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Pollution Index Assessment of Lake Maninjau Water Quality Status

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Abstract: Lake Maninjau with its strategic functions, faces pressures from both climate change and anthropogenic activities that can degrade water quality and ecological functions. This study aims to determine the water quality status of Lake Maninjau over the 2022–2025 period as an initial step to support lake restoration and the achievement of Sustainable Development Goal (SDG) 6. Surface water samples were collected twice a year from six stations representing the lake's spatial characteristics using the grab sampling method. Analyzed parameters included pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and phosphate (PO_4) following methods established in the Indonesian National Standards and relevant international standards. The water quality status was assessed using the Pollution Index method based on the Decree of the Minister of State for the Environment Number 115 of 2003. The results revealed fluctuating temporal shifts throughout the observation period. In 2022, water quality ranged from good conditions to light pollution. Conditions deteriorated during 2023–2024, with the majority of stations classified as light pollution. By 2025, all monitoring sites recovered to the good conditions. The observed fluctuating patterns of the Pollution Index during the 2022–2025 period indicate that the Lake Maninjau aquatic system remains highly vulnerable to dynamic external pressures, such as organic load accumulation and the lake's natural hydrological dynamics in the form of upwelling events. Consequently, consistent nutrient load reduction is urgently required, particularly through the regulation of floating net cage capacities based on carrying capacity assessments and structured water quality monitoring.

Keywords: Lake Maninjau; Pollution Index; Water Quality Status

Introduction

Lake Maninjau is a volcanic lake located at coordinates 0°19′ South Latitude and 100°12′ East Longitude in Tanjung Raya District, Agam Regency, at an altitude of approximately 461.5 meters above sea level. This lake has an area of approximately 99.5 km², a catchment area of approximately 24,800 ha, and a maximum depth of 165 m (KLH, 2011). Lake Maninjau plays a strategic role in supporting regional development, including as an energy source for hydroelectric power plants, a tourist destination, and a source of livelihoods for local communities through capture fisheries and aquaculture activities. Anthropogenic activities taking place in the Lake Maninjau area put pressure on the aquatic ecosystem and contribute to the decline in its water quality (Kurniati et al., 2021). The rapidly growing floating net cages activity is one of the main sources of environmental pressure in Lake Maninjau. The number of floating net cages increased from 3,500 in 2001 to

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17,417 in 2021, far exceeding the lake's estimated carrying capacity of only 6,000 (Syarkawi & Pradyuda, 2026). This situation increases the burden of organic pollution due to leftover feed and fish farming waste, which exceeds the water's assimilation capacity, thus contributing to the decline in water quality and the degradation of Lake Maninjau's ecosystem (Pramadinanti, 2023). In addition to cultivation activities, the use of lake water by the community for domestic needs such as bathing, washing, and other daily activities also has the potential to increase pressure on water quality (Syarkawi & Pradyuda, 2026). Decreased water quality due to anthropogenic activities (community/industrial) can lead to contamination and have a direct impact on aquatic ecosystems (Rumanta et al., 2024). These conditions led to Lake Maninjau being designated as a national priority lake for restoration based on Presidential Regulation Number 60 of 2021 concerning the Rescue of National Priority Lakes.

Water quality decline and lake pollution are global environmental issues closely linked to the sustainable development agenda, particularly Sustainable Development Goal (SDG) Goal 6 on access to clean water and sanitation, which emphasizes the importance of improving water quality through pollution reduction, wastewater management, and increased safe water reuse (Fayomi & Onyari, 2024). Specifically, this goal is outlined in Target 6.3, which emphasizes the importance of water quality monitoring and data reporting as a basis for assessing pollution levels and the condition of water bodies. This aims to support sustainable water resource management and the formulation of effective water quality improvement strategies (Hering, 2017). In addition to anthropogenic pressures, climate change is expected to increase the vulnerability of aquatic ecosystems, particularly in coastal areas and regions that are highly dependent on water resources, making the need for information and adaptation strategies increasingly critical (Anggis & Lestaryanti, 2026). These conditions indicate that water quality management must not only focus on pollution control but also take into account the environmental resilience to the impacts of climate change. In the context of saving Lake Maninjau, implementation of Target 6.3 can be achieved through a water quality assessment as an initial and fundamental step in supporting lake ecosystem restoration efforts. This assessment plays a crucial role in comprehensively describing the condition of the water body, identifying pollution levels, and providing a scientific basis for aquatic ecosystem management and restoration (Komarudin et al., 2025). The results of water quality assessments can serve as a basis for developing adaptive management policies and actions, thus supporting long-term environmental protection, maintaining the ecological sustainability of lakes, and promoting sustainable water resource management practices (Purwaningsih et al., 2025)

