	77.2	84.6	77.2	84.6	77.2
3	DO (mg/L)	2	2.3	6	4	3	1	300	260.9	200	173.9	150	130.4	100	100
4	BOD (mg/L)	0.7	2	2	3	6	12	35	100	23.3	66.7	11.7	33.3	5.8	16.7
5	Coliform (MPN/100 mL)	350	540	1000	5000	10000	10000	35	35	7	7	3.5	3.5	3.5	3.5
Amount								108.5	113.8	75	78.2	58.9	58.3	45	46.5
Category								Very Severe	Very Severe	Very Severe	Very Severe	Severe	Severe	Moderate	Moderate

Based on the Water Pollution Index (WIP) calculations using the quality standards in Appendix VI of Government Regulation No. 22 of 2021 for Classes I–IV, the water quality conditions at two locations in Lake Tondano show varying levels of pollution depending on the quality standard category used.

For Class I, both locations are in the Very Severe category, with WIP exceeding 70, indicating severe water pollution throughout the lake. This poses a high risk to the ecosystem and public health. Waste management, zoning, and pollution mitigation strategies are essential to maintain water quality and the sustainability of the Lake Tondano ecosystem.

For Class II, both locations are also in the Very Severe category. This is a crucial finding. The current water conditions are far below standards for vital and sensitive uses. If Lake Tondano water is to be used as a drinking water source or for sensitive fish farming, the existing pollution is already at a severe level. Domestic waste management, lake use zoning, and regular WIP monitoring are needed to prevent further deterioration.

For Class III, both locations fall into the Severe category (IPA 58.3 – 58.9). While key parameters such as DO and pH may be 'safe' or within the permitted limits for this designation, high BOD and the presence of coliforms indicate ecosystem degradation and potential health hazards if the water is used without adequate treatment.

For Class IV, both locations fall into the Moderate category. This indicates that the water can still be used for irrigation, and the pollution level is still 'manageable' compared to more stringent standards. However, these conditions still pose ecological stress to the lake's waters as a whole.

b. Sedimentation

The sedimentation rate at the Mawalelong River estuary is shown in Table 2. The average sedimentation rate was 5.94 + 4.75 ≈ 5.35 mL/hour.

Table 2: Sedimentation Rate at the Mawalelong River Estuary, Lake Tondano, Minahasa Regency

Location	Coordinate	Sedimentation Height (cm)	Sediment Volume (mL)	Sedimentation Period (jam)	Sedimentation Rate (mL/jam)
1	123365°U, 124.86876°T	1.5	35.62	6	5.94
2	123361°U, 124.86872°T	1.2	28.50	6	4.75

The relatively high sedimentation rate at two locations indicates that the Mawalelong River estuary is a major source of sediment supply to Lake Tondano. The sediment consists of fine particles, organic matter, and vegetation remains such as water hyacinth. This sediment accumulation can cause shallowing and accelerate the lake's ecological succession process. If this continues without management; this area has the potential to transform from a lake into a swamp or new land.

Conclusion

The Water Pollution Index of both locations falls into the moderate to very severe category, indicating significant ecological pressure. Sedimentation rates are high (averaging 5.35 mL/hour). Sediment in the river estuary originates not only from residential runoff but also from agricultural activities, aquaculture, coastal development, tourism, vegetation clearing, and water transportation around the estuary area. Therefore, sedimentation control is necessary by

planting erosion-retaining vegetation, cleaning the river estuary, and regularly monitoring water quality (pH, DO, BOD, TDS, Coliform) and sedimentation.

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