Application of water quality index (WQI) for surface water quality assessment in Maninjau Lake, Agam, West Sumatra, Indonesia

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Abstract. Maninjau Lake was designated as a national strategic area and a national tourism strategic area in 2019 as part of an effort to prevent damage, maintain, and restore the function of the lake's water bodies, water catchment areas, and lake borders for the welfare of the community in a sustainable way. Some local people use Maninjau Lake as a location for floating net cage (FNC) fish farming operations, which is thought to have an impact and alter the quality of the waters. Therefore, an investigation was needed to monitor Maninjau Lake's surface water quality. The investigation was conducted by measuring the quality of surface water at five observation stations. Analysis of water quality used the STORET (Storage and Retrieval of Water Quality Data System) method by comparing it with Class 2 lake water quality standards. The results of this study indicated that the waters of Maninjau Lake, especially Stations 1, 2, and 3, were heavily polluted, while Stations 4 and 5 were moderately polluted. To preserve the Maninjau Lake ecosystem, continuous monitoring of water quality is required. One of the steps to deal with it is a comprehensive lake spatial arrangement so that the proposed policy steps will greatly assist efforts to restore water conditions.

Key Words: floating net cages (FNC), national strategic area, national tourism strategic area, STORET method.

Introduction. Lakes are inland water ecosystems that are very important for human life. The use of the lake by various sectors and activities of people's lives around the lake causes environmental pressure on the lake waters. As a result of environmental pressures, the functions and benefits of lakes have recently been noticeably declining (Nugroho et al 2014). Environmental pressures occur in the form of damage to the aquatic environment and lake pollution due to uncoordinated management and utilization among the sectors involved. Dembowska and Józefowicz (2015) and Dembowska et al (2015) define a lake as an inland body of water without direct water exchange with the ocean. Lake ecosystems consist of the physical, chemical, and biological properties contained in these water bodies.

Lakes are unique ecosystems on the earth's surface (Syandri et al 2020). Lakes provide humankind with food, raw materials, and water resources (Maimaitihan et al 2019) and maintain ecological balance, biodiversity, and resources for endangered species (Wang et al 2019). In addition, lakes also play an essential role in water conservation, flood control, climate change (Aguilera et al 2016), pollution degradation (Horppila 2019; Ahmed & Thompson 2019), maintenance of climate change (Tal 2019), and natural resources. Around the world, lakes are also used for social and economic benefit due to tourism and recreation.

Maninjau Lake is a test-volcanic area that stretches over an area of 99.5 km². It has an essential role as a tourist destination and hydroelectric generator. It is also used for floating net cage (FNC) operations and fishing activities (Syandri et al 2014a; Syandri et al 2015a). The number of FNC increased exponentially between 2001 and 2018 and by 90.14% in the last five years (Junaidi et al 2022). FNC business enthusiasts are increasing. The difference in the number of floating net cages in each village is mainly due to the length of the coastline owned by each village. The fish commonly cultivated in the lake are *Cyprinus carpio* and *Oreochromis niloticus* (Syandri et al 2017).

Despite the progress that has been made in managing FNC operations in Maninjau Lake, such as improvements in cultivation technology (Syandri et al 2018a,b), lake anthropogenic eutrophication remains one of the most obvious and common water quality problems. Phosphorus (P) is usually a limiting nutrient for productivity in lakes and is critical in the eutrophication process (Zhang et al 2019; Wang et al 2019). The phosphorus load from fish farming activities in Maninjau Lake is 693.4 tons year^{-1}. At the same time, from the water catchment area, it is 20 tons year^{-1}. This impacts the fertility status of Maninjau Lake to become hypertrophic with a total concentration of P and chlorophyll-a of 540 and 41.4 µg L^{-1} respectively, with a brightness level of 1.1 m. This illustrates that the pollutant load of phosphorus has exceeded the ecological carrying capacity of Maninjau Lake, which is 223.4 tons year^{-1} (Warsa & Haryadi 2019).

In this decade, the pressure on the environment of Maninjau Lake was not only caused by the growing development of fish farming in FNC but also due to increasingly intensive land use in the water catchment area, land use on the lake's border for settlements, the conversion of paddy fields into fishponds and the designation of others for infrastructure development (Syandri et al 2014a). These activities have led to an increase in organic loading on lake water bodies which has a direct impact on decreasing water quality (Syandri et al 2015a) and fish species diversity (Dina et al 2011; Syandri et al 2014b), so that when a water mass reversal occurs (embankments), this can cause mass mortality of fish within the FNC. The impact of the sediment accumulation is that when the mass of water is turned over, the water becomes heavily polluted and dissolved oxygen (DO) levels decrease below 3 mg L^{-1}. The increase in toxic compounds causes yearly mass fish deaths and economic losses to fishery actors.

Water pollution is the most severe threat to human health. It is estimated that about 80% of all diseases in humankind are caused by one or another aspect of unhealthy water. Contamination of lakes and other reservoirs is a common phenomenon in almost all developing countries, especially urban ones. Demographic expansion and lack of civil facilities have made these natural lake waters situation very delicate, and many environmental issues are present. Most urban and rural lakes have disappeared due to human negligence (Iscen et al 2008; Prasanna et al 2010), and others that can maintain this pressure, have water that is undrinkable or unable to meet human needs (Zhang et al 2009).

To preserve the Maninjau Lake ecosystem, continuous water quality monitoring is required. Water quality data for lake monitoring is available in 3 data packages for one year, namely data representing the rainy, transitional, and dry seasons. Various methods have been used to provide information on the water quality of Maninjau Lake (Syandri et al 2015b; Sulastri et al 2016; Helviza 2020; Nazir et al 2017). This information includes surface water quality conditions from physical, chemical, and biological parameters, which show that the water quality of Maninjau Lake continues to decline every year. However, the information presented is only limited to specific years.

This study aimed to determine the surface water quality status in Maninjau Lake. This research shows stations with water quality status that is heavily or lightly polluted, so they need to get more attention and manage potential sources of pollution in that location. In this study, surface water quality status was determined using the STORET (Storage and Retrieval of Water Quality Data System) method developed by the United States Environmental Protection Agency (US EPA 2002) based on Minister of Environment Decree No. 115 of 2003 concerning Guidelines for Determining Water Quality Status. This method is one of the methods commonly used in determining the water quality status of lakes, rivers, and seas (Suparno et al 2023; Rintaka et al 2019; Sentosa et al 2018; Piranti et al 2018; Saputra et al 2017; Walukow 2010). The results of this study are expected to provide up-to-date information on surface water quality, which can be used as material for monitoring and consideration in decision-making at the central and regional levels regarding managing the Maninjau Lake ecosystem.

Material and Method

Description of the study sites. Maninjau Lake is located in Agam, West Sumatera, Indonesia. In this study, surface water sampling was carried out at five stations (T1, T2, T3, T4, T5), namely: Muko Muko (0°17'26.60"S 100°9'18.66"E), Koto Malintang (0°16'40.32"S 100°9'34.28"E), Muaro Suak (0°15'45.67"S 100°10'33.02"E), Payinggahan Nagari Maninjau (0°18'35.57"S 100°13'25.75"E) and Tanjung Sani (0°23'53.01"S 100°11'40.38"E) (Figure 1).

The water was sampled from February to April 2023, once a month, with three water samples to represent the region's rainy, transition, and dry seasons. The description of the sampling station is as follows: 1) Muko Muko (T1) is the water exit of Maninjau Lake; there is a turbine and a sluice gate to regulate lake water. Since it was made a Hydro Electric Power Center (HEPC), the water outlet has always been regulated so that the lake's waste was stuck in this location. The existence of FNC is limited to 30 units; community activities were focused on tourism, education, and housing; 2) Koto Malintang (T2) where farmers' activities in tilapia (*Oreochromis niloticus*) cultivation using the FNC system were the highest, with 3,459 units and other activities regard paddy fields cultivation; 3) Muaro Suak (T3) where in this location is the estuary of the Batang Suak River, which flows from Nagari Koto Gadang. Community activities are FNC system fish farming of 660 units and paddy fields; 4) Payinggahan Nagari Maninjau (T4) is a tourist spot and other activities are fish farming in 1,332 units of FNC; 5) Tanjung Sani (T5) has the largest number of villages on Maninjau Lake, and farmers who cultivate tilapia with FNC use 4,364 units. In this area forest covers are steep, and the area is prone to landslides (CSA 2018).

