The effect of anthropogenic activities on the spatial distribution of total nitrogen and total phosphate in Lake Maninjau

Puti S. Komala*1), Zulkarnaini Zulkarnaini1), Roselyn I. Kurniati2), Mhd Fauzi3)

1) Universitas Andalas, Department of Environmental Engineering, 25163, Padang, Indonesia
2) Universitas Universal, Department of Environmental Engineering, 29432, Batam, Indonesia
3) Doctoral Student of Environmental Engineering, Institut Teknologi Bandung, 40132, Bandung, Indonesia

*Corresponding author

Abstract: This study aimed to analyse the effect of anthropogenic activities on the spatial distribution of total nitrogen (TN) and total phosphate (TP) in Lake Maninjau, Indonesia, during the dry season. Sampling was carried out at ten observation locations representative for various activities around the lake. Cluster analysis and ANOVA were used to classify pollutant sources and observe differences between TN and TP at each site. Concentrations of TN and TP are categorised as oligotrophic-eutrophic. The ANOVA showed spatially that some sampling locations, such as the Tanjung Sani River, floating net cages, and hydropower areas have different TN concentrations. At the same time, TP levels were consistently significantly different across sampling sites. ANOVA and cluster analysis confirmed that floating net cages were the first cluster and the primary contributor to TN and TP. The second and third clusters come from anthropogenic activities around the lake, such as agriculture, settlement, and livestock. The fourth cluster with the lowest TN and TP is the river that receives the anthropogenic activity load but has a high flow velocity. The cluster change analysis needs to be conducted when there are future changes in the composition of floating net cages, agriculture, and settlements.

Keywords: anthropogenic activities, cluster analysis, dry season, Lake Maninjau, spatial distribution, total nitrogen, total phosphate

INTRODUCTION

Nitrogen and phosphorus are essential nutrients in lake ecosystems to control primary productivity and food chain structure (Zhong et al., 2021). However, high-intensity human activities have led to the discharge of excessive nutrients into lakes over the last several decades, causing eutrophication (Wu et al., 2019; Han et al., 2020; Zhong et al., 2021). Excess nitrogen and phosphate inputs are significant factors in shifting lakes from oligotrophic to hypertrophic states, resulting in considerable increases in toxic cyanobacteria blooms, posing a severe threat to lake ecosystems (Li, Sha and Wang, 2017). Eutrophication occurs due to long-term natural processes such as nutrients from the soil being carried away by currents and then settling in lakes or rivers so that their accumulation causes the growth of aquatic plants (Alexander, Smith and Schwarz, 2000). It is accelerated by input from human activities, impacting ecosystems and decreasing water oxygen levels (Alexander, Smith and Schwarz, 2000).

Nitrogen and phosphorus originate from sewage, commercial, agricultural, and industrial sources (Robertson and Saad, 2011; Eimers et al., 2023). Agriculture and settlements have increased nitrogen in China’s Yellow River due to excessive use of the fertilisers and detergents (Tao et al., 2010). In addition, aquaculture activities, such as floating net cages, contribute to nitrogen content and phosphorus content in water bodies derived from feed residues and fish metabolism (Islam, 2005). The influx of nitrogen and phosphorus from human activities can continuously lead to deterioration in water quality.
Monitoring water quality and identifying pollutant sources responsible for decreasing water quality are necessary. Spatial analysis is one technique that can help identify similarities and differences between pollution sources. In contrast, cluster analysis can divide them into categories or groups based on proximity or similarity (Barakat et al., 2016). Meanwhile, cluster analysis can also help to analyse the spatial distribution of water quality parameters and study the seasonal variation effects (Liu, Yu and Chung, 2011).

Lake Maninjau is one of the lakes in Indonesia that has experienced severe pollution. Recently, this lake has been one of the priority lakes to reduce the high level of contamination (Kementerian Lingkungan Hidup, 2011). Pollution sources entering Lake Maninjau come from floating net cages, agriculture, settlements, and livestock. The current research focuses on assessing total nitrogen (TN) and total phosphate (TP) parameters based on the pollutant sources around the lake. Although there have been many studies on the water quality of Lake Maninjau, research on the correlation between pollutant sources and spatial clustering is still minimal, especially regarding TN and TP. Meanwhile, the sources of activities that are potential causes of the pollution can be studied by clustering areas with similar water quality characteristics. Thus, controlling the primary pollutant sources can be prioritised.

