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Study of the Physical and Chemical Characteristics of Lake Tondano, North Sulawesi

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A B S T R A C T

This study aims to examine the physical and chemical characteristics of the lake's waters to evaluate its current water quality status. The research method used was descriptive quantitative, with purposive sampling at several observation stations representing the inlet, mid-lake, and residential/aquaculture areas. The physical parameters measured were temperature, while the chemical parameters included pH and dissolved oxygen (DO). The study results showed that the water temperature was within the normal range (25-28°C). Chemically, the pH value was 6.2-8.6 and the dissolved oxygen (DO) value was between 4.8-8.7 mg/L, indicating a significant organic pollution load. Based on the pollution index analysis, the lake's waters are categorized as lightly to moderately polluted. More integrated management of aquaculture and domestic waste is needed to prevent further water quality degradation.

INTRODUCTION

Lake Tondano is the largest lake in North Sulawesi Province, with a surface area of approximately 4,278 hectares. As a volcanic lake located in the Minahasa highlands, it is a strategic natural resource due to its biodiversity and vital role in supporting the livelihoods of the surrounding communities. Its strategic functions include serving as a raw water source for the Regional Drinking Water Company (PDAM), serving as the main power plant for the Tonsealama and Tanggari Hydroelectric Power Plants (PLTA), and serving as a center for inland fisheries activities through the Floating Net Cage (KJA) system.

However, with increasing population growth and the intensity of land use in the watershed (DTA), the lake faces serious ecological pressures. Anthropogenic activities such as the discharge of domestic waste from lakeside settlements and leftover fish feed from aquaculture activities (Ondang et al., 2018) state that human activities around the Lake Tondano watershed (DTA), including settlements, put pressure on water quality and environmental carrying capacity. In the Indonesian Fisheries Research journal, they specifically stated that leftover feed from fish farming in floating net cages (KJA) is the main nutrient source that triggers water quality decline and changes in the lake's trophic status. Samuel et al. (2011) and agricultural wastewater containing chemical fertilizers have triggered nutrient enrichment (eutrophication). In addition to domestic waste, agricultural activities around Lake Tondano contribute significantly to water quality degradation. The use of chemical fertilizers on agricultural land in the water catchment area causes runoff that carries high levels of nutrients into the lake (Ondang et al., 2018). This phenomenon triggers nutrient enrichment or eutrophication, which is characterized by a drastic increase in Nitrogen and Phosphorus concentrations in the water (Samuel et al., 2011). According to Effendi (2003), the continued accumulation of nutrients from agricultural waste will trigger the uncontrolled growth of aquatic vegetation, such as water hyacinth, which ultimately disrupts the ecosystem balance and reduces oxygen levels in the lake's interior. This phenomenon is evident in the expanding population of water hyacinth (Eichhornia crassipes), which covers part of the lake's surface. These various community activities can affect the physical and chemical parameters of the lake's waters.

These changes in biological conditions reflect the dynamics of the physical and chemical characteristics of the waters. Decreasing fluctuations in dissolved oxygen (DO) are an important indicator in assessing the health of the lake's ecosystem. If this decline in water quality is left unchecked without comprehensive monitoring, the lake's economic and ecological functions are threatened with permanent degradation. To address the physical and chemical parameters of the lake's waters under various community activities, a study of their physical and chemical characteristics is necessary. By understanding the physical (temperature) and chemical (pH, DO) parameters, the local government can provide baseline data for conservation and management of the lake's waters. Therefore, it is urgent to conduct this study as a basis for sustainable environmental management.

THEORETICAL REVIEW

Lake Ecosystems and Limnological Characteristics

Lakes are inland aquatic ecosystems with a relatively long water residence time. Limnologically, lake conditions are strongly influenced by the ratio of the catchment area (CTA) to the lake's surface area. Lake Tondano, as a volcanic lake, experiences the dynamics of weathering of its parent rock, which contributes to the natural mineral content of its water. According to Wetzel (2001), the limnological characteristics of a lake are determined by the interaction between the morphometry of the lake basin, the geological conditions of the catchment area (CTA), and solar energy input. Lake Tondano, as a volcanic lake, has unique limnological dynamics due to its geographical location on a plateau surrounded by active and inactive mountains, which naturally contribute specific mineralogy to the water body.

Limnologically, lake water quality is strongly influenced by nutrient cycling, particularly nitrogen (N) and phosphorus (P). Effendi (2003) stated that in freshwater ecosystems, phosphorus is often a limiting factor for primary productivity. If phosphorus levels increase drastically due to external (anthropogenic) activities, the ecosystem balance will be disrupted and trigger eutrophication.