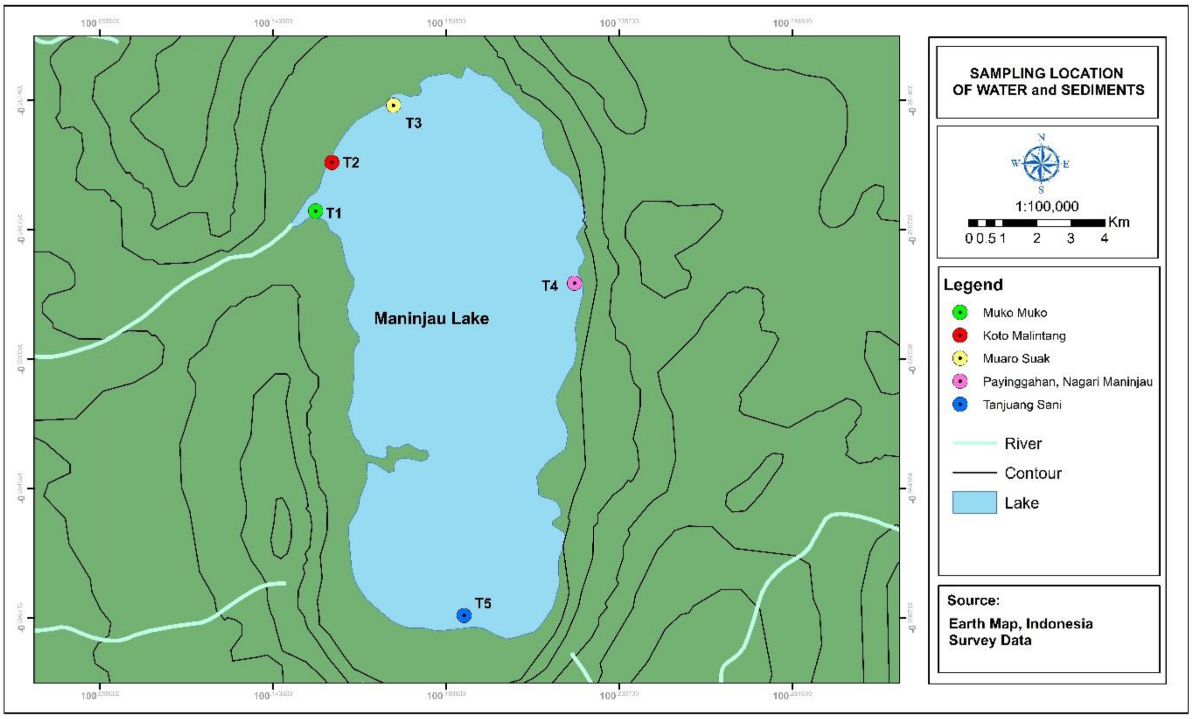

Figure 1. Water sampling locations in Maninjau Lake, West Sumatera, Indonesia (Indonesia Geospatial Portal 2022).

Water sample collection and analysis. Surface water samples were taken from five stations based on the Indonesian National Standard SNI 6989.57 (2008) on how to take water samples. The water samples were collected in a clean 1L plastic bottle, labeled, then put into a cooler. Physical, chemical, and biological parameters such as brightness (Secchi disk), temperature (thermometer), pH (pH meter), and DO (DO meter) were measured directly in the field and other parameters, such as biological oxygen demand (BOD_5), chemical oxygen demand (COD), BOD_5/COD, ammonia (NH_3), nitrite (N-NO_2), nitrate (N-NO_3), total nitrogen, phosphate, hydrogen sulfide (H_2S), sulfates and total coliforms, were analyzed at the Chemistry and Environmental Laboratory of Andalas University.

Determination of water quality status. Measurement of the surface water quality index of Maninjau Lake was analyzed using the STORET method, which refers to the Decree of the Minister of Environment of the Republic of Indonesia No. 115 of 2003 concerning Guidelines for Determining Water Quality Status. The basic principle of the STORET method is to compare water quality with the water quality standard according to its designation (GRRI 2021), to determine the water quality status of an area. The value system is presented in Table 1 and classified into four classes.

Table 1

Classification of water quality

Score	*Class*	*Water quality characteristic*
0	A	Meet the quality standards
-1 to -10	B	Lightly contaminated
-11 to -30	C	Moderately polluted
≥ - 31	D	Heavily polluted

Source: US EPA (2002), Decree of the Minister of Environment of the Republic of Indonesia No. 115 of 2003.

Determination of water quality status using the STORET method can be carried out in the following stages according to Decree of the Minister of Environment of the Republic of Indonesia No. 115 of 2003: 1) had collected water data from the maximum, minimum, and average values of physical, chemical and biological parameters; 2) had obtained the value of each water quality parameter compared to the standard value according to water class; 3) if the measurement result met the water quality standard value (measurement result ≤ quality standard) then the score given was 0; 4) if the value does not meet the water quality standard value, then the score was given by Table 2; 5) STORET Water Quality Index is the total score obtained by using a scoring system determined from the residual score; and 6) according to the total score, water quality can be determined based on Table 1.

Table 2

Determination of water quality status value system

Number of samples	*Score*	*Parameters*		
		Physical	*Chemical*	*Biological*
<10	Maximum	-1	-2	-3
	Minimum	-1	-2	-3
	Mean	-3	-6	-9
≥ 10	Maximum	-2	-4	-6
	Minimum	-2	-4	-6
	Mean	-6	-12	-18

Source: Canter (1977), Decree of the Minister of Environment of the Republic of Indonesia No. 115 of 2003.

Data analysis. The study used a completely randomized design (CRD) consisting of five samplings and three replications to cover different seasons namely: dry, transitional, and rainy. The resulting data was calculated as the mean ± SD. A one-way analysis of variance (ANOVA) was conducted at 95% confidence level (α = 0.05) to test the significance between samples. $P < 0.05$ was considered significant, and where the means differed significantly, a post hoc test was performed using Tukey's Honest Significant Difference. All statistics were performed with SPSS software version 23 for Windows.

Results and Discussion

Water quality analysis. The results of measurements of several surface water quality parameters at five sampling stations and different seasons in Maninjau Lake are presented in Table 3.