The study aims to analyse the spatial distribution of TN and TP concentrations in all observation locations and the inter-relationships between them. Furthermore, pollutant sources are grouped through cluster testing to support the identification of sources that play a role in the TN and TP distribution.

STUDY MATERIALS AND METHODS

SAMPLING LOCATION

The location of this research is Lake Maninjau, Tanjung Raya District, West Sumatra Province, Indonesia, with an area of 99.5 km², a catchment area of 248 km², and a maximum depth of 165 m. There are ten observation locations, i.e. the middle of the lake, floating net cages, hydropower, lake outlet, and six lake inlets (Fig. 1, Tab. 1). The research began in early March 2020 and continued from June to July 2020. The study, which was supposed to be conducted once a month due to the COVID-19 pandemic, has been delayed. However, sampling is still performed in the months with relatively low rainfall.

SAMPLING AND ANALYSIS

Water sampling makes reference to the Indonesian National Standard concerning water and wastewater – Section 57: Surface water sampling method by the composite way (SNI 6989.57:2008), i.e. mixing water samples at various depths, as...
shown in Table 1. Due to its shallow depth (about 20 cm), samples were only taken in the middle of the river depth.

The water samples were taken from the lake area using a vertical water sampler, while at the inlet and outlet of the river, 1 dm$^3$ sample bottles were used. The samples were preserved with H$_2$SO$_4$ until pH reached 2 ($\approx$10 drops). After preservation, samples were placed in a cool box before being analysed at the Water Laboratory of the Environmental Engineering Department, Andalas University. Analysis of water samples for the concentration of total nitrogen (TN) refers to the APHA (2017), while total phosphate (TP) refers to the SNI 06.6989.31.2005, regarding water and wastewater – Section 31: How to test phosphate levels by spectrophotometer for ascorbic acid. Results of the TN and TP analysis are compared to Ministry of Environment Regulation No. 28 of 2009 (Peraturan, 2009).

STATISTICAL ANALYSIS

ANOVA was used to determine differences in TN and TP concentrations between observation sites with a 95% confidence level. Furthermore, hierarchical cluster analysis with average linkage was used to classify the concentrations of TN and TP based on the sampling location with the help of SPSS 23.0. Hierarchical clustering can be used to obtain multilevel groupings of TN and TP concentrations at the observation sites and obtain similar characteristics within a cluster. This analysis was carried out to assist the previously performed ANOVA test.

RESULTS AND DISCUSSION

TOTAL NITROGEN DISTRIBUTION

The spatial distribution of total nitrogen (TN) concentrations at the observation sites ranged 0.45 ±0.01–0.95 ±0.13 mg∙dm$^{-3}$ (Fig. 2), which indicates oligotropic to eutrophic conditions based on Indonesian Ministry of Environment Regulation No. 28 of 2009 (Peraturan, 2009). Concentration variations are influenced by physical, biological, and chemical processes in water (Vagnetti et al., 2003). The highest TN concentration from the floating net cages site was 0.95 ±0.13 mg∙dm$^{-3}$ due to feed residues and fish metabolism. This can increase nutrients, such as nitrogen and phosphorus, but decrease dissolved oxygen around the floating net cages, causing anoxic conditions (Chen et al., 2012).

The highest concentration of TN comes from the lake inlet, namely the Bandar Ligin River in Nagari Sungai Batang, i.e. 0.69 ±0.06 mg∙dm$^{-3}$. The river area is close to extensive agricultural land and densely populated areas. Fertilisers widely used in this area are Urea and SP36 fertilisers. Urea is known to contain 46% nitrogen, while SP36 fertiliser contains 36% phosphor (Dermiyati et al., 2016). Agriculture is one of the causes of eutrophication in water bodies (Khatri and Tyagi, 2015). Excessive use of fertilisers causes residual fertiliser to accumulate in the soil, resulting in nitrogen in water bodies (Hong et al., 2017). The lowest concentration of TN is in the Tanjung Sani River, which is 0.42 ±0.01 mg∙dm$^{-3}$. The Tanjung Sani River is visually clearer than other rivers. The clarity of water in Tanjung Sani River is owed to the lack of activity in the river area and the higher river flow rate than in other rivers. The increased flow rate of the river allows pollutants to be diluted, thus reducing pollution. The Tanjung Sani region is the largest area in Tanjung Raya District, around 75 km$^2$, while the other