The current limnological characteristics of Lake Tondano indicate changes in its thermal and chemical profiles. Based on research by Lumentut and Sendow (2021), temperature stratification in several areas of the lake has begun to be disrupted by massive siltation. This causes water mass agitation (water turnover), bringing nutrients from the lake bottom to the surface, which ultimately triggers an explosion in water hyacinth and phytoplankton populations.

Physical Water Parameters

Physical water characteristics are early indicators that determine the comfort of a habitat for aquatic biota and influence chemical processes in the water. The main physical parameters studied in Lake Tondano include temperature, clarity, and suspended solids.

1. Temperature

Water temperature is a major controlling factor for organism metabolism and gas solubility in water. According to Effendi (2003), increasing water temperature can reduce oxygen solubility (DO) and increase the rate of organic matter decomposition. In Lake Tondano, water temperature is influenced by the highland elevation (±670 meters above sea level). However, research by Lumentut and Sendow (2021) shows that fluctuations in lake surface temperature are currently being influenced by changes in land cover around the catchment area (DTA), causing thermal stratification to become unstable during certain seasons.

2. Clarity and Turbidity

Clarity is a measure of water transparency determined visually using a Secchi disk. This parameter reflects the penetration of sunlight required for photosynthesis by phytoplankton and aquatic plants. Wetzel (2001) stated that

low clarity is usually caused by high concentrations of suspended solids (TSS) or algal blooms. In Lake Tondano, clarity values often fall below 1 meter, especially in densely populated coastal areas and floating net cages (KJA), due to the accumulation of uneaten food and fine sediment.

Water Chemical Parameters

The chemical characteristics of water are indicators of the level of pollution and fertility of a lake ecosystem. The chemical parameters measured in the study of Lake Tondano include acidity (pH), dissolved oxygen (DO), and nutrient content (nitrogen and phosphorus).

1. Acidity (pH)

The pH value describes the concentration of hydrogen ions in water and is an indicator of acid-base balance. According to Effendi (2003), most freshwater biota are highly sensitive to pH changes and typically grow optimally in the pH range of 6.5–8.5. In Lake Tondano, the pH value tends to be stable in the weakly basic range (7.2–7.9). However, Lumentut and Sendow (2021) noted that in areas with high water hyacinth densities, pH fluctuations can occur due to the intensity of photosynthesis and respiration of these aquatic plants, which affect the carbonate balance in the water.

2. Dissolved Oxygen (DO)

Dissolved oxygen is the most critical chemical parameter for the survival of aquatic organisms. Based on Government Regulation No. 22 of 2021, Class II water for fisheries purposes must have a minimum DO level of 4 mg/L. Decreased DO in Lake Tondano is often detected in the bottom layer (hypolimnion) and in the central area of floating net cages (KJA). This is caused by the high oxygen consumption by decomposing bacteria to decompose leftover fish food and waste that accumulates at the bottom of the water.

Trophic Status and Eutrophication

Tropical status is a classification of water fertility levels determined by nutrient content, clarity, and algal biomass. According to Wetzel (2001), the change in trophic status from natural conditions to excessive nutrient enrichment is called eutrophication.

Trophic Status Classification

Based on the OECD (Organization for Economic Co-operation and Development) criteria and Minister of Environment Regulation No. 28 of 2009, lake trophic status is divided into four main categories:

Oligotrophic: Nutrient-poor waters with high clarity and low productivity.

Mesotrophic: Waters with moderate fertility.

Eutrophic: Fertile waters with high nutrient content (nitrogen and phosphorus), often characterized by turbidity due to algae.

Hypereutrophic: A very fertile condition where there is an explosion in aquatic plant populations and a drastic decline in water quality.

Eutrophication Phenomenon in Lake Tondano

Eutrophication in Lake Tondano is categorized as anthropogenic or cultural eutrophication, namely nutrient enrichment accelerated by human activities. Based on a study by Hariyadi (2018), Lake Tondano is currently at a eutrophic to hypereutrophic level. The main indicator of this phenomenon in Lake Tondano is the accumulation of total phosphorus, which exceeds the standard threshold for natural lake fertility.

Impact of Eutrophication on the Ecosystem

1. The most obvious impact of eutrophication in Lake Tondano is the explosion of macrophyte populations, particularly water hyacinth (Eichhornia crassipes). According to Effendi (2003), although aquatic plants play a role in absorbing pollutants, uncontrolled growth will cover the water surface, inhibit sunlight penetration, and increase the rate of evapotranspiration.
2. Furthermore, when these plants die and sink to the lake bottom, the decomposition process will deplete dissolved oxygen reserves in the lower layers of the water. These anoxic (oxygen-free) conditions trigger the release of toxic gases such as H_2S and ammonia, which risk causing mass fish deaths, particularly in floating net cages (KJA) in the Eris and Remboken areas (Gerung & Sinjal, 2020).