Table 3

Surface water quality from different stations and seasons in Maninjau Lake

No	*Parameter*	*Month*	*Stations*				
			1	*2*	*3*	*4*	*5*
1	Brightness (m)	Febr.	2±0.2^{a}	3±0.3^{b}	3±0.2^{b}	5±0.4^{c}	6±0.1^{d}
		March	2±0.1^{a}	3±0.2^{b}	3.5±0.2^{c}	5.5±0.3^{d}	6±0.2^{e}
		April	3±0.2^{a}	3.5±0.2^{b}	3.5±0.2^{b}	6±0.2^{c}	6±0.1^{c}
2	TDS (mg L^{-1})	Febr.	36±0.4^{a}	49±0.3^{b}	49±0.3^{b}	25±0.4^{c}	20±0.2^{d}
		March	35±0.2^{a}	45±0.1^{b}	45±0.3^{b}	23±0.1^{c}	19±0.3^{d}
		April	30±0.1^{a}	40±0.3^{b}	39±0.2^{c}	21±0.0^{d}	18±0.1^{e}
3	TSS (mg L^{-1})	Febr.	3±0.2^{a}	5±0.2^{b}	3.5±0.0^{c}	2±0.3^{d}	2±0.1^{d}
		March	3±0.2^{a}	4±0.1^{b}	5±0.2^{c}	2±0.2^{d}	2±0.0^{d}
		April	2±1.9^{a}	2±1.9^{a}	2±1.9^{a}	1±0.8^{b}	1±0.9^{b}
4	Temperature (°C)	Febr.	29±0.1^{a}	29.3±0.2^{a}	28.6±0.2^{b}	29.3±0.1^{a}	28.5±0.2^{b}
		March	29.1±0.2^{a}	29.1±0.1^{a}	28.7±0.1^{b}	29.1±0.2^{a}	28.7±0.2^{b}
		April	29.3±0.3^{a}	29.3±0.2^{a}	2923±0.2^{a}	29.2±0.1^{a}	29±0.2^{a}
5	BOD (mg L^{-1})	Febr.	2.7±0.1^{ab}	2.5±0.2^{a}	2.8±0.1^{b}	4.5±0.2^{c}	5.5±0.1^{d}
		March	2.8±0.1^{a}	2.5±0.1^{b}	2.6±0.2^{ab}	4.3±0.1^{c}	5.1±0.1^{d}
		April	2.9±0.1^{a}	2.7±0.1^{a}	2.7±0.2^{a}	5±0.1^{b}	5.6±0.2^{c}
6	COD (mg L^{-1})	Febr.	50.1±0.1^{a}	75.3±0.1^{a}	63.25±0.1^{a}	15.3±0.1^{a}	17.8±0.2^{a}
		March	57.3±0.2^{a}	69.2±0.1^{b}	58.8±0.1^{c}	17.9±0.1^{d}	19.7±0.2^{e}
		April	52±0.2^{a}	62±0.1^{b}	53.7±0.2^{c}	15.9±0.1^{d}	16.7±0.2^{e}
7	BOD/COD	Febr.	0.054±0.001^{a}	0.033±0.002^{b}	0.044±0.000^{c}	0.294±0.002^{d}	0.309±0.001^{e}
		March	0.049±0.000^{a}	0.036±0.002^{b}	0.044±0.000^{c}	0.24±0.002^{d}	0.259±0.001^{e}
		April	0.056±0.002^{a}	0.043±0.001^{a}	0.05±0.000^{a}	0.347±0.056^{b}	0.335±0.002^{b}
8	DO (mg L^{-1})	Febr.	4.5±0.1^{a}	3.8±0.2^{b}	3.8±0.1^{b}	6.1±0.2^{c}	6.3±0.2^{c}
		March	4.2±0.1^{a}	3.7±0.2^{b}	3.7±0.1^{b}	5.5±0.2^{c}	5.4±0.2^{c}
		April	4.1±0.0^{a}	3.5±0.1^{b}	3.8±0.1^{c}	5.7±0.2^{d}	5.8±0.2^{d}
9	pH	Febr.	7.1±0.1^{a}	7.4±0.2^{b}	7.4±0.2^{b}	7.5±0.1^{b}	7.6±0.1^{b}
		March	7.2±0.1^{a}	7.5±0.2^{bc}	7.4±0.1^{ab}	7.7±0.2^{c}	7.6±0.1^{bc}
		April	7.1±0.2^{a}	7.6±0.2^{b}	7.6±0.1^{b}	7.9±0.1^{b}	7.9±0.2^{b}
10	NH_3 (mg L^{-1})	Febr.	0.12±0.02^{a}	0.31±0.01^{b}	0.35±0.00^{c}	0.11±002^{a}	0.1±0.00^{a}
		March	0.11±0.02^{a}	0.25±0.02^{b}	0.31±0.0^{c}	0.12±0.02^{a}	0.1±0.00^{a}
		April	0.11±0.03^{a}	0.22±0.02^{b}	0.25±0.0^{b}	0.1±0.02^{a}	0.11±0.00^{a}
11	N-NO_2 (mg L^{-1})	Febr.	0.04±0.02^{a}	0.08±0.01^{b}	0.07±0.00^{b}	0.02±0.01^{a}	0.03±0.00^{a}
		March	0.03±0.02^{ac}	0.07±0.01^{b}	0.06±0.0^{c}	0.02±0.02^{a}	0.04±0.0^{ac}
		April	0.02±0.01^{a}	0.06±0.02^{b}	0.06±0.0^{b}	0.03±0.02^{a}	0.02±0.0^{a}
12	N-NO_3 (mg L^{-1})	Febr.	0.32±0.02^{a}	0.91±0.02^{b}	0.82±0.00^{c}	0.51±0.03^{d}	0.47±0.0^{e}
		March	0.25±0.02^{a}	0.84±0.02^{b}	0.76±0.00^{c}	0.47±0.02^{d}	0.45±0.0^{d}
		April	0.2±0.02^{a}	0.73±0.01^{b}	0.64±0.00^{c}	0.36±0.02^{d}	0.37±0.00^{d}
13	Total Nitrogen (mg L^{-1})	Febr.	0.55±0.02^{a}	0.85±0.01^{b}	0.9±0.00^{c}	0.35±0.02^{d}	0.32±0.0^{d}
		March	0.4±0.02^{a}	0.8±0.01^{b}	0.85±0.00^{c}	0.37±0.02^{d}	0.3±0.0^{e}
		April	0.41±001^{a}	0.82±0.01^{b}	0.81±0.0^{b}	0.3±0.01^{c}	0.27±0.0^{d}
14	Phosphate (mg L^{-1})	Febr.	0.31±0.01^{a}	0.48±0.02^{b}	0.38±0.00^{c}	0.21±0.01^{d}	0.25±0.00^{e}
		March	0.25±0.01^{a}	0.41±0.02^{b}	0.35±0.00^{c}	0.19±0.01^{d}	0.21±0.00^{d}
		April	0.15±0.02^{a}	0.25±0.01^{b}	0.17±0.00^{a}	0.11±0.01^{c}	0.15±0.13^{a}
15	H_2S (mg L^{-1})	Febr.	0.001±0.000^{a}	0.004±0.001^{b}	0.004±0.000^{b}	0.001±0.000^{a}	0.001±0.000^{a}
		March	0.001±0.000^{a}	0.003±0.001^{b}	0.004±0.000^{b}	0.001±0.000^{a}	0.001±0.000^{a}
		April	0.001±0.000^{a}	0.003±0.001^{b}	0.003±0.000^{b}	0.001±0.000^{a}	0.001±0.000^{a}
16	Sulfates (mg L^{-1})	Febr.	1.82±0.02^{a}	1.82±0.01^{a}	1.72±0.00^{b}	1.73±0.01^{b}	2.32±0.00^{c}
		March	1.77±0.01^{a}	1.76±0.01^{a}	1.7±0.00^{b}	1.73±0.01^{c}	1.99±0.00^{d}

		April	1.6±0.02^{a}	1.65±0.01^{b}	1.65±0.00^{b}	1.59±0.01^{a}	1.9±0.00^{c}
17	Total coliform (CFU/100 mL)	Febr.	200±10^{a}	400±10^{b}	350±5^{c}	150±10^{d}	100±5^{e}
		March	220±10^{a}	390±10^{b}	333±6^{c}	155±5^{d}	125±10^{e}
		April	200±10^{a}	375±10^{b}	300±10^{c}	143±10^{d}	130±10^{d}

Note: Average ± SD (n=3) with different superscript letters horizontally indicating significant differences (p<0.05). February: rainy season (there is strong water turbulence); March: transition season (there is moderate water turbulence); April: dry season (there is light water turbulence).