<table>
<thead>
<tr>
<th>No. location</th>
<th>Sampling location</th>
<th>Composite depth</th>
<th>Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Batang Kurambit (inlet)</td>
<td>the centre of the river</td>
<td>00°21'28&quot;S; 100°11'27&quot;E</td>
</tr>
<tr>
<td>2</td>
<td>Batang Kularian (inlet)</td>
<td>the centre of the river</td>
<td>00°15'36.6&quot;S; 100°10'02.6&quot;E</td>
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<tr>
<td>3</td>
<td>Banda Baluran (inlet)</td>
<td>the centre of the river</td>
<td>00°14'51.8&quot;S; 100°11'28.5&quot;E</td>
</tr>
<tr>
<td>4</td>
<td>Batang Maransi (inlet)</td>
<td>the centre of the river</td>
<td>00°17'03.4&quot;S; 100°13'27&quot;E</td>
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<tr>
<td>5</td>
<td>Bandar Ligin (inlet)</td>
<td>the centre of the river</td>
<td>00°15'19&quot;S; 100°12'30&quot;E</td>
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<tr>
<td>6</td>
<td>Tanjung Sani (inlet)</td>
<td>the centre of the river</td>
<td>00°21'43.9&quot;S; 100°12'57.3&quot;E</td>
</tr>
<tr>
<td>7</td>
<td>Batang Antokan (outlet)</td>
<td>the centre of the river</td>
<td>00°20'51.6&quot;S; 100°13'20.4&quot;E</td>
</tr>
<tr>
<td>8</td>
<td>Floating net cages</td>
<td>0 m, 9 m, 19 m</td>
<td>00°13'13.3&quot;S; 100°10'8.8&quot;E</td>
</tr>
<tr>
<td>9</td>
<td>Hydropower</td>
<td>0 m, 5 m</td>
<td>00°17'36.1&quot;S; 100°08'58.8&quot;E</td>
</tr>
<tr>
<td>10</td>
<td>Middle of the lake</td>
<td>0 m, 22 m, 40 m, 100 m, 130 m</td>
<td>00°17'24.1&quot;S; 100°08'58.8&quot;E</td>
</tr>
</tbody>
</table>

Source: own elaboration.
regions cover 7–29 km². Likewise, the population density is the smallest at 100 people per km² compared to the other regions with 123–344 people per km². Most residents already use septic tanks for wastewater treatment (Kurniati, Komala and Zulkarnaini, 2021). However, the effluent from septic tanks is discharged into the surrounding drainage so that it still has the potential to pollute the waters. The contribution of the Tanjung Sani settlement to wastewater contamination in Tanjung Raya District is less when compared to other locations in the district. As a result, this region’s TN input to lake waters is also lower.

The ANOVA test also confirmed these results that TN concentrations spatially tended not to differ significantly between observation sites (P > 0.05) (Tab. 2) except in the Tanjung Sani River (6), floating net cages (8) and hydropower plants (9) which showed significant differences (P < 0.05).

TN concentration in the Tanjung Sani River significantly differed from the Batang Kurambit River, Batang Kularian, Baluran River, Batang Maransi River, floating net cages, hydropower, and middle of the lake. The Tanjung Sani River is a tributary flowing to the lake, which has a reasonably high flow rate of 0.5 m³·s⁻¹ compared to the other rivers, which have flow rates of 0.05–0.41 m³·s⁻¹. As a result, the concentration of TN is lower than that of the other rivers.

**TOTAL PHOSPHATE DISTRIBUTION**

The range of TP concentrations in Maninjau Lake at each observation location ranged 0.18 ±0.02–0.66 ±0.06 mg·dm⁻³ (Fig. 3). Based on the Ministry of Environment No. 28 of 2009 (Peraturan, 2009), the concentration of TP in the waters of Lake Maninjau is in the mesotrophic to eutrophic category. The highest TP level in Lake Maninjau is at floating net cages, where inlet water comes from the Bandar Ligin River. Aquaculture feed contributes 2.3% of phosphorus to the waters (Verdegem, 2013). Phosphorus is a chemical that is mostly solid or dissolved (Li et al., 2021). Dissolved phosphorus, such as PO₄³⁻, PO₃³⁻, PO₂³⁻, interacts with sediments and deposits on the lake bottom (Wu et al., 2016; Wang et al., 2020). TP level in the water column is associated with combined P with Al/Fe released from sediment to the overlying water (Wang et al., 2020).