Determining pollution indices and analyzing water quality status are essential approaches for comprehensively evaluating water conditions. The pollution index method integrates several water quality parameters into a single index value that comprehensively represents the level of pollution in a water body. Previous research on the water quality of Lake Maninjau has been conducted, including by (Sunaryani, 2023). who analyzed water quality and trophic status using the STORET method based on data from 2011–2020. The results showed that Lake Maninjau's water quality had declined to a state of severe pollution, particularly in areas with floating net cage activity, and that trophic status tended toward eutrophic to hypereutrophic levels in several locations. However, that study focused more on evaluating water quality and trophic status over the past decade and did not reflect water quality conditions in more recent periods. Despite the differences in research periods, the pollution index approach allows for an integrated evaluation of pollution levels by combining several water quality parameters, providing a more comprehensive picture of water conditions. Given that Lake Maninjau is a national priority lake undergoing restoration efforts, latest water quality information is crucial for evaluating the dynamics of water conditions and the effectiveness of management efforts. Therefore, this study aims to determine the pollution index and analyze the water quality status of Lake Maninjau over the most recent period to provide the latest scientific information on water conditions and pollution levels. Water quality indices can also serve as an important reference for local governments in formulating environmental management and sustainable aquatic resource management policies (Afrianti et al., 2026). In the context of Lake Maninjau, the results of this study are expected to provide a scientific basis for developing more effective strategies for ecosystem management and restoration, while also supporting adaptive environmental policies to maintain the ecological sustainability of the lake.

Method

The research was conducted at Lake Maninjau, Tanjung Raya District, Agam Regency, West Sumatra Province. The research consisted of several stages, including the determination of sampling locations, surface water sample collection, laboratory analysis of water quality parameters, comparison with the applicable water quality standards, and calculation and classification of the Pollution Index. The overall research procedure is presented in Figure 1.

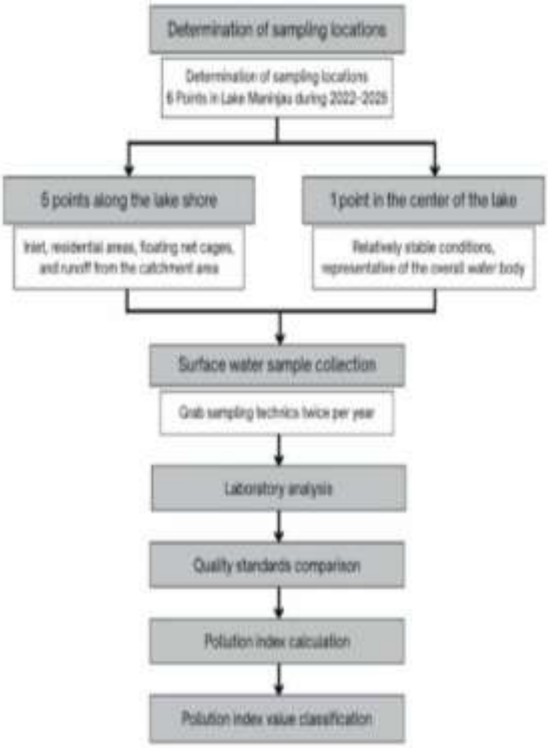

Figure. 1 Research flowchart

Some sampling processes in 2022-2025 can be seen in Figure 2. The sampling locations, spread around the lake and one location in the center, were chosen based on considerations of the spatial representativeness of water quality (Amru et al., 2022). The locations around the lake were chosen to represent areas directly affected by anthropogenic activities, such as inlets, residential areas, floating net cage cultivation activities, and runoff from the catchment area. Meanwhile, the location in the center of the lake was used to represent relatively more stable water conditions and reflect the accumulation of water mass and the distribution of water quality parameters in general. Therefore, the combination of these sampling locations is expected to comprehensively describe the spatial variation in Lake Maninjau's water quality. The distribution of surface water quality monitoring locations in Lake Maninjau is presented in Table 1 and Figure 3.