Physical parameters

Brightness and turbidity. Brightness is one of the supporting factors in freshwater fish farming, especially for carp (*Cyprinus carpio*) and tilapia (*Oreochromis niloticus*). The brightness results of the water from in situ observations with a Secchi disk mean that the deeper the measurement results, the better the light penetration into the lake, which contributes to the process of photosynthesis in the lake. In addition, a high brightness level in a lake indicates more transparent waters, and vice versa. Brightness is inversely proportional to turbidity and depth. Findings in the field (Table 3, Figure 2a) show that during the rainy, transitional, and dry seasons (February – April 2023), low brightness (< 4 m) occurred at Stations 1, 2, and 3 due to high turbidity. This turbidity was caused by water turbulence, microorganisms, or plankton, and pollution that can come from inside the lake (such as leftover fish feed that was wasted into the lake) or enter from the river waters around the lake. If plankton was the source of the turbidity, then the amount of individual plankton, or floating microorganisms that always float with the flow of the water, was reflected in the turbidity. Statistically, the best brightness is found at Station 5 both in the rainy season (February) and transition (March), but in the dry season (April) for Stations 4 and 5 results are not significantly different (p>0.05) This finding is in accordance with the opinion of Effendi (2003), which states that the water brightness value is influenced by weather conditions, time of measurement, turbidity, suspended solids, and the accuracy of the person making the measurements. Light intensity will decrease with increasing depth. According to Buitrago et al (2005), the optimal water brightness for fish farming is 3 m. In this study, it was found that brightness is closely related to turbidity (sediment particles in the water column). The higher the number of dissolved particles, the more turbid the water. This value indicates that the waters of Maninjau Lake are suitable for freshwater fish farming using the FNC system.

Total dissolved solids (TDS). In the waters of Maninjau Lake, solids are found in three forms, suspended, volatile, and dissolved. Suspended solids include silt, stir-red bottom sediments, decaying plant material, or sewage treatment waste. Suspended solids will not pass through the filter, while dissolved solids will. TDS is the level of nutrient solution in water. TDS values at all stations and seasons are below the permitted threshold (Table 3, Figure 2b), which is < 1000 mg L^{-1}. They are still suitable for tourism activities and fish growth (GRRI 2021). The low TDS value is suspected of having dissolved salt levels in lake waters or aquatic biota being able to utilize the dissolved ions or minerals. The concentration of TDS in water bodies is influenced by various factors, including fertilizers and organic matter. Fertilizers from fields and lawns can add various ions to lake waters. Organic matter from wastewater treatment plants can contribute to higher levels of nitrate or phosphate ions. Many aquatic life forms are affected if TDS levels are high, mainly due to dissolved salts. Dissolved solids levels at Stations 1, 2, and 3 were higher than at Stations 4 and 5, but still below 1000 mg L^{-1}. Statistically, the best TDS is at Station 5, and when compared among seasons, the dry season at Station 5 has the smallest TDS and is significantly different (p<0.05) from other seasons. This value indicates that the waters of Maninjau Lake are suitable for tourism and FNC system freshwater fish farming. Dissolved solids in water describe the concentration of inorganic salts and small amounts of organic matter dissolved in water. Inorganic substances may originate from mineral deposits and salts released from the soil and carried into the water.

Total suspended solids (TSS). TSS in water significantly affects the brightness of lake water. The higher the amount of TSS in the water, the lower the lake brightness value. The TSS values (Table 3, Figure 2c) of all stations are still below 50 mg L^{-1} (GRRI 2021), so it can be said that it is feasible to be used as a location for freshwater fish farming. However, the TSS value in the rainy season is higher than in the dry season, causing natural waters to become more turbid and even forming organic deposits at the bottom of the lake. This organic matter deposition can reduce the oxygen content of the waters through natural oxidation processes, including microbial respiration and aerobic decomposition, which can harm cultivated biota. According to Effendi (2003), TSS consists of silt, fine sand, and microorganisms, mainly caused by soil erosion or erosion carried into water bodies. Land clearing for settlements causes soil erosion when it rains. This can be seen from the color of the waters in Maninjau Lake, which turned brown due to high soil particles entering the lake. Statistically, the best TSS was found at Stations 4 and 5, especially during the dry season, and was significantly different ($p<0.05$) from Stations 1, 2, and 3.

Temperature. Freshwater fish are poikilothermic water animals, so their body temperature will adjust to the water temperature, affecting behaviour and metabolism. Water temperature is a controlling factor for all aquatic life. All biological and chemical processes in the aquaculture process are affected by temperature. Temperature is one of the most important external factors affecting fish production. Fish growth is reduced at temperatures above or below the optimum, and death can occur at extreme temperatures (Joseph et al 1993). Boyd (1982) reported that the water temperature range of 26.06-31.97^{o}C suits warm water fish farming. Based on Table 1 and Figure 2d, the temperature at intervals of 28.5 and 29.3^{o}C is suitable for fish farming in Maninjau Lake. In general, sampling stations and seasons have no significant effect ($p>0.05$) on temperature. This finding is in line with the opinion of Bolorunduro and Abdullah (1996), that a temperature range between 28 and 31^{o}C is ideal for tropical fish farming. In addition, temperature also affects the rate of chemical and biological reactions. The increased rate of chemical reactions caused by temperature and low levels of dissolved oxygen will initiate stress in aquatic organisms. In line with that, Effendi (2003) stated that an increase in temperature will increase viscosity, chemical reactions, evaporation, and volatility and cause a decrease in dissolved gases (O_2, CO_2, N_2, CH_4, etc.).

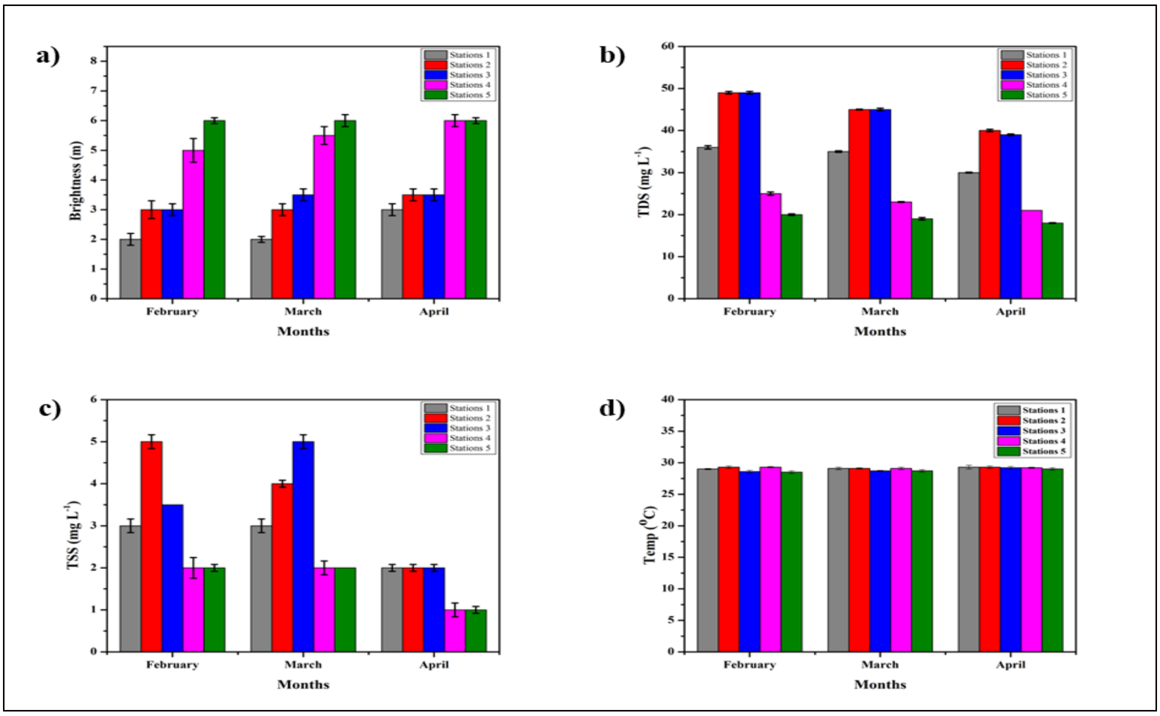

Figure 2. Physical parameters of water quality from 5 stations in Maninjau Lake: a) brightness, b) TDS, c) TSS, d) temperature.