**Table 2. Total nitrogen significance values in sampling locations**

<table>
<thead>
<tr>
<th>Location</th>
<th>1</th>
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<td>2</td>
<td>0.17</td>
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<tr>
<td>3</td>
<td>0.34</td>
<td>0.9</td>
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<td>4</td>
<td>0.60</td>
<td>0.44</td>
<td>0.51</td>
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<tr>
<td>5</td>
<td>0.04*</td>
<td>0.63</td>
<td>0.85</td>
<td>0.21</td>
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<tr>
<td>6</td>
<td>0.0001*</td>
<td>0.01*</td>
<td>0.05</td>
<td>0.02*</td>
<td>0.003*</td>
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<td>7</td>
<td>0.39</td>
<td>0.97</td>
<td>0.93</td>
<td>0.57</td>
<td>0.77</td>
<td>0.06</td>
<td>–</td>
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<tr>
<td>8</td>
<td>0.01*</td>
<td>0.04*</td>
<td>0.09</td>
<td>0.02*</td>
<td>0.06</td>
<td>0.004*</td>
<td>0.08</td>
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<tr>
<td>9</td>
<td>0.01*</td>
<td>0.09</td>
<td>0.2</td>
<td>0.04*</td>
<td>0.13</td>
<td>0.003*</td>
<td>0.18</td>
<td>0.39</td>
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<tr>
<td>10</td>
<td>0.1</td>
<td>0.34</td>
<td>0.47</td>
<td>0.17</td>
<td>0.47</td>
<td>0.02*</td>
<td>0.43</td>
<td>0.25</td>
<td>0.58</td>
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Explanations: * significantly different at P > 0.05, 1–10 = as in Tab. 1.
Source: own study.

Significant differences in TN concentration were also recorded between the floating cage net area and Kurambit, Kularian, Maransi, and Tanjung Sani. It is due to floating net cages contributing the highest TN concentration input in Lake Maninjau. Compared to traditional land-based aquaculture, cage aquaculture has the largest nutrient feed source and a higher percentage of feed loss. Some cage culture systems use feed with a higher N content instead of organic and inorganic fertilisers with high N and P contents (Islam, 2005). This area is located near the lake’s edge, thus increasing the TN input from the lake inlet. Aquaculture farmers in Lake Maninjau use 75% of submerged feed, which is easily soluble in water and causes precipitation (Kurniati, Komala, and Zulkarnaini, 2021). At the location of the hydropower plant, the concentration of TN tends to be significantly different from the Kurambit, Maransi, and Tanjung Sani Rivers. The TN concentration obtained was higher when compared to the other three locations.

The high TN has been found in the hydropower plant located near the Maninjau Lake outlet. In addition, the hydropower area in Nagari Koto Malintang is the densest fish farming area in Lake Maninjau, thus causing a significant difference from other regions.

**Fig. 3.** Total phosphate (TP) concentration at sampling locations; 1–10 = as in Tab. 1; source: own study
According to the sampling site, the spatial distribution of TP shows significant differences \((P < 0.05)\) (Tab. 3). It indicates that activities in the sampling area affect TP levels in the water. The lake inlet sources come from Batang Kuralian, Batang Baluran, and Batang Maransi Rivers to hydropower, aquaculture cages, and the lake centre tends to be significantly different. The concentration of TP entering Lake Maninjau is derived from agricultural activities, settlements, livestock, and forest erosion. Anthropogenic activities result in an increase in nitrogen and phosphorus in aquatic ecosystems (HELCOM, 2018).

Among them are agricultural activities, where farmers use the Urea, SP36, and Phonksa brands on Lake Maninjau (Kurniati, Komala and Zulkarnaini, 2021). SP36 fertiliser contains 36% phosphorus content increasing the phosphorus content in the waters of Lake Maninjau.

**TOTAL NITROGEN AND TOTAL PHOSPHATE CLUSTERS**

The cluster analysis is used to categorise all sampling locations into similar groups spatially. The ten sampling sites represent the inlet and outlet of the lake, lake water utilization, and the area near pollution. The cluster analysis from 10 sites was divided into 4 clusters (Fig. 4).

ANOVA also supports the cluster analysis results, revealing significant differences in TN and TP concentrations between sampling locations. The cluster classification is set from the lowest to the largest TN and TP concentration, namely clusters 4, 3, 1, and 2. The cluster was developed based on the similarity of pollution loads caused by human activities in these areas. In these regions, human activity mainly focuses on agriculture, communities, cattle farming, and hotels.

