JOURNAL OF WATER AND LAND DEVELOPMENT
e-ISSN 2083-4535
Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)
JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2024.149109
2024, No. 60 (I–III): 71–78

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

Puti S. Komala*[1)], Zulkarnaini Zulkarnaini[1)], Roselyn I. Kurniati[2)], Mhd Fauzi[3)]

[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

RECEIVED 25.05.2023 ACCEPTED 05.12.2023 AVAILABLE ONLINE 01.03.2024

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 interrelationships 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 km^2, a catchment area of 248 km^2, 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

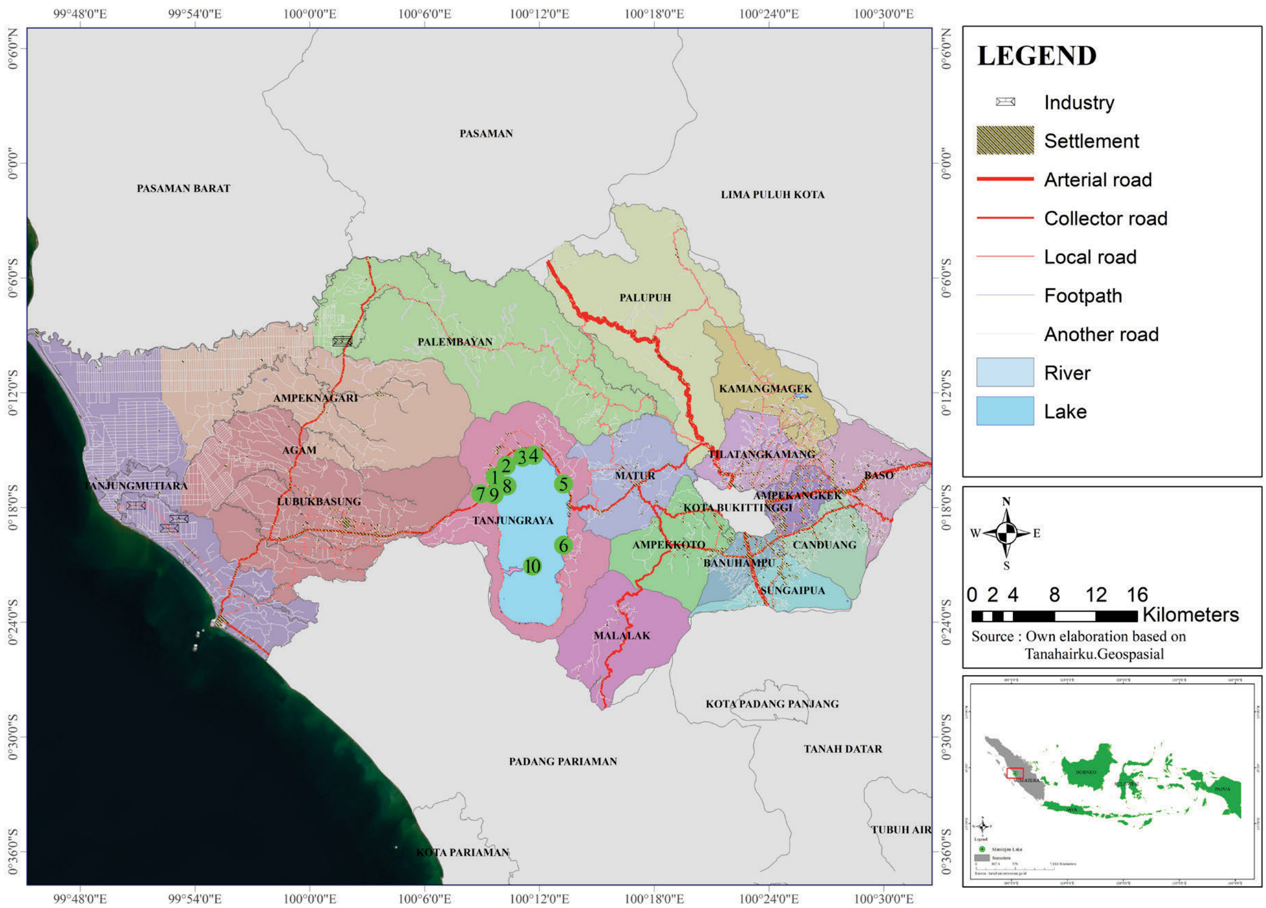

Fig. 1. Administrative map of Agam District; 1 = Batang Kurambit River, 2 = Batang Kularian River, 3 = Banda Baluran River, 4 = Batang Maransi River, 5 = Bandar Ligin River, 6 = Tanjung Sani, 7 = Batang Antokan River, 8 = floating net cages, 9 = hydropower, 10 = middle of the lake; source: own elaboration based on Tanahairku Geospasial

Table 1. Composite sampling depth and location

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

Source: own elaboration.