Figure 2. Some Sampling Processes

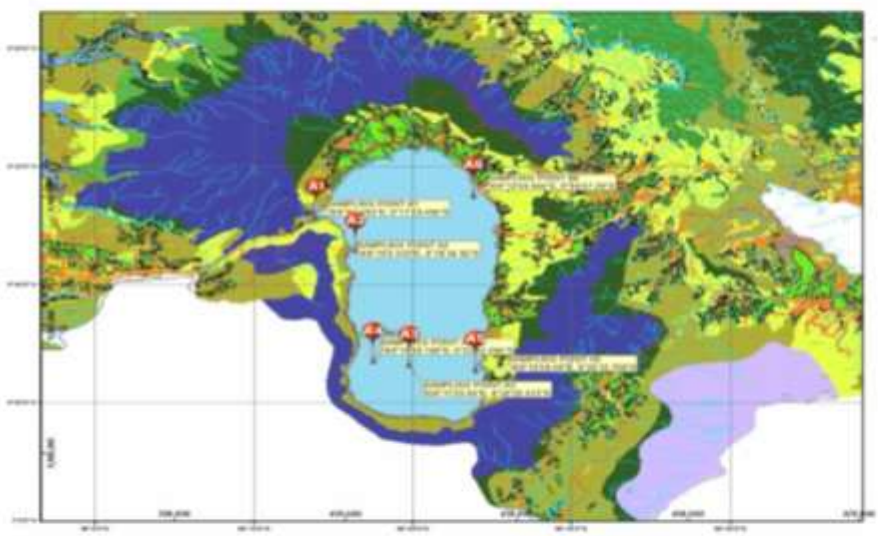

Figure. 3 Sampling Stations

Table 1. Locations for monitoring surface water quality in Lake Maninjau

Sampling Point	Information	Coordinate Points	
		LS	BT
A1	Jorong Muko-Muko Kecamatan Tanjung Raya	-0.291526	100.151137
A2	Jorong Sungai Tampang Kecamatan Tanjung Raya	-0.309700	100.167370
A3	Tengah Danau Maninjau	-0.372920	100.189150
A4	Jorong Galapuang Kecamatan Tanjung Raya	-0.370890	100.175030
A5	Nagari Tanjung Sani Kecamatan Tanjung Raya	-0.376030	100.216550
A6	Nagari Bayur Kecamatan Tanjung Raya	-0.279800	100.215740

Water sampling was conducted using the grab sampling technique, a method in which water samples are collected directly at a single, specific point in time at each monitoring station. In this technique, instantaneous samples are obtained from the designated locations, ensuring that the acquired data accurately represent the water quality conditions of the water body at the exact moment of collection (Martín-García et al., 2023).

The collected water samples were then analyzed at the Environmental Laboratory Unit of the Agam Regency Environmental Service to determine the concentration of each water quality parameter. The sample analysis process conformed to the methods established in the Indonesian National Standards and relevant international standards utilized by the laboratory. The detailed testing techniques for each water quality parameter are presented in Table 2.

Table 2. Sample Analysis Techniques

Parameter	Unit	Test Method
pH	-	SNI 06-6989.11-2019
Total Suspended Solids (TSS)	mg/L	SNI 06-6989.3:2019
Dissolved Oxygen (DO)	mg/L	SNI 06-6989.14-2004
Biochemical Oxygen Demand (BOD_5)	mg/L	пSNI 6989.72:2009
Chemical Oxygen Demand (COD)	mg/L	SNI 6989.2:2019
Total Phosphate (PO_4-P)	mg/L	SNI 6989.31:2021
Nitrate (NO_3-N)	mg/L	15/IK-M/LL (Spectrophotometry)
Fecal Coli	MPN/100 ml	APHA 9221 F, 2012

The results of the lake water quality analysis then compared with Class II water quality standards as regulated in Government Regulation No. 22 of 2021. The regulation states that if a region has not yet established a water class classification, then Class II water quality standards must be used. Therefore, this study used Class II standards as a reference because the water class classification at the study site had not yet been established. Class II water quality standards are intended for waters used for freshwater fish farming, livestock farming, agricultural irrigation, and water recreation facilities and infrastructure.

Furthermore, the determination of water quality status is carried out using the pollution index method which refers to the Decree of the Minister of State for the Environment Number 115 of 2003. The calculation of the pollution index value is carried out using the following Formula 1.

$$PI_j = \sqrt{\frac{\left(\frac{Ci}{Lij}\right)^2 M + \left(\frac{Ci}{Lij}\right)^2 R}{2}} \tag{1}$$

Where,

PI_j : Pollution Index

Ci : Concentration of water quality parameters

Lij : Concentration of water quality parameters in water standard designation

$$\left(\frac{Ci}{Lij}\right)^2 M \tag{2}$$

$$\left(\frac{Ci}{Lij}\right)^2 R \tag{3}$$

Where, equations (2) and (3) are maximum value of $\frac{Ci}{Lij}$ and average value of $\frac{Ci}{Lij}$

The Pollution Index value obtained is then compared with the Pollution Index value classification to determine the level of water quality conditions, as referred to in the Decree of the Minister of State for the Environment Number 115 of 2003. The classification or grouping of pollution index values used in determining water quality status is presented in Table 3.

Table 3. Classification of Pollution Index Values

Water Pollution Index	Water Conditions
$0 \le PI_j \le 1$	Good Conditions
$1 < PI_j \le 5$	Light Pollution
$5 < PI_j \le 10$	Moderate Pollution
$PI_j > 10$	Severe Pollution

Result and Discussion

Water Quality of Lake Maninjau

The results of surface water quality monitoring conducted at Lake Maninjau for several parameters including pH, DO, BOD, COD, TSS, and PO_4 were compared with Appendix VI of Government Regulation Number 22 of 2021.

pH

pH is a key parameter in determining the lake water quality index because its value directly reflects the overall chemical balance of the water (Malla-Pradhan et al., 2024).The results of the pH parameter analysis can be seen in Figure 4.