Anthropogenic activities, such as agriculture, residential, and livestock, significantly contribute to TN and TP (Varol et al., 2012). Of all clusters, only cluster 4 has one member, namely the Tanjung Sani River. This river has the lowest concentration of TN and TP compared to other locations. Most of them are agricultural, forest, and sparsely populated areas.

ANOVA supports the cluster analysis results, revealing significant differences in TN and TP concentrations in other locations. Cluster 3 consists of the Batang Kurambit River, Batang Kuralian River, Banda Baluran River, and the Batang Maransi River, and the inlets of the Maninjau Lake. Nutrients from these rivers originate generally from settlements, agriculture, and livestock. The largest source of nutrients is the Kuralian River due to traditional markets, relatively dense residential areas, and a large agricultural land category of 13,116 m² in the Tanjung Raya area. Meanwhile, the lowest nutrient load comes from the Kurambit River, which has low-density settlements and small agricultural land of 830 m². The data show that agriculture plays an essential role as a nutrient contributor.

Members of cluster 1 include the middle of the lake, hydropower, Bandar Ligin, and Batang Antokan. These sites have higher TN and TP values than clusters 3 and 4 watersheds. The relatively high nutrient levels in the most profound areas of the lake indicate that the influence of human activities has been evenly distributed through mixing to reach the middle of the lake. The proximity of the hydropower plant to Batang Antokan, the only outlet of Lake Maninjau, suggests that the two are in the same cluster.

In addition, the hydropower plant is located near the most floating net cages, namely Nagari Koto Malintang. The Bandar

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<th>Location</th>
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<tr>
<td>3</td>
<td>0.08</td>
<td>0.03*</td>
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<tr>
<td>4</td>
<td>0.01*</td>
<td>0.07</td>
<td>0.17</td>
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<tr>
<td>5</td>
<td>0.001*</td>
<td>0.001*</td>
<td>0.008*</td>
<td>0.01*</td>
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<tr>
<td>6</td>
<td>0.001*</td>
<td>0.002*</td>
<td>0.0004*</td>
<td>0.0001*</td>
<td>6.25 × 10⁻⁷</td>
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<td>7</td>
<td>0.002*</td>
<td>0.001*</td>
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<td>8</td>
<td>0.002*</td>
<td>0.001*</td>
<td>0.005*</td>
<td>0.008*</td>
<td>0.05</td>
<td>0.0002*</td>
<td>0.18</td>
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<tr>
<td>9</td>
<td>0.0008*</td>
<td>0.0007*</td>
<td>0.002*</td>
<td>0.004*</td>
<td>0.08</td>
<td>5.54 × 10⁻⁷</td>
<td>0.58</td>
<td>0.96</td>
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<tr>
<td>10</td>
<td>0.01*</td>
<td>0.007*</td>
<td>0.02*</td>
<td>0.05</td>
<td>0.45</td>
<td>0.001*</td>
<td>0.96</td>
<td>0.23</td>
<td>0.74</td>
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</tbody>
</table>

Explanations: * = significantly different at \(P > 0.05\), 1–10 = as in Tab. 1.
Source: own study.
Ligin River, one of the tributaries of Lake Maninjau located in Nagari Sungai Batang, contributes the highest loads of TN and TP. The primary pollution sources in this area include agriculture, densely populated settlements, and livestock. According to 2019 statistical data, these villages include three villages with the highest rice field area of around 389 ha, and the fourth village has the largest population of 3,582 people (Badan Pusat Statistik Kabupaten Agam, 2019). This shows that the area of agricultural land in Sungai Batang is relatively large compared to the other six villages, i.e. Tanjung Sani, Maninjau, Duo Koto, Paninjauan, Koto Gadang and Koto Malintang, which range 126–274 ha. High TN and TP levels are mainly due to fertiliser use in agriculture and municipal wastewater discharge (Razmkhah, Abrishamchi and Torkian, 2010; Tao et al., 2010).

Cluster 2 has only one member, the floating net cages area, the highest source for TN and TP, located in the Koto Malintang village. The high TN and TP levels come from feed residue and fish metabolism. The accumulation of feed residues settled to the bottom increases the TN and TP levels (Pawar, Matsuda and Fujisaki, 2002). Despite having the second-lowest population density (124 people per km²) and the third-lowest agricultural area (174 ha), effluent from the onsite treatment of individual households and agricultural fertiliser residues that are expected to enter the drainage to the nearby river increase the nutrient load in this area. The continuous influx of TN and TP can result in accelerated phytoplankton growth.