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_2SO_4 until pH reached 2 (≈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 $mg{\cdot}dm^{-3}$ (Fig. 2), which indicates oligotrophic 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 $mg{\cdot}dm^{-3}$ 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 $mg{\cdot}dm^{-3}$. 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 $mg{\cdot}dm^{-3}$. 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

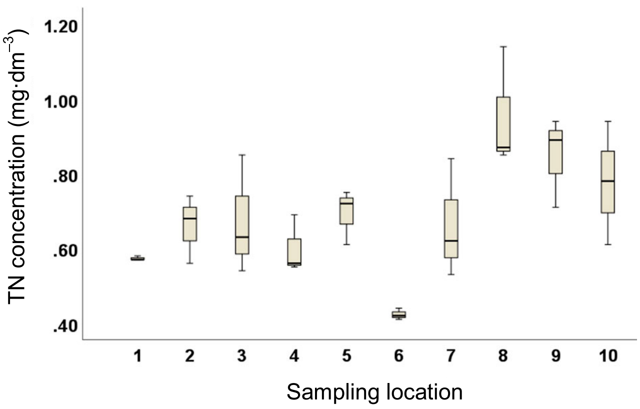

Fig. 2. Total nitrogen (TN) concentration at sampling locations; 1–10 = as in Tab. 1; source: own study

regions cover 7–29 km^2. Likewise, the population density is the smallest at 100 people per km^2 compared to the other regions with 123–344 people per km^2. 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 $m^3 \cdot s^{-1}$ compared to the other rivers, which have flow rates of 0.05–0.41 $m^3 \cdot s^{-1}$. As a result, the concentration of TN is lower than that of the other rivers.

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.

TOTAL PHOSPHATE DISTRIBUTION

The range of TP concentrations in Maninjau Lake at each observation location ranged 0.18 ±0.02–0.66 ±0.06 $mg \cdot dm^{-3}$ (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 PO_4^{3-}, PO_3^{3-}, PO_2^{3-}, 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

Location	1	2	3	4	5	6	7	8	9	10
1	–									
2	0.17	–								
3	0.34	0.9	–							
4	0.60	0.44	0.51	–						
5	0.04*	0.63	0.85	0.21	–					
6	0.0001*	0.01*	0.05	0.02*	0.003*	–				
7	0.39	0.97	0.93	0.57	0.77	0.06	–			
8	0.01*	0.04*	0.09	0.02*	0.06	0.004*	0.08	–		
9	0.01*	0.09	0.2	0.04*	0.13	0.003*	0.18	0.39	–	
10	0.1	0.34	0.47	0.17	0.47	0.02*	0.43	0.25	0.58	–

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

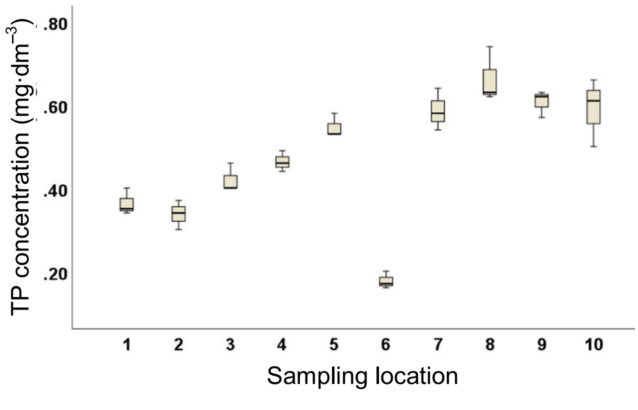

Fig. 3. Total phosphate (TP) concentration at sampling locations; 1–10 = as in Tab. 1; source: own study