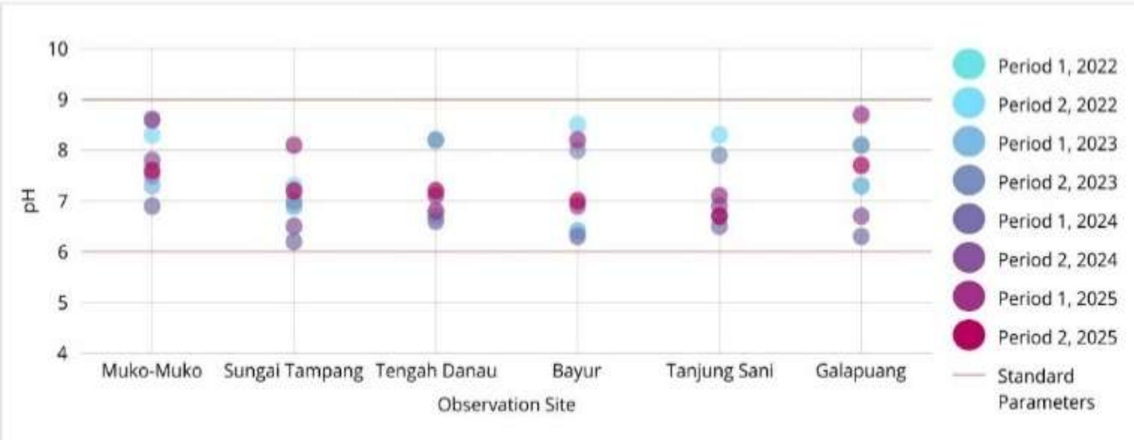

Figure 4. pH levels of lake water samples

Based on the graph of pH measurement results at several observation locations in Lake Maninjau during the period 2022-2025, it can be seen that the pH value is generally still within the standard range of lake water quality (pH 6-9). Ecologically, the pH value is one of the important parameters that affect the survival of aquatic organisms because pH plays a role in controlling chemical reactions in water, nutrient availability, and the toxicity level of several compounds such as ammonia and heavy metals (Pinheiro et al., 2021). Waters with a pH that is too low (acidic) can cause physiological disorders in fish and other aquatic organisms, while a pH that is too high (alkaline) can increase ammonia toxicity which is harmful to aquatic biota (Parvathy et al., 2023).

Dissolved oxygen (DO)

Dissolved Oxygen (DO) represents the amount of oxygen dissolved in water and plays a crucial role in regulating chemical and biological processes in natural waters. DO concentrations are influenced by various factors, such as biological activities, chemical redox processes, oxygen solubility, gas exchange between air and water, and nutrient influx into water bodies. This parameter is widely used as a water quality indicator because it reflects the capacity of a water body to support aquatic life and maintain ecosystem balance. (Brezonik & Arnold, 2022). The results of the DO parameter analysis can be seen in Figure 5.

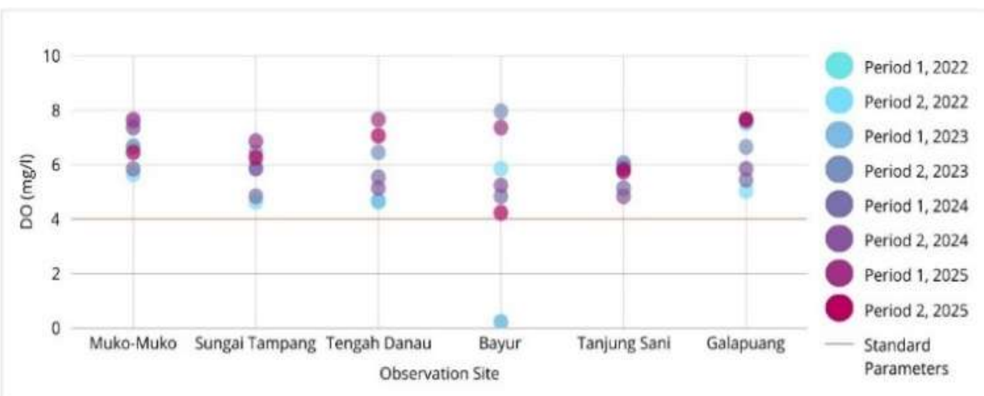

Figure 5. DO concentrations in Lake Maninjau

The graph of DO measurement results for the 2022–2025 period shows that DO concentrations ranged from 4 to 8 mg/L at most monitoring sites. These concentrations generally remained above the minimum threshold of 4 mg/L. However, there was one monitoring site during one of the periods that showed a very low DO concentration (approacing 0 mg/L).

The deterioration of lake water quality, especially in terms of the availability of dissolved oxygen levels, can be caused by the accumulation of high levels of organic matter in the water (Anamika et al., 2025). This accumulation of organic matter generally originates from uneaten fish feed and metabolic waste produced by floating net cage activities (Wojewódka-Przybył et al., 2024). In Lake Maninjau, the contribution of floating net cages to organic matter input is significant, with more than 50% of total organic matter derived from this activity. The magnitude of this input indicates that floating net cage activities are one of the factors affecting water quality conditions. However, the high organic load from floating net cages is not the sole cause of the decrease in DO concentration to near 0 mg/L or anoxic conditions (Carey et al., 2022; Dresti et al., 2023). This condition is actually the result of the interaction of two interrelated factors. These factors are the long-term accumulation of organic matter on the lake bottom and natural hydrological dynamics in the form of upwelling or water mass turnover due to the disruption of the thermal stability of the water column (Ladwig et al., 2021). These conditions are generally triggered by high precipitation level (Olsson et al., 2025), high-velocity winds (P€oschke et al., 2015; Sadeghpour et al., 2025), or a sudden drop in ambient air temperature (Tau et al., 2025).