Chemical parameters

Biological oxygen demand (BOD_5). BOD_5 is oxygen required for biochemical reactions during the decomposition of organic matter by bacteria (Connell & Miller 1984). BOD_5 is a critical parameter in estimating the pollution status of water bodies. BOD_5 itself is not a pollutant and does not pose a direct hazard. Still, it can cause indirect harm by reducing DO concentration levels which are detrimental to fish life and other beneficial uses. BOD_5 is the fraction of dissolved organic matter degraded and easily assimilated by bacteria. BOD_5 indicates the quantitative presence of biodegradable organic matter, which consumes DO from water. A higher BOD_5 value results in an unpleasant odour and an unhealthy environment. The higher BOD_5 value is due to the favourable environmental conditions for microbiological activity at higher temperatures (Tamot et al 2008). BOD_5 is directly related to the decomposition of dead organic matter in lakes. Hence, higher BOD_5 values can directly correlate with pollution status and have an inverse relationship with DO concentrations. Statistically, the BOD_5 values at Stations 4 and 5 were the highest and significantly different ($p<0.05$) compared to Stations 1, 2, and 3. These values exceeded the permissible quality standard, namely < 3 mg L^{-1} (GRRI 2021). This condition indicated that there has been a buildup of organic matter derived from organic matter from fish, excess feed, and waste, resulting in high oxygen demand, and in the dry season (April), when the water temperature increases, the decomposition rate increases (Yee et al 2012), and water input from rivers to lakes carry a lot of organic matter. Nuraini et al (2019) stated that waters with a high BOD_5 value indicated pollution by organic matter. The BOD_5 value in water can be affected by the type of waste, the level of acidity (pH), and the overall condition of the water. In contrast to DO, high BOD_5 in waters makes them toxic, which endanger aerobic organisms, such as fish and other benthic fauna that use primary substrates as their habitat.

Chemical oxygen demand (COD). The COD value indicates the level of dissolved oxygen needed to chemically decompose or degrade certain organic substances because they are difficult to destroy biologically. COD measures the oxygen equivalent of the organic matter content if a sample is susceptible to oxidation by strong chemical oxidants (APHA 1995). COD is widely used to measure susceptibility to oxidation of organic and inorganic materials present in water bodies and effluents from sewage and industrial plants (Chapman 1996). Thus, COD is a reliable parameter for assessing water pollution levels. Based on Table 3 and Figure 3b, COD analysis results from Stations 4 and 5 were still below the Class 2 quality standard threshold (<25 mg L^{-1}), except for Stations 1, 2, and 3. The cause of the high COD at Stations 1, 2, and 3 is thought to be due to the use of fertilizers to stimulate the growth of phytoplankton and excessive feeding of fish in lake waters. Based on the season, from February to April, the COD value tends to increase except at Station 2. This is thought to be due to an increase in organic matter from fish, excess feed, and accumulated waste. This finding is supported by Boyd (1981), that the COD value increases with increasing organic and inorganic matter content in the waters. Effendi (2003) reported that waters with a COD value of <20 mg L^{-1} were said to be unpolluted. The high COD concentration is proportional to the increased BOD_5 concentration in the water. The lower the oxygen content in the waters, the greater the COD and BOD_5 values in these waters (Aldo et al 2015). The difference between the decomposition reactions of BOD_5 and COD is that BOD_5 uses microorganisms and takes quite a long time. In contrast, COD uses chemical reactions and requires a relatively short time. The higher the waste contained in the pond, both organic and inorganic, the more oxygen is needed (Tamyiz 2015).

BOD_5/COD ratio. The BOD_5/COD ratio indicates the biodegradability of wastewater; the higher the ratio, the lower the biodegradability of sewage (Papadopoulos et al 2001). According to Mangkoedihardjo (2006), BOD_5/COD is nothing more than an indicator of the output impact of organic substances in water, sewage, leachate, compost, and other similar materials that occur in the environment, both in the natural environment and in the artificial environment. BOD_5/COD, suitable for cultivation and biological processes, is in the biodegradable range of 0.2 - 0.5. Table 3 shows the ratio of BOD_5/COD at Stations 4 and 5 in all seasons with intervals of 0.2 and 0.5, indicating that the pollutants in these waters are biodegradable. This is reinforced by the opinion of Fresenius et al (1989) stated that BOD_5/COD between 0.2 - 0.5 can degrade pollutants through biological processes. However, the decomposition process is slower because decomposing microorganisms require acclimatization to the waste. Based on the sampling season, the highest biodegradation occurred during the dry season. This fact is contrary to the findings of Sakrabani et al (2009), where the highest biodegradation process occurs at the beginning of the rainy season which is directly related to the availability of the amount of oxygen used to decompose biodegradable substrates. While BOD_5/COD values at Stations 1, 2, and 3 were very low, and difficult to decompose (persistent/non-biodegradable), on the other hand, Tamyiz (2015) stated that the effectiveness of precipitation can increase with increasing pH. An increase in pH has also been proven in research to increase waste's biodegradability. This is indicated by an increase in the ratio of BOD_5/COD, which indicates a decrease in levels of complex organic compounds that are difficult to biodegrade (Budhi et al 1999). The ability to increase biodegradability can be done using plants like *Eichornia crassipes*. Using plants can increase the BOD_5/COD ratio from 0.05-0.11 to 0.3-0.5 for two months (Mangkoedihardjo 2006). The results of the statistical analysis showed that Station 4 had the best BOD_5/COD ratio and was significantly different ($p<0.05$) from the other stations.

Dissolved oxygen (DO). Dissolved oxygen is an essential parameter in assessing water quality. It reflects the physical and biological processes that occur in the water. The DO value indicates the pollution in a body of water (Amankwaah et al 2014). It is essential in production and life support processes; it is also necessary for the decomposition and decay of organic matter. Based on Table 3 and Figure 3c, higher DO values at all stations were recorded during the rainy season (February), than in the transition season and the dry season (March-April) due to the mixing of water by the action of strong winds and rain. DO is very important as an indicator of water quality, especially for eutrophication. The DO values from Stations 1, 4, and 5 were at the established quality standard of > 4 mg L^{-1} (GRRI 2021), while at other stations, it was below the permissible standard. The best DO in different seasons was Stations 4 and 5 because they were not significantly different ($p>0.05$). DO concentration in water mainly depends on temperature, dissolved salts, wind speed, pollution load, photosynthetic activity, and respiration rate (Tamot et al 2008). The low DO at Stations 2 and 3 is mainly due to DO consumption by microorganisms in decomposing organic matter (Yee et al 2012). Oxygen levels below 4.0 mg L^{-1} are considered critical for rearing tropical fish (Mallasen et al 2012). The massive growth of plankton can cause problems of nocturnal DO depletion and the production of ammonia and other poisons. Nsonga (2014) reported that DO levels of 6.5 mg L^{-1} or above 5 mg L^{-1} are ideal for warm water fish. It has been reported that oxygen depletion in the water around FNC is due to fish respiration (Cornel & Whoriskey 1993). Daniel et al (2005) stated that DO concentrations below 3.5 mg L^{-1} were undesirable for fish farming. Boyd (1998) concluded that water's desired DO concentration ranges from 5 to 15 mg L^{-1}. Pollution from fish farming activities within the FNC system, resulting in fish mortality, has frequently occurred in Maninjau Lake during dry seasons when wind conditions are low, resulting in low oxygen. Rani et al (2004) reported lower dissolved oxygen values in the dry season due to higher decomposition rates of organic matter and limited water flow in low-holding environments due to high temperatures. Karnatak and Kumar (2014) reviewed that local water quality problems, and deficient dissolved oxygen, often occur in fish farming in FNC. Low dissolved oxygen in the FNC area may not affect other organisms in the lake.