Trophic State Index (TSI)

Trophic status determination in this study refers to the Trophic State Index (TSI) method by Carlson. This index combines three main parameters: Secchi depth (brightness), Chlorophyll-a concentration, and Total Phosphorus. The use of this index allows for a more accurate assessment of the declining trend in Lake Tondano's environmental quality over time.

Implications for Lake Tondano Ecosystem Management

Physical and chemical data imply the need for a paradigm shift in Lake Tondano management. Management strategies can no longer be implemented in isolation but must be integrated from upstream to downstream.

1. Nutrient and Eutrophication Control

High levels of phosphate and nitrate imply that physical water hyacinth removal efforts alone will be ineffective unless land-based nutrient sources are controlled. According to Sihotang and Utomo (2019), the primary strategy is to reduce nutrient loading through improving residential drainage systems and limiting the use of chemical fertilizers on agricultural land around the lake. The use of constructed wetlands is recommended as a natural filter before water from the inlet river enters the lake (Effendi, 2003).

2. Fishery Carrying Capacity (KJA)

Low levels of dissolved oxygen (DO) in the cultivation area imply that the density of floating net cages (KJA) exceeds the environmental carrying capacity. Based on the recommendations of Gerung and Sinjal (2020), the management implications include the need to implement strict fish production quotas and zoning of floating net cages (KJA) to prevent further accumulation of leftover

feed. This is reinforced by Wetzel's (2001) theory, which states that excessive organic matter will trigger permanent anoxic conditions at the lake bottom.

3. Sedimentation and Silting Mitigation

Massive sedimentation rates pose a serious threat to water storage for hydroelectric power plants and irrigation. According to Sudaryono (2015), the technical implications that must be addressed immediately include land rehabilitation in the Watershed Area (DTA) in the Masarang and Lembean hills to curb erosion. Without upstream soil conservation efforts, dredging of sediment in the lake body will only be a costly and unsustainable temporary solution.

4. Collaborative Governance

Administratively, the cross-sectoral nature of Lake Tondano implies the importance of inter-institutional coordination. In accordance with Government Regulation No. 22 of 2021, water quality management must involve routine monitoring and strict law enforcement against domestic and small industrial waste disposal around Tondano City (Hariyadi, 2018).

METHODOLOGY

Research Time and Location

This research will be conducted from April to December 2025. Water sampling will be conducted in the morning between 8:00 and 11:00 a.m. Central Indonesian Time (WITA). This will ensure representative temperature and oxygen levels. The research location will be focused on the waters of Lake Tondano, Minahasa Regency, North Sulawesi.

Tools and Materials

Tools: Water Sampler (Kemmerer), DO Meter, pH Meter, Secchi Disk (for clarity), Thermometer, GPS (for determining coordinates), polyethylene sample bottle (1 liter), cool box, and stationery.

Materials: Lake water samples, sample labels, and preservative solution (2% or 3%) if required for specific chemical parameters in the laboratory.

Determining Observation Stations

The sampling locations were determined using the Purposive Sampling method, a sampling technique with specific considerations to represent water conditions. The observation stations were divided into five main points:

1. Station 1: Lake area with aquatic vegetation
2. Station 2 (Middle Lake Area): Located in the pelagic zone (center of the lake) as a control (open water area) without aquatic vegetation.
3. Station 3 (Inlet): Located at the mouth of the river entering the lake and the vegetation area (Kakas) to monitor the input load from the land.
4. Station 4 (Cultivation Area): Located in the Floating Net Cage (KJA) area to monitor the impact of leftover feed and fish metabolism.
5. Station 5 (Outlet): Located at the lake outlet (Tondano River/PLTA area) to monitor the quality of water leaving the lake system. A map of the lake where the research was conducted can be seen below.

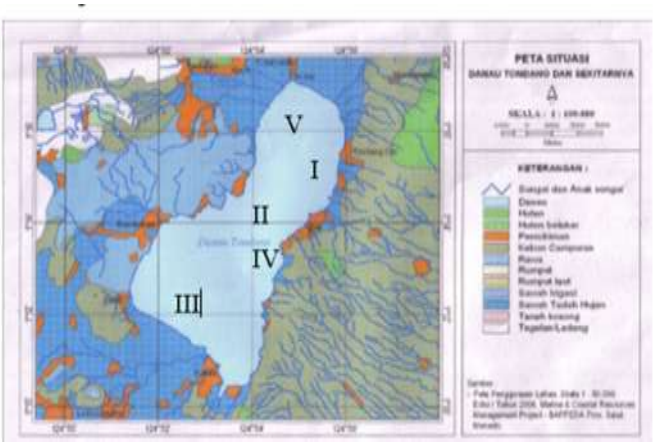

Figure 1. Map of the Lake Where the Research Is Located

Sampling Procedure

Measurements of physical parameters such as temperature and clarity were conducted directly (in situ) in the field.