Normally, lakes undergo thermal stratification, which forms three main layers. Namely the epilimnion as the warm and oxygen-rich upper layer, the metalimnion as the transition layer, and the hypolimnion as the cooler and oxygen-poor lower layer (Adjovu et al., 2023; Boehrer et al., 2008). An upwelling phenomenon forces the large-scale displacement of the hypolimnion to the surface; this subsequent water mass mixing results in a sharp decrease in surface oxygen concentrations (Sadeghpour et al., 2025). Furthermore, toxic compounds such as hydrogen sulfide (H_2S) are also transported to the upper layer (Sone et al., 2023). This combination constitutes the primary cause of recurrent mass fish kills in tropical lakes (Fukushima et al., 2017). Consequently, the anoxic conditions in Lake Maninjau must be understood as a result of the interaction between high anthropogenic organic loads from floating net cages and the lake's natural hydrological dynamics.

Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand is is a measure of the amount of dissolved oxygen required by microorganisms to decompose biodegradable organic matter present in water or wastewater. This parameter is widely used as a water quality indicator because it reflects the magnitude of organic pollution loading within a water body. BOD values are generally determined through the incubation of samples under dark conditions at a temperature of 20 °C for a specific duration, with BOD_5 representing the amount of oxygen consumed during a five-day testing period (Brezonik & Arnold, 2022; Nweke et al., 2022). The results of the BOD parameter analysis can be seen in Figure 6.

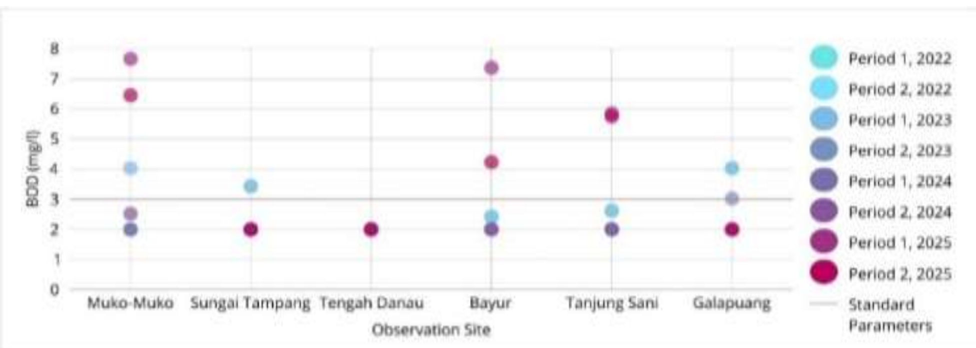

Figure 6. BOD concentrations in Lake Maninjau

Based on the BOD measurement charts from the 2022–2025 period, BOD concentrations generally ranged between 2 and 4 mg/L. However, higher values reaching approximately 6–7 mg/L were recorded during specific periods, particularly at the Muko-Muko and Bayur stations. These elevated BOD values at certain sampling locations indicate an increased organic matter loading in the water column (Al-Fanharawi & Al-Khafaji, 2023). This condition is consistent with the recorded DO patterns, where locations with higher BOD values tended to exhibit lower DO concentrations (Dharmawan et al., 2020; Razif, 2022). This inverse relationship between BOD and DO reflects intensive organic matter decomposition by heterotrophic microorganisms, which consume substantial amounts of dissolved oxygen for aerobic respiration (Liqoarobby et al., 2021). High BOD values may indicate excessive organic pollution originating from domestic waste, aquaculture activities, and the decomposition of organic materials entering the aquatic system. Elevated BOD concentrations can reduce dissolved oxygen levels due to the increasing oxygen demand during microbial decomposition of organic matter. This condition may create an unfavorable environment for aquatic organisms, particularly cultured fish, as it can disrupt fish metabolism, increase physiological stress, and potentially lead to fish mortality when accompanied by low DO concentrations (Iskandar et al., 2024).

Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is the amount of oxygen required to oxidize all oxidizable organic and inorganic compounds in water or wastewater under certain test conditions (Nweke et al., 2022). The results of the COD parameter analysis can be seen in Figure 7.