Cluster analysis results suggest that pollution load from community activities and environmental circumstances around Lake Maninjau impact TN and TP cluster classification. Floating net cages are a significant factor and the primary activity that produces TN and TP. Despite decreasing the number of fish cages, it still has the most considerable pollution impact compared to settlements, agriculture, livestock, etc. Except for the Bandar Ligin River, the lake inlets are grouped into clusters with similar TN and TP pollutant loads. Lakes located in populated areas tend to experience a decrease in water quality due to anthropogenic activities (Moore et al., 2003; Khim, Jung and Cheong, 2005; Anda de et al., 2019; Murphy and Sprague, 2019; Li et al., 2021; Tiwari et al., 2021).

Both cluster analysis and ANOVA demonstrate that floating net cage activities significantly influence nitrogen and phosphorus levels in Lake Maninjau, followed by agriculture, settlement, and livestock. Therefore, it is necessary to control the wastewater discharge from those activities that increase TN and TP in waters, in particular to reduce factors that determine water fertility.

The Lake Maninjau trophic status was still eutrophic in 2008. Then it has increased to a hypertrophic state since 2013 (Henny and Nomostaryo et al., 2016; Syandri, 2016; Komala, Silvia and Windi, 2023). As reported by Junaidi, Syandri and Azriza (2014), in 2001–2013, the total organic matter (TOM) value was 19.94 mg·dm⁻³ at the Koto Malintang station, 16.69 mg·dm⁻³ at Koto Kaciek, and 9.32 mg·dm⁻³ at Bayur. This demonstrates that organic matter accumulation has resulted in severely contaminated lake water and mass fish deaths in floating net cages yearly. The increasing number of fish deaths in Lake Maninjau indicates an ecosystem disaster. Syandri et al. (2017) reported that after the mortality event, N and P levels affected water quality. According to this study, mass mortality of Oreochromis niloticus and Cyprinus carpio caused by floating net cages in Lake Maninjau is a substantial source of N, P, and TOM. After fish deaths, the level of these values at 30 m depth was much higher than at the surface.

According to information collected from the Agam Regency Fisheries Service, there were 17,426 floating net cage plots in Lake Maninjau in 2018; however, the number of cages was regulated by the Agam Regency Government in 2019, resulting in a fall of 12,312 units. In 2020, there were 12,310 fish cages, a slight decrease from 2019. In addition to the government’s policy to reduce fish farming, the COVID-19 pandemic also hurt community activities. According to Komala, Silvia, and Windi (2023), the TN concentration in 2018 was 0.92–1.12 mg·dm⁻³, and the TP concentration was 0.42–0.58 mg·dm⁻³. At the time, the lake’s tropical condition was hypertrophic, as evidenced by the abundance of Microcystis aeroginosa and Synedra acus species. In contrast, in the current study, in 2020–2021, TN and TP levels have dropped to 0.45–0.95 mg·dm⁻³ and 0.18–0.66 mg·dm⁻³, respectively. This demonstrates how the COVID-19 epidemic has had a significant impact on nutrient concentrations in lake waters because of the declining number of floating fish nets and decreased community activities.

This study has several limitations, including data and sample collection which were carried out during the COVID-19 pandemic in 2020–2021. This limitation resulted in a delayed sampling period. Additionally, the sampling time was constrained because it frequently started to rain or storm on the lake in the afternoon, making it necessary to discontinue sampling. The few officers available to drive boats around the lake during the pandemic was another restriction that made sampling difficult.

CONCLUSIONS

This study used cluster analysis and ANOVA to classify and determine spatial similarities between total nitrogen (TN) and total phosphate (TP) in Lake Maninjau during the dry season. The concentration of TN and TP shows that the trophic status has already reached a eutrophic state in Lake Maninjau. The ANOVA showed that spatially, in some sampling locations like the Tanjung Sani River, floating net cages, and hydropower areas had different TN concentrations. At the same time, TP levels were consistently significantly different across sampling sites. The cluster identified four groups based on the similarity of TN and TP concentrations in 10 observation sites. Floating net cages and Tanjung Sani’s River are the only clusters with one member. In contrast, the other groups have several members. The cluster analysis shows that the human activities correspond to cluster members, such as floating net cages, agriculture, settlements, and animal husbandry. The cluster analysis can exploit potential correlations between water quality measures, identify key sources of pollution, and categorise sampling sites. The cluster change analysis needs to be conducted when there are future changes in the composition of floating net cages, agriculture, and settlements.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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