Water samples were collected at a depth of 0.5–1 meter using a water sampler. The samples were placed in polyethylene bottles, labeled, and stored in a cool box to ensure their chemical characteristics remained unchanged during transportation to the laboratory.

Table 1. Water Quality Data Collection Instrument Specifications

No	Parameter / Function	Tool Name	Specification / Brand	Measurement Metothod
1.	Water Sampling	Van Dorn Water	Sampler (3 Liter Capacity)	Grab sampling
2.	Water Temperature:	Reversible Thermometer	Reversing protected Thermometer	In- Situ
3.	Acidity (pH):	Water quality Checker	Horiba WQC Meter	In-situ (Digital)
4.	Dissolved Oxygen(DO):	Water quality Checker	Horiba WQC Meter	In-situ (Digital)

Data Analysis

The Principal Component Analysis (PCA) method is very effective in identifying the dominant variables that most influence changes in water quality in lake ecosystems (Rosalina et al., 2023; Rares et al., 2025). Water characteristic analysis was conducted by comparing field measurement results to the latest quality standards stipulated in Government Regulation No. 22 of 2021 (Husein, 2025; Anonymous, 2025).

RESULTS AND DISCUSSION

General Conditions of the Research Site:

Lake Tondano is administratively surrounded by densely populated settlements and intensive agricultural land. Habitat conditions are the primary

determinant of the presence and distribution of organisms in a body of water. According to Ricklefs & Relyea (2014), interactions between abiotic environmental factors and internal demographic processes, such as growth rate and dispersion, collectively shape population distribution patterns within an ecosystem. Based on observations at five stations in Lake Tondano, the following water quality parameters were obtained:

Table 2. Description of Physico-chemical Parameters in Lake Tondano

Station	Temperature (°C) (Min-Max)	pH (Min-Max)	DO (mg/L) (Min-Max)
I	26.2 – 27.5	6.5 – 8.6	4.8 – 8.7
II	26.2 – 27.6	6.8 – 8.4	5.2 – 7.1
III	25.4 – 27.6	6.4 – 8.4	5.3 – 8.2
IV	25.5 – 27.7	6.2 – 8.5	5.2 – 7.6
V	25.2 – 27.2	6.4 – 8.6	4.8 – 7.4

The uniformity of values for these three parameters indicates that, on a macro scale, the physicochemical conditions of the water in Lake Tondano remain fairly homogeneous. The absence of significant differences between stations indicates that environmental pressures (such as air temperature and water circulation) were evenly distributed throughout the body of water at the time of sampling.

Based on field measurements, the physical characteristics of Lake Tondano are as follows: The average temperature ranges from 25.4°C to 27.7°C. This value is within normal limits for aquatic biota growth and supports organic decomposition.

Clarity: The lowest clarity levels were found at Station 4, with values ranging from 0.8 to 1.2 meters. This is due to the high density of microalgae (phytoplankton) and suspended matter from leftover feed.

Temperature Dynamics and Water Stability

Temperature measurements ranging from 25.4 to 27.7°C indicate stable thermal conditions ideal for the metabolism of aquatic organisms. Based on analysis of variance, the absence of significant differences between stations ($\alpha = 0.05$) indicates that heat distribution in Lake Tondano tends to be even. This is influenced by the characteristics of volcanic lakes and effective water mass circulation, so that temperature fluctuations in the inlet, outlet, and vegetation areas remain within the biological tolerance limits of aquatic biota. Thermal conditions in Lake Tondano are significantly influenced by environmental dynamics, primarily through heat energy input from solar radiation intensity and elevation factors (Ondang et al., 2018). Based on observations of the water column, temperatures in this lake tend to exhibit vertical stability, although their absolute values remain highly dependent on fluctuations in external thermal input (Remen et al., 2016). As a key physical parameter, temperature plays a crucial role in regulating the metabolic rate of aquatic organisms and determining the solubility of dissolved oxygen (DO) in water (Wanda et al.,

2020). Therefore, temperature instability influenced by meteorological factors can ultimately become a crucial limiting factor for optimal growth and survival of cultivated biota (Ondang et al., 2018).