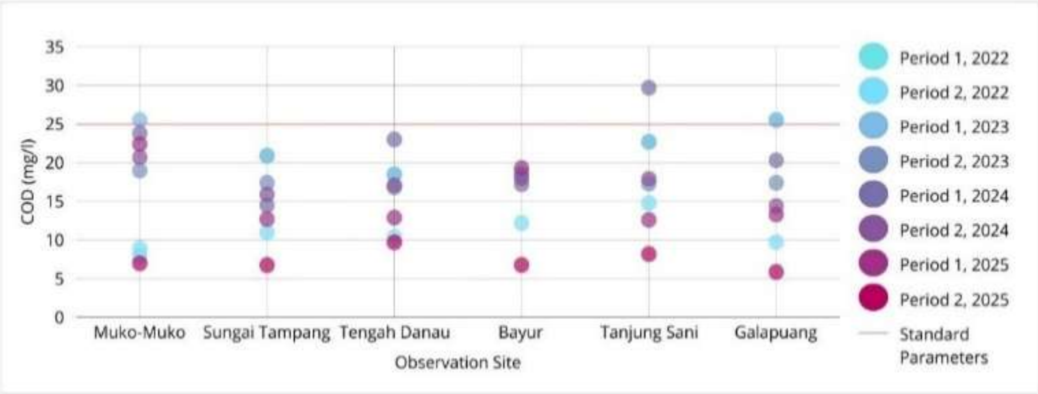

Figure 7. Chemical Oxygen Demand (COD) concentrations in Lake Maninjau

Based on the COD measurement charts from the 2022–2025 period, COD concentrations ranged between 6 and 30 mg/L. Most of the values remained below or near the water quality standard threshold of approximately 25 mg/L. However, during certain periods, particularly at the Tanjung Sani and Muko-Muko stations, COD levels were observed to approach or even exceed this threshold. This condition indicates an increased presence of both organic matter and other chemical compounds that require oxygen for oxidation processes (Hendrasarie & Cahyarani, 2019). In lake aquatic systems, elevated COD is generally associated with the influx of organic waste from anthropogenic activities around the water body, including domestic wastewater, agricultural runoff, as well as uneaten feed and fish feces from floating net cage aquaculture (Moussa & Mostafa, 2021; Y. Zhang et al., 2023).

Total Suspended Solids (TSS)

TSS are suspended particles in water, including organic and inorganic materials, which affect light penetration and aquatic ecosystems (Giardino et al., 2017). The results of the TSS parameter analysis can be seen in Figure 8.

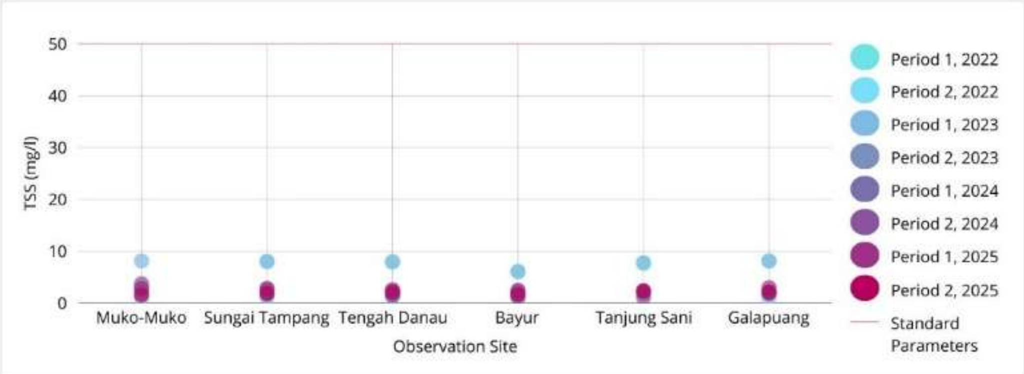

Figure 8. Total Suspended Solids (TSS) concentrations in Lake Maninjau

Based on the TSS measurement results graph for the 2022-2025 period, it can be seen that all TSS concentration values at all monitoring points are still far below the quality standard threshold, indicating that the level of suspended solids in these waters is still relatively low. Low TSS concentrations, as shown in this graph, indicate that water turbidity is relatively low, so that sunlight penetration into the water column is still quite good (Lestari et al., 2023). This condition is important for the lake ecosystem because sunlight is needed by phytoplankton and aquatic plants for photosynthesis (Henderson & Bukaveckas, 2022; Lai et al., 2024).

Phosphate (PO_4)

Phosphorus plays a major role in biological metabolism. Compared to other macronutrients required by biota, phosphorus is the least abundant element and is generally the primary limiting factor for biological productivity in most freshwater bodies. Consequently, phosphorus is closely linked to phytoplankton biomass and production rates, as well as hypolimnetic oxygen concentrations and other trophic status indicators (Dillon & Molot, 2023).The results of the Phosphate parameter analysis can be seen in Figure 9.