pH. Acids and bases can be hazardous to health and aquatic life. These chemicals are corrosive/irritant and may be toxic to aquatic organisms. The type and amount of dissolved minerals, gases, and aquatic organisms determine the natural pH level of a body of water. According to Effendi (2003), pH is also strongly related to carbon dioxide. The higher the pH value, the lower the free carbon dioxide level. Usually, the pH range of

6.4-8.3 is favourable for fish growth (Robert et al 1940). Hepher and Pruginin (1981) reported that this value ranged from 6.5 to 9.0, which is suitable for fish culture. The pH can drop in fish farming in FNC due to waste accumulation (Pitta et al 1999; Demir et al 2001). Based on Table 3 and Figure 3d, pH values at all stations were higher in the dry season (April) than in the rainy and transitional seasons (February-March). This condition may be due to increased photosynthetic activity and decomposition of allochthonous material in the lake, increasing nutrient concentrations at lower temperatures. Higher sewage inputs and agricultural wastes were also responsible for the higher pH values in water. Mallasen et al (2012) stated that the decomposition of food and respiration released carbon dioxide, which reacts with water and produces carbonic acid and hydrogen ions, acidifying the medium. The average pH value of Maninjau Lake surface water was still within the threshold for water quality standards which state that pH must be between 6 – 9 (GRRI 2021). The pH of water indicated the presence of hydrogen ions in water because hydrogen ions are acidic. Overall, the pH conditions of the water from the five sampling stations are alkaline. Romanescu et al (2016) said water acidification could be influenced by water temperature through the distribution of seasons and day and night cycles.

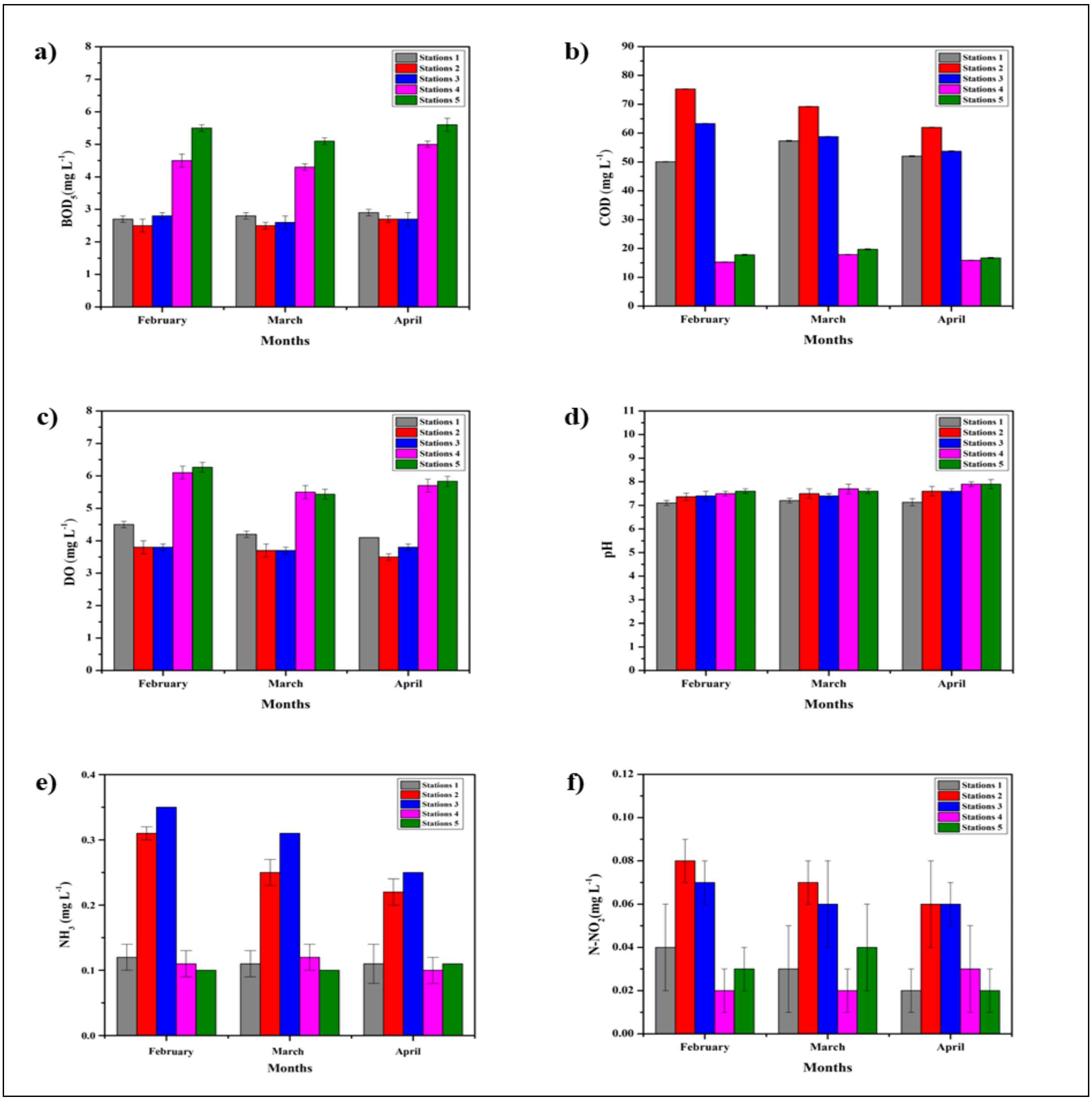

Figure 3. Chemical parameters of water quality from 5 stations in Maninjau Lake: a) BOD_5, b) COD, c) DO, d) pH, e) ammonia (NH_3), f) nitrite ($N\text{-}NO_2$).

Ammonia (NH_3). Ammonia is the main nitrogenous waste produced by aquatic animals through metabolism and excreted through the gills (Cao et al 2007). Based on Table 3 and Figure 3e, the ammonia concentration has exceeded the permissible threshold, namely <0.02 mgL^{-1} (Jhingran 1991), <0.05 mg L^{-1} (Lawson 1995), and <0.1 mg L^{-1} (Boyd 1998). Daniel et al (2005) stated that ammonia concentrations > 0.2 mg L^{-1} were undesirable for fish farming. Furthermore, according to Lucas and Southgate (2005), ammonia levels of less than 1 mg L^{-1} are still suitable for tilapia cultivation. In this study, the highest ammonia values occurred at Stations 2 and 3 (rainy season), presumably due to the entry of domestic waste and agricultural fertilizer runoff (Effendi 2003), and excrement from fish (Nyanti et al 2012).

Nitrite (N-NO_2). Nitrite is a by-product of oxidized NH_3 or ammonium (NH_4^+), an intermediate in converting NH_3 or NH_4^+ to nitrate (NO_3-). This process is accomplished through nitrification carried out by highly aerobic, gram-negative, chemoautotrophic bacteria found naturally in the system. Nitrite concentrations in natural waters are deficient. Nitrite toxicity can increase if low water pH levels (Shishaye 2017). Based on Table 3 and Figure 3f, nitrite concentrations in all seasons and stations are still below the permissible threshold, which is <0.3 mg L^{-1}. The findings in the field are supported by the opinion of Boyd (1998), that the desired concentration of nitrite in water is less than 0.3 mg L^{-1} in fish farming. The increase in nitrite in February (Stations 2 and 3) is caused by an increase in water runoff during the rainy season, which transports ammonium and ammonia cations contained in fertilizers as well as nitrites and nitrates due to the nitrification process (Wang et al 2019). However, if the levels are high, it can cause hypoxia due to deactivation of haemoglobin in fish blood, a condition known as "brown blood disease" (Lawson 1995).