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 Kurambit, Batang Kularian, 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 Kularian 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 Kularian River due to traditional markets, relatively dense residential areas, and a large agricultural land category of 13,116 m^2 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 m^2. 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

Table 3. Total phosphate significance values in sampling locations

Location	1	2	3	4	5	6	7	8	9	10
1	–									
2	0.41	–								
3	0.08	0.03*	–							
4	0.01*	0.07	0.17	–						
5	0.001*	0.001*	0.008*	0.01*	–					
6	0.001*	0.002*	0.0004*	0.0001*	$6.25 \cdot 10^{-5}$*	–				
7	0.002*	0.001*	0.008*	0.01*	0.03*	0.0001*	–			
8	0.002*	0.001*	0.005*	0.008*	0.05	0.0002*	0.18	–		
9	0.0008*	0.0007*	0.002*	0.004*	0.08	$5.54 \cdot 10^{-5}$*	0.58	0.96	–	
10	0.01*	0.007*	0.02*	0.05	0.45	0.001*	0.96	0.23	0.74	–

Explanations: * = significantly different at $P > 0.05$, 1–10 = as in Tab. 1.
Source: own study.

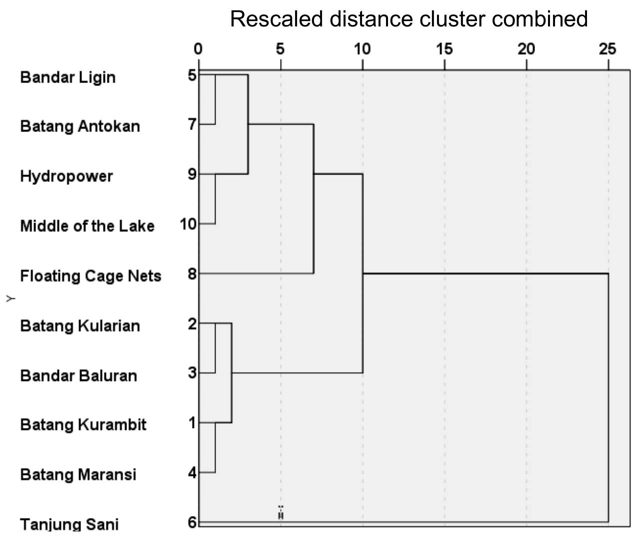

Fig. 4. Dendogram cluster analysis graph using average linkage; source: own study

Ligin River, one of 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 from 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 km^2) 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 Azrita (2014), in 2001–2013, the total organic matter (TOM) value was 19.94 $mg\cdot dm^{-3}$ at the Koto Malintang station, 16.69 $mg\cdot dm^{-3}$ at Koto Kaciek, and 9.32 $mg\cdot dm^{-3}$ 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 $mg\cdot dm^{-3}$, and the TP concentration was 0.42–0.58 $mg\cdot dm^{-3}$. 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 $TN\cdot dm^{-3}$ and 0.18–0.66 mg $TP\cdot dm^{-3}$, 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 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.

ACKNOWLEDGMENTS

The authors thank the Non-Tax State Revenue Fund (PNBP) Universitas Andalas No. 093/UN.16.09.D/PL/2021.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

REFERENCES

Alexander, R.B., Smith, R.A. and Schwarz, G.E. (2000) "Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico," *Nature*, 403, pp. 758–761.

Anda de, J. *et al.* (2019) "Morphometric and water quality features of Lake Cajititlan, Mexico," *Environmental Monitoring and Assessment*, 191, 2. Available at: https://doi.org/10.1007/s10661-018-7163-8.

APHA (2017) *Standard methods for the examination of water and wastewater*. 21st edn. Washington D.C.: American Public Health Association.

Badan Pusat Statistik Kabupaten Agam (2019) Kecamatan Tanjung Raya dalam Angka 2019. Available at: https://agamkab.bps.go.id/publication/2019/09/26/7dbbb9c46b344f103c5f1e4c/kecamatan-tanjung-raya-dalam-angka-2019.html (Accessed: August 05, 2023).

Barakat, A. *et al.* (2016) "Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques," *International Soil and Water Conservation Research*, 4(4), pp. 284–292. Available at: https://doi.org/10.1016/j.iswcr.2016.11.002.