Chemical Parameters:

1. Acidity Balance (pH)

A measured pH value in the range of 6.2–8.6 reflects neutral to slightly alkaline water conditions. The consistency of pH values across various research stations indicates that the buffering capacity of the waters, represented by pH, is a crucial factor in the stability of the Lake Tondano ecosystem. According to Gatson et al. (2015), pH fluctuations have a direct impact on the survival of organisms, particularly in minimizing ammonia toxicity for farmed fish. This aligns with Effendi's (2003) opinion, which states that alkalinity acts as a balancing factor, preventing drastic changes in pH due to photosynthesis and respiration. In Lake Tondano, pH conditions in the neutral to slightly alkaline range strongly support physiological processes and efficient feed utilization for aquatic biota (Kalesaran et al., 2020). Despite the presence of domestic and agricultural activities near the coast, the current water chemistry still supports fish physiological processes and the survival of basic microorganisms.

2. Dissolved Oxygen (DO) Concentration and the Impact of Community Activities

Dissolved oxygen levels between 4.8 and 8.7 mg/L are a key indicator that the waters still have the capacity to support aquatic life. However, the lowest point, at 4.8 mg/L, requires special attention, especially at Station IV (the Floating Net Cage area). Low DO in this area is often triggered by the decomposition of leftover fish food and feces, which consume large amounts of oxygen. The availability of dissolved oxygen (DO) in Lake Tondano is a vital indicator of the health of the aquatic ecosystem. According to Samuel et al. (2011), oxygen distribution in the lake is under severe pressure due to the accumulation of organic matter from leftover feed from Floating Net Cage (KJA) cultivation. Other anthropogenic activities, such as domestic waste disposal and agricultural runoff, accelerate organic decomposition, which consumes large amounts of oxygen, creating anoxic zones in the bottom layers of the water (Ondang et al., 2018; Remen et al., 2016). The impact of decreasing DO concentrations directly limits the movement of biota and increases the risk of mass mortality of farmed fish due to environmental stress (Wanda et al., 2020). Conversely, high oxygen levels in vegetated areas demonstrate the role of aquatic plant photosynthesis in supplying oxygen to the water column.

Implications for Ecosystem Management

Using the Pollution Index (PI) method, Lake Tondano's overall water quality falls into the Lightly to Moderately Polluted category. Moderately Polluted: Found in areas directly adjacent to residential areas and fish farming centers. This pollution is caused by environmental degradation in Lake Tondano, rooted in the ever-increasing accumulation of organic pollutant loads, which are now indicated to have exceeded the lake's assimilation capacity, or its ability to naturally process waste (Samuel et al., 2011). According to Lumenta (2017), this

imbalance occurs due to massive nutrient inputs from aquaculture feed residues and anthropogenic waste, which are no longer commensurate with the lake's water volume and circulation rate. This condition causes the accumulation of organic sediment at the bottom of the water, which triggers excessive decomposition, thus lowering the threshold value for overall ecosystem health (Remen et al., 2016; Ondang et al., 2018). Without restrictions on the number of fish cages and a domestic waste management system, Lake Tondano is feared to experience rapid shallowing due to sedimentation and aquatic weed growth. Therefore, a management strategy that integrates regular water quality monitoring with zoning of community activities is needed.

CONCLUSIONS AND RECOMMENDATIONS

Based on the research results, it can be concluded that the water quality of Lake Tondano is generally within tolerance limits, supporting aquatic life. Physicochemical parameters indicate a temperature range of 25–28°C, acidity (pH) between 6.2–8.6, and dissolved oxygen (DO) concentration between 4.8–8.7 mg/L. Statistically, there were no significant differences in these parameters between observation stations, although local fluctuations were found in areas adjacent to community activities and inlets.

Recommendations

1. Waste Control: More stringent preventive measures are needed to minimize the entry of domestic waste, leftover feed from floating net cages (KJA), and agricultural residues into the lake. This is crucial for maintaining water quality standards and preventing the acceleration of eutrophication.
2. Biota Conservation: Preserving the lake's ecosystem must be a priority through integrated waste disposal regulations to ensure the long-term survival of aquatic biota.

Continuous water quality monitoring is recommended for early detection of ecological changes that could threaten Lake Tondano's strategic function.

FURTHER STUDY

Future research is recommended to conduct longitudinal monitoring of water quality parameters to assess seasonal variations and long-term environmental changes in Lake Tondano. Further studies may also examine the impact of anthropogenic activities such as aquaculture, agriculture, and domestic waste on nutrient loading and ecological balance. Additionally, integrating biological indicators and geospatial analysis would provide a more comprehensive understanding of ecosystem health and support sustainable lake management strategies in North Sulawesi.

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