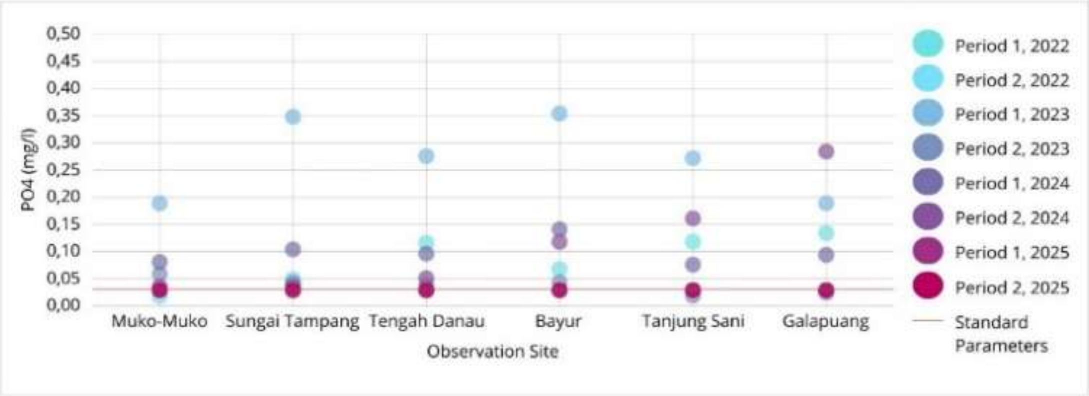

Figure 9. Phosphate (PO_4) concentrations in Lake Maninjau

The PO_4 measurement results across the six observation stations during the 2022–2025 period indicate that PO_4 concentrations in 2022 were higher than those in subsequent periods. Several locations, such as Sungai Tampang, Bayur, and Tanjung Sani, recorded the highest PO_4 values, ranging from 0.27 to 0.35 mg/L. This pattern indicates a pronounced nutrient enrichment at the beginning of the observation period (Badamasi et al., 2019; Feng et al., 2023). In lake ecosystems, phosphate is the primary limiting nutrient that heavily determines the growth of phytoplankton and algae (Bai et al., 2022; Wu et al., 2022). An increase in phosphate concentrations can elevate primary productivity in water bodies, subsequently triggering excessive algal growth. This phenomenon has the potential to degrade water quality and disrupt the balance of aquatic ecosystems (Yang et al., 2021).

The Sungai Tampang location, which serves as an inlet, exhibited the highest phosphate concentrations at the beginning of the observation period, indicating that this area potentially acts as the primary pathway for land-based nutrient influx into the lake body. These nutrient sources are presumably derived from agricultural runoff, domestic wastewater, soil erosion, and aquaculture activities around the water body (Wang et al., 2017; Warsa & Haryadi, 2019). This condition aligns with various lake management studies demonstrating that an increased nutrient load from the catchment area is proven to accelerate the eutrophication process, particularly in tropical lakes facing high anthropogenic pressure within their riparian zones (Allafta et al., 2021; Han et al., 2023; Withers et al., 2024).

The conditions at the Bayur station are also noteworthy, as the high PO_4 concentrations at this location occurred simultaneously with elevated BOD values and relatively low DO concentrations during the same period. The relationship among these three parameters indicates interconnected ecological processes that mutually influence the aquatic system. High phosphate concentrations act as a primary nutrient driving excessive phytoplankton growth. When this algal biomass dies and settles, its decomposition consumes substantial amounts of dissolved oxygen, consequently leading to an increase in BOD values and a decrease in DO concentrations in the water column (Crossman et al., 2021).

During the 2023–2025 period, PO_4 concentrations at most observation stations showed a gradual decline, falling within the range of 0.02 to 0.15 mg/L. This decrease can be interpreted as an indication of reduced nutrient pressure on the surface water layer. This condition is presumed to be influenced by several processes, such as phosphate uptake by phytoplankton, phosphate sedimentation into the bottom sediments, and potential pollution control efforts within the catchment area (Ibáñez & Peñuelas, 2019). Ecologically, declining phosphate concentrations have the potential to reduce the risk of algal blooms and help maintain the stability of dissolved oxygen concentrations in the surface water layer (Berthold & Schumann, 2020). However, low PO_4 concentrations in the surface layer do not necessarily indicate that the lake has fully recovered. A critical mechanism that warrants consideration in lake ecology studies is internal phosphorus loading—a process involving the re-release of phosphorus from bottom sediments into the water column when the lower water layer experiences oxygen-poor or anoxic conditions, which can intermittently release phosphate back into the water column and trigger an increase in aquatic nutrient concentrations (Neweshy et al., 2022; Tammeorg et al., 2026).

Water Quality Status of Lake Maninjau

Based on the laboratory sample analysis results, the next step involves calculating the Pollution Index of the Lake Maninjau water body. The calculation results for the Lake Maninjau Pollution Index from the 2022–2025 period is presented in Table 4.

Table 4. Results of the Pollution Index calculation for Lake Maninjau in 2022-2025

Sample point	Pollution Index							
	2022		2023		2024		2025	
	Period I	Period II	Period I	Period II	Period I	Period II	Period I	Period II
Muko-Muko	0.60	0.77	3.65	1.81	2.33	1.06	0.73	0.70
Tampang River	1.58	1.27	4.61	1.33	2.73	1.08	0.69	0.71
Middle of the Lake	2.90	0.79	4.24	1.15	2.60	1.61	0.71	0.71
Bayur	2.18	0.78	4.70	1.35	3.19	2.91	0.69	0.80
Tanjung Sani	2.92	0.78	4.22	0.58	2.26	3.39	0.69	0.69
Galapuang	3.12	0.78	3.65	0.78	2.57	4.27	0.67	0.68

Subsequently, the water quality status of Lake Maninjau was determined by evaluating the obtained Pollution Index values. The water quality status of Lake Maninjau is presented in Table 5.