Chen, Y. *et al.* (2012) "Spatial and temporal variations in nitrogen and phosphorous nutrients in the Yangtze River Estuary," *Marine Pollution Bulletin*, 64(10), pp. 2083–2089. Available at: https://doi.org/10.1016/j.marpolbul.2012.07.020.

Dermiyati, D. *et al.* (2016) "Effectiveness of Organonitrofos Plus fertilizer on sweet corn and soil chemical properties of Ultisols," *Journal of Tropical Soils*, 21(1), pp. 9–17. Available at: http://dx.doi.org/10.5400/jts.2016.v21i1.9-17.

Eimers, M.C. *et al.* (2023) "Phosphorus and nitrogen deposition within a large transboundary watershed: Implications for nutrient stoichiometry and lake vs watershed budgets," *Journal of Great Lakes Research*, 49, pp. 44–52. Available at: https://doi.org/10.1016/j.jglr.2022.08.011.

Han, C. *et al.* (2020) "Geochemistry of phosphorus release along transect of sediments from a tributary backwater zone in the Three Gorges Reservoir," *Science of The Total Environment*, 722, 136964. Available at: https://doi.org/10.1016/j.scitotenv.2020.136964.

HELCOM (2018) *First version of the 'State of the Baltic Sea' report – June 2017 – to be updated in 2018*. Available at: http://stateofthebaltic-sea.helcom.fi (Accessed: September 17, 2020).

Henny, C. and Nomosatryo, S. (2016) "Changes in water quality and trophic status associated with cage aquaculture in Lake Maninjau, Indonesia," *IOP Earth and Environmental Science*, 31(1), 012027, pp. 1–9. Available at: https://doi.org/10.1088/1755-1315/31/1/012027.

Hong, B. *et al.* (2017) "Advances in NANI and NAPI accounting for the Baltic drainage basin: spatial and temporal trends and relationships to watershed TN and TP fluxes, "*Biogeochemistry*, 133, pp. 245–261. Available at: https://doi.org/10.1007/s10533-017-0330-0.

Islam, M.S. (2005) "Nitrogen and phosphorus budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem: review and analysis towards model development," *Marine Pollution Bulletin*, 50(1), pp. 48–61. Available at: https://doi.org/10.1016/j.marpolbul.2004.08.008.

Junaidi, Syandri, H. and Azrita (2014) "Loading and distribution of organic materials in Maninjau Lake West Sumatra Province-Indonesia," *Journal of Aquaculture Research & Development*, 5(7), pp. 1–4.

Kementerian Lingkungan Hidup (2011) *Profil 15 Danau Prioritas Nasional 2010–2014 Kementerian Lingkungan Hidup [Profile of 15 National Priority Lakes 2010-2014 Ministry of Environment]*. Available at: https://menyelamatkandanaulimboto.files.wordpress.com/2011/11/gab-profil-15-danau_edit5_fix-cetak_.pdf (Accessed: February 9, 2020).

Khatri, N. and Tyagi, S. (2015) "Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas," *Frontiers in Life Science*, 8(1), pp. 23–39. Available at: https://doi.org/10.1080/21553769.2014.933716.

Khim, B.-K., Jung, H.M. and Cheong, D. (2005) "Recent variations in sediment organic carbon content in Lake Soyang (Korea)," *Limnology*, 6(1), pp. 61–66. Available at: https://doi.org/10.1007/s10201-004-0134-5.

Komala, P.S., Silvia, S. and Windi, S. (2023) "Phytoplankton dynamics and its relation to physicochemical parameters in the dry season of Maninjau Lake, West Sumatera, Indonesia," *Journal of Ecological Engineering*, 24(9), pp. 218–231. Available at: https://doi.org/10.12911/22998993/169233.

Kurniati, R.I., Komala, P.S. and Zulkarnaini, Z. (2021) "Analisis beban pencemar total nitrogen dan total fosfat akibat aktivitas antropogenik di Danau Maninjau [Analysis of total nitrogen and total phosphate pollutant loads due to anthropogenic activities in Lake Maninjau]," *Jurnal Ilmu Lingkungan*, 19(2), pp. 355–364. Available at: https://doi.org/10.14710/jil.19.2.355-364.

Li, Y. *et al.* (2021) "Sedimentary organic carbon and nutrient distributions in an endorheic lake in semiarid area of the Mongolian Plateau," *Journal of Environmental Management*, 296, 113184. Available at: https://doi.org/10.1016/j.jenvman.2021.113184.