Nitrates (N-NO_3). Nitrate is formed through nitrification, namely the oxidation of nitrite (NO_2) to nitrate (NO_3) by aerobic bacteria. Nitrates not absorbed directly by aquatic plants are denitrified in anaerobic sediments (Furnas 1992). Surface water can also be contaminated with sewage and other wastes that are rich in nitrates. Higher nitrate concentrations in drinking water are toxic (Umavathi et al 2007). Runoff from landfill sites and agricultural activities significantly affects nitrate concentrations in receiving waters. Fertilizers used in agriculture, through leaching and surface runoff into rivers during heavy rains, can also contribute to high nitrate levels in receiving rivers (Rao 2011). High nitrate concentrations in water can stimulate the growth and development of aquatic organisms. Nitrate content is a determining factor in determining the feasibility of a cultivation location. Based on Table 3 and Figure 4g, nitrate concentrations at all seasons and stations are still below the permissible threshold, which is between 0.2 and 10 mg L^{-1} (Boyd 1998). In the rainy season (Stations 2 and 3) high nitrate concentrations were found and statistically, the two stations were not significantly different ($p>0.05$). This is due to the agitation of water and sediment by wind, currents, and rainwater. In this sediment, nitrate is produced from the biodegradation of organic matter into ammonia which is then oxidized to nitrate. The amount of nitrate is usually more significant than that of nitrite because nitrite is unstable in the presence of oxygen, and nitrite is also a transition form from ammonia to nitrate. Nitrate is an unwanted ion in water because it endangers human health (Ewaid & Abed 2017).

Total nitrogen. Floating net cages (FNC) and settlements are the main activities affecting the pollutant load (Oakley 2014). FNC systems generate a pollutant load containing total nitrogen (TN) from feed and fish metabolism (Halwart et al 2007). The high TN produced depends on the amount of fish production and feed use (Nguyen et al 2013). Resident residues such as washing water, faeces, and urine will produce liquid waste containing nitrogen (Vinnerås 2001). Based on Table 3 and Figure 4h, it is shown that the concentration of total nitrogen (TN) at Stations 2 and 3 is higher than the other stations, and the two stations were significantly different ($p<0.05$) because the number of FNC was higher, and the human population per area was denser. The high concentration of TN originating from FNC indicates an accumulation of TN in the waters originating from FNC waste as a source of nutrient supply entering the lake. Mazón et al (2007) and Price and Morris Jr. (2013) stated that aquaculture activities contributed 65.1% nitrogen in dissolved form, while feed contributed 68-86% nitrogen to the aquatic environment and the rest was consumed by fish. This condition indicates that nitrogen contributes significantly to water quality. The concentration of TN in the rainy season (February) is higher than in the transitional and dry seasons (March-April), presumably because during the rainy and transitional seasons there are strong winds and waves which precipitate nitrogen sources in sediments that are lifted to the surface of the water. In general, TN concentrations at all stations meet the permissible limits, namely <0.75 mg L^{-1} (GRRI 2021) except for Stations 2 and 3 at all seasons.

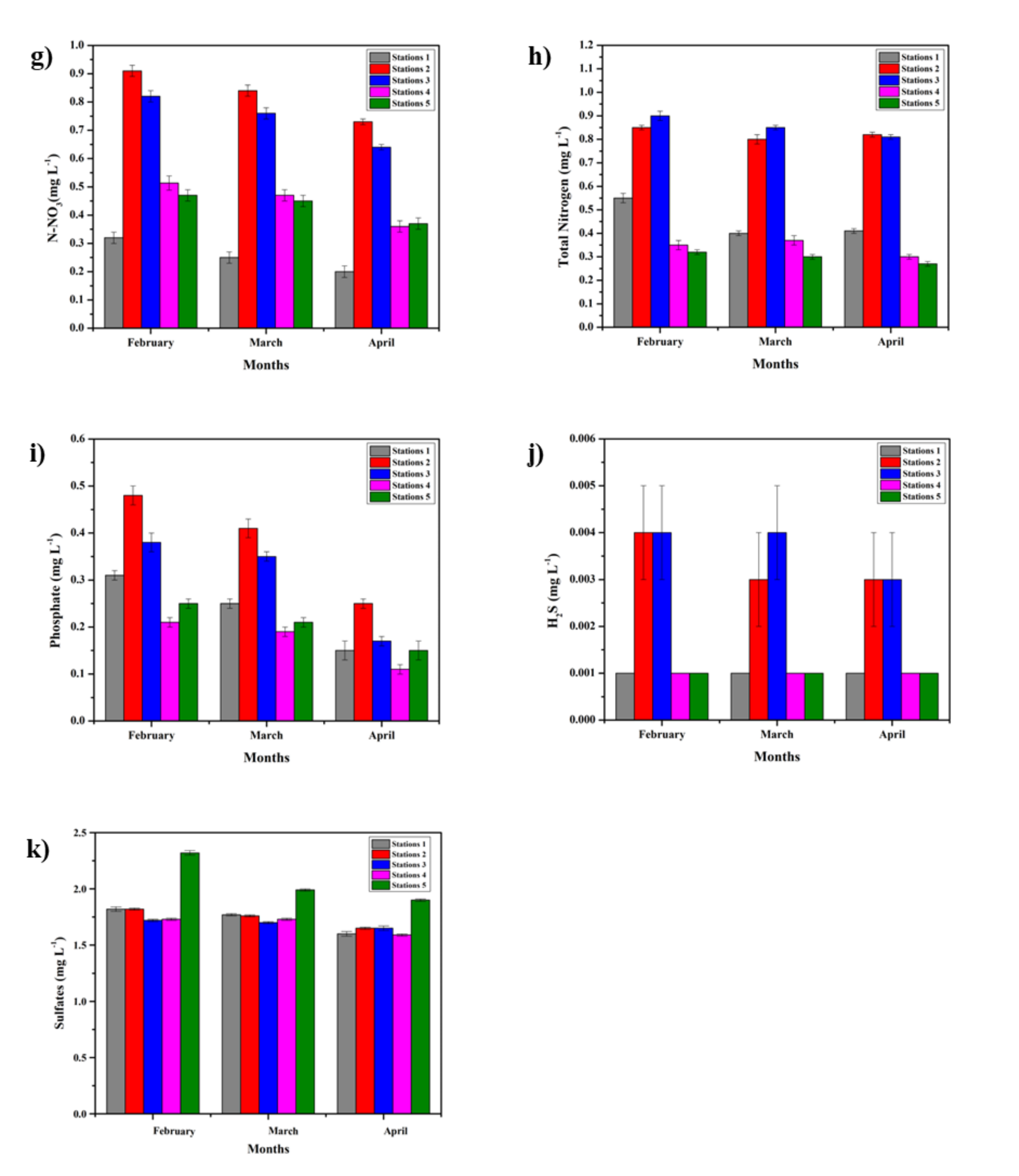

Figure 4. Chemical parameters of water quality from 5 stations in Maninjau Lake: g) nitrate (N-NO_3), h) total nitrogen (TN), i) phosphate, j) hydrogen sulfide (H_2S), k) sulfates.

Phosphate-P (PO_4^{3-}-P). Phosphate is a crucial and limiting nutrient element in maintaining lake fertility. It is recognized as the main factor produced by fish farming that influences the lake environment (Jones & Lee 1982; Ketola 1982; Kelly 1992). The main route of phosphorus entry into the aquatic environment from cage culture is through the feed given to fish (Gavine et al 1995). A large number of cages in an area can exceed the carrying capacity of the aquatic environment, which can cause problems with high levels of phosphorus (Mallasen et al 2012). Phosphorus is an essential plant nutrient and most commonly controls the growth of aquatic plants (algae and macrophytes) in fresh water. It is found in fertilizers, human and animal waste, and yard waste. There is no form (vapor) of phosphorus in the atmosphere. Based on Table 3 and Figure 4i, phosphate concentrations at all stations and seasons are above the permissible threshold, namely < 0.75 mg L^{-1} (GRRI 2021), 0.005 - 0.2 mg L^{-1} (Boyd 1998), 0.025 mg L^{-1} (Santos et al 2012). Phosphate is a common component of fertilizers and organic waste from industry and households. Phosphates are essential for vegetation growth, but high concentrations will cause eutrophication. Kelly (1992, 1993) reported that the accumulation of decomposed solid waste released labile phosphorus into the water column.