Table 5. Results of Determining the Quality Status of Lake Maninjau in 2022-2025

Sample point	Pollution Index							
	2022		2023		2024		2025	
	I	II	I	II	I	II	I	II
A1	Good Conditions	Good Conditions	Light Pollution	Light Pollution	Light Pollution	Light Pollution	Good Conditions	Good Conditions
A2	Light Pollution	Light Pollution	Light Pollution	Light Pollution	Light Pollution	Light Pollution	Good Conditions	Good Conditions
A3	Light Pollution	Good Conditions	Light Pollution	Light Pollution	Light Pollution	Light Pollution	Good Conditions	Good Conditions
A4	Light Pollution	Good Conditions	Light Pollution	Light Pollution	Light Pollution	Light Pollution	Good Conditions	Good Conditions
A5	Light Pollution	Good Conditions	Light Pollution	Good Conditions	Light Pollution	Light Pollution	Good Conditions	Good Conditions
A6	Light Pollution	Good Conditions	Light Pollution	Good Conditions	Light Pollution	Light Pollution	Good Conditions	Good Conditions

Based on the Pollution Index analysis results from the 2022–2025 period, the water quality of Lake Maninjau exhibited a fluctuating degradation pattern. In 2022, several monitoring stations were still classified under the good condition status, indicating that the assimilation capacity of the water body was still able to counteract the ongoing anthropogenic pressures. However, this condition did not persist into the subsequent periods. From 2023 to 2024, all sampling sites were dominated by a lightvollution status, indicating a continuous accumulation of pollution pressure. Ecologically, a slightly polluted status in water bodies is associated with increased nutrient loading, particularly nitrogen and phosphorus, which triggers the early stages of eutrophication (Devlin & Brodie, 2023). This condition is inextricably linked to the high intensity of floating net cage aquaculture, which is known to contribute to more than 50% of the total organic matter input into the lake (Azrita, 2014), alongside additional pressure from catchment runoff and domestic wastewater discharge from settlements along the riparian zone (Kurniati et al., 2021). The high influx of organic matter and nutrients from these various sources synergistically drives water quality degradation and disrupts the aquatic ecosystem equilibrium, which is ultimately reflected in the deteriorating pollution index values during this period.

During the first and second sampling periods of 2025, all monitoring stations demonstrated a recovery in water quality status, returning to the good conditions. This condition serves as a positive ecological signal, indicating a reduction in pollution pressure within Lake Maninjau. Although quantitative data regarding changes in the number of operational floating net cages were unavailable in this study, the observed improvement in the Pollution Index status is presumed to be linked to a decreased influx of organic matter and nutrient loading into the water body (Kubo et al., 2019). This is supported by the fact that floating net cage aquaculture is known to contribute more dominant pollution loads compared to other sources, such as settlements, agriculture, and livestock around the lake (Komala et al., 2024).

Nevertheless, the fluctuating patterns of the Pollution Index observed throughout the 2022–2025 period indicate that the Lake Maninjau aquatic system remains highly vulnerable to dynamic external pressures (Supriya et al., 2025; W. Zhang et al., 2025). The water quality improvement observed in 2025 should not be interpreted as a stable and permanent condition. This limitation is due to the persistent potential for internal phosphorus loading from the bottom sediments, which can re-elevate nutrient concentrations in the water column, particularly during upwelling events that induce intensive water mass mixing (Zhao et al., 2024). If pollution loads are not controlled consistently and sustainably, the water body potentially risks a resurgence in eutrophication levels (Yusal et al., 2025).

Consequently, preventive and ecosystem-based management strategies are urgently required. Such efforts can be implemented by controlling nutrient loads through the regulation of floating net cage capacities based on carrying capacity assessments, managing domestic waste in the riparian zones, and conducting regular, structured water quality monitoring to serve as a foundation for adaptive and sustainable lake management decisions.

Conclusion

The water quality analysis of Lake Maninjau over the 2022–2025 period revealed that its water quality status fluctuated between good conditions and light pollution categories based on Pollution Index calculations. In 2022, several monitoring stations maintained good conditions; however, this condition deteriorated during the 2023–2024 period, during which all sampling points shifted to a light pollution status, illustrating a progressive accumulation of pollution pressure. The parameters that most consistently exceeded or approached regulatory thresholds throughout the study were PO_4, with peak concentrations reaching 0.30–0.35 mg/L in 2022, and BOD, which reached 6–7 mg/L particularly at the Muko-Muko and Bayur stations. Together, these values indicate that eutrophication pressure and organic loading are the primary drivers of water quality degradation. The elevated levels of both parameters are inextricably linked to floating net cage aquaculture, which contributes over 50% of the total organic matter influx into the lake, compounded by nutrient inputs from catchment runoff and domestic wastewater along the riparian zones. During the 2025 sampling periods, all sampling points demonstrated a recovery back to the good conditions. The fluctuating patterns observed throughout the study period indicate that the Lake Maninjau aquatic system remains highly vulnerable to dynamic external pressures. Without consistent nutrient load reductions—specifically through the regulation of floating net cage capacities based on carrying capacity assessments and structured water quality monitoring—the risk of shifting back toward polluted conditions or advanced eutrophication remains a distinct ecological threat to the long-term sustainability and functions of Lake Maninjau.

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J.K: preparation of original draft, results, discussion, methodology, conclusion, analysis, review, proofreading and editing.

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Conflicts of Interest

The authors declare no conflict of interest.

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