Hydrogen sulfide (H_2S). H_2S is a gas found in water from urban waste and agricultural and industrial activities. Sulfate compounds from organic waste containing sulfur are degraded anaerobically to form H_2S. The toxicity of H_2S depends on the pH of the water. The lower the pH of the water, the higher the toxicity of H_2S. Leftover feed not consumed by cultivated organisms is also a source of H_2S in cultivated land because the anaerobic atmosphere allows H_2S oxidation. Efforts can be made to prevent and control the effects of hydrogen sulfide poisoning in aquaculture waters by increasing the pH of the water through liming and increasing the oxygen content of the sea by oxygenation. Based on Table 3 and Figure 4j, the concentration of H_2S at Stations 2 and 3 has exceeded the permissible threshold, which is < 0.002 mg L^{-1} (GRRI 2021). Whereas at Stations 1, 4, and 5 it is still within the optimal interval limit as indicated by the absence of an unpleasant odour from the decomposition process of organic matter. Furthermore, Tanjung et al (2019) explained that the concentration of sulfur in water can come from the aerobic decomposition of organic matter. Materials containing sulfur and microorganisms provide aerobic conditions for sulfate reduction. Sulfate concentrations in waters are seasonal and can affect several cycles of trace metals in waters. The continuous accumulation of nutrients and organic wastes triggers more microbial activity, which produces more sulfides and other toxic gases, causing oxygen depletion within the upper layers of the hypolimnion. Phosphorus loading both internally and externally has prolonged Maninjau Lake in eutrophic conditions. In long hot weather, the algae blooms are sometimes accompanied by the toxic *Microcystis* genus algae, which is also harmful to fish. Blue-green algae populations account for 40 to 60% of all algae in almost all areas, especially around fish cages (Sulastri et al 2012). Poor water quality for a long time, such as exposure to lower oxygen, can affect the ecosystem structure in lakes (Hackenson 2005).

Sulfate (SO_4^{2-}). Sulfate is a constituent of total dissolved solids (TDS) and can form salts with sodium, potassium, magnesium, and other cations. Sulfates are not poisons in the category of heavy metals, pesticides, or other natural or man-made toxic substances, but rather common salts necessary for life at certain concentrations. Based on Table 3 and Figure 4k, sulfate concentrations in all seasons and stations are still below the permissible limit, which is <300 mg L^{-1} (GRRI 2021). Boyd (1998) states that a sulfate concentration of 5 to 100 mg L^{-1} is desirable for a freshwater culture system. The reduction in sulfate concentration is thought to be due to chemical reactions in the environment or system. For example, if there is a reaction between sulfate and another substance to form a compound that is insoluble in water, the concentration of sulfate in water will decrease.

Microbiological parameters

Total coliforms. Total coliforms are a group of bacteria commonly found in aquatic environments produced from human, animal, and domestic waste (Whitehead et al 2018; Frena et al 2019). The nature of this bacteria has no taste, smell, or color, so laboratory analysis must be carried out. The results can be used as a microbiological indicator of a body of water measured in mL units (Divya & Solomon 2016; Xue et al 2018). Based on Table 3, the total coliform content in Maninjau Lake at different seasons and stations is still below the permissible threshold, namely 5000 CFU/100 mL. The low total coliform is caused by the low number of coliform bacteria identified in waters which are wastes of humans, animals, fish, and household waste.

Source of pollution. The level of utilization of Maninjau Lake for fish farming using FNC is very high, so it has an impact on water quality. Sources of pollutants from community activities in the agricultural area around the lake in the form of fertilizing with inorganic fertilizers such as NPK fertilizer (nitrogen-phosphorus-potassium) and others, as well as organic fertilizers and spraying pests with pesticides and activities that produce organic matter, residual agricultural products will have organic matter waste and fertilizer residue. Inorganic materials and pesticides will eventually flow into the lake waters. This finding is consistent with the results of research by Marganof (2007) which stated that local activities such as fishing, agriculture, animal husbandry, villages, and hotels on the shores of the lake are sources of lake water pollution.

Pollution status. The water quality of Maninjau Lake at different seasons and stations has fluctuating values. Furthermore, the determination of water quality status using the STORET method is carried out in accordance with the Decree of the Minister of Environment of the Republic of Indonesia No. 115 of 2003. The results of Station 1 calculations can be seen in Table 4, with the same calculations for other stations, and then recapitulated in Table 5. Based on Table 5, the waters of Maninjau Lake, especially Stations 1, 2, and 3, are classified as Class D (heavily polluted), while Stations 4 and 5 are classified as Class C (moderately polluted). Parameters that do not meet Class 2 lake water quality standards for Station 1 are brightness, COD, and phosphate, for Station 2 are brightness, COD, DO, total nitrogen, phosphate, H_2S, for Station 3 are brightness, COD, DO, total nitrogen, phosphate, H_2S and for Stations 4 and 5 are phosphate.

Table 4

Calculation of water quality status based on the STORET method for Station 1

No	*Parameters*	*Class 2 Quality Standard*	*Measurement Results*			*Score*
			Maximum	*Minimum*	*Mean*	
	Physical					
1	Brightness (m)	> 4	3	2	2.33	-10
2	TDS (mg L^{-1})	<1000	36	30	33.66	0
3	TSS (mg L^{-1})	<50	3	2	2.67	0
4	Temperature (°C)	Dev. 3	29.3	29.1	29.13	0
	Chemical					
5	BOD_5(mg L^{-1})	<3	2.9	2.7	2.8	0
6	COD (mg L^{-1})	<25	57.3	50.1	53.13	-14
7	BOD/COD	-	0.056	0.049	0.052	-
8	DO (mg L^{-1})	>4	4.5	4.1	4.26	0
9	pH	6-9	7.2	7.1	7.13	0
10	NH_3 (mg L^{-1})	-	0.12	0.11	0.11	-
11	N-NO_2 (mg L^{-1})	-	0.04	0.02	0.03	-
12	N-NO_3 (mg L^{-1})	-	0.32	0.20	0.25	-
13	Total Nitrogen (mg L^{-1})	<0.75	0.55	0.41	0.45	0
14	Phosphate (mg L^{-1})	<0.03	0.31	0.15	0.23	-14
15	H_2S (mg L^{-1})	<0.002	0.001	0.001	0.001	0
16	Sulfates (mg L^{-1})	<300	1.82	1.60	1.73	0

	Microbiological					
16	Total coliform (CFU/100 mL)	<5000	220	200	200.67	0
	Sum					-38

Note: Dev 3 is the difference with the air temperature above the water surface.

Table 5

Summary of calculation results of water quality status in Maninjau Lake

Station	*Sampling locations*	*Score*	*Class*	*Status*
1	Muko Muko	-38	D	heavily polluted
2	Koto Malintang	-80	D	heavily polluted
3	Muaro Suak	-80	D	heavily polluted
4	Payinggahan Nagari Maninjau	-14	C	moderately polluted
5	Tanjung Sani	-14	C	moderately polluted

Conclusions. It can be concluded that the waters of Maninjau Lake especially at Stations 1, 2, and 3 are classified in Class D (heavily polluted), while Stations 4 and 5 are classified in Class C (moderately polluted). Parameters that do not meet Class 2 lake water quality standards, for Station 1 are brightness, COD, and phosphate, for station 2 are brightness, COD, DO, total nitrogen, phosphate, H_2S, for station 3 are brightness, COD, DO, total nitrogen, phosphate, H_2S, and for Stations 4 and 5 are phosphate.

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Conflict of interest. The authors declare that there is no conflict of interest.

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