Li, X., Sha, J. and Wang, Z.-L. (2017) "Chlorophyll-A prediction of lakes with different water quality patterns in China based on hybrid neural networks," *Water*, 9(7), 524, pp. 1–13. Available at: https://doi.org/10.3390/w9070524.

Liu, W.-C., Yu, H.-L. and Chung, C.-E. (2011) "Assessment of water quality in a subtropical alpine lake using multivariate statistical techniques and geostatistical mapping: A case study," *International Journal of Environmental Research and Public Health*, 8(4), pp. 1126–1140. Available at: https://doi.org/10.3390/ijerph8041126.

Moore, J.W. *et al.* (2003) "Lake eutrophication at the urban fringe, Seattle region, USA," *AMBIO: A Journal of the Human Environment*, 32(1), pp. 13–18. Available at: https://doi.org/10.1579/0044-7447-32.1.13.

Murphy, J. and Sprague, L. (2019) "Water-quality trends in US rivers: Exploring effects from streamflow trends and changes in watershed management," *Science of The Total Environment*, 656, pp. 645–658. Available at: https://doi.org/10.1016/j.scitotenv.2018.11.255.

Pawar, V., Matsuda, O. and Fujisaki, N. (2002) "Relationship between feed input and sediment quality of the fish cage farms," *Fisheries Science*, 68(4), pp. 894–903. Available at: https://doi.org/10.1046/j.1444-2906.2002.00508.x.

Peraturan (2009) *Peraturan Menteri Lingkungan Hidup dan Kehutanan Nomor 28 Tahun 2009 Tentang Daya Tampung Beban Pencemaran Air Danau dan/atau Waduk [Regulation of the Minister of Environment and Forestry No. 28 of 2009 on Water Pollution Load Capacity of Lakes and/or Reservoirs]*. Available at: https://

jdih.maritim.go.id/cfind/source/files/permen-lhk/mlh-p.28.pdf (Accessed: August 19, 2020).

Razmkhah, H., Abrishamchi, A. and Torkian, A. (2010) "Evaluation of spatial and temporal variation in water quality by pattern recognition techniques: A case study on Jajrood River (Tehran, Iran)," *Journal of Environmental Management*, 91(4), pp. 852–860. Available at: https://doi.org/10.1016/j.jenvman.2009.11.001.

Robertson, D.M. and Saad, D.A. (2011) "Nutrient inputs to the Laurentian Great Lakes by source and watershed estimated using SPARROW watershed models," *Journal of the American Water Resources Association (JAWRA)*, 47(5), pp. 1011–1033. Available at: https://doi.org/10.1111/j.1752-1688.2011.00574.x.

SNI 06.6989.31.2005 *Air dan air limbah – Bagian 57: Cara uji kadar fosfat dengan spektrofotometer secara asam askorbat (Bahasa) [How to test phosphate levels with an ascorbic acid spectrophotometer]*. Jakarta: Badan Standardisasi Nasional.

SNI 6989.57:2008 *Air dan air limbah – Bagian 57: Metoda pengambilan contoh air permukaan (Bahasa) [Water and wastewater – Part 57: Surface water sampling methods]*. Jakarta: Badan Standardisasi Nasional.

Syandri, H. (2016) "Kondisi kualitas air pada daerah pemeliharaan ikan keramba jaring apung di Danau Maninjau [Water quality conditions in fish farming areas of floating net cages in Lake Maninjau]," *Prosiding Seminar Nasional Tahunan Ke-V Hasil-Hasil Penelitian Perikanan dan Kelautan B3*, 6, pp. 301–310.

Syandri, H. *et al*. (2017) "Levels of available nitrogen-phosphorus before and after fish mass mortality in Maninjau Lake of Indonesia," *Journal of Fisheries and Aquatic Science*, 12(4), pp. 191–196. Available at: https://doi.org/10.3923/jfas.2017.191.196.

Tao, Y. *et al*. (2010) "Long-term variations and causal factors in nitrogen and phosphorus transport in the Yellow River, China," *Estuarine, Coastal, and Shelf Science*, 86(3), pp. 345–351. Available at: https://doi.org/10.1016/j.ecss.2009.05.014.

Tiwari, P.K. *et al*. (2021) "A mathematical model to restore water quality in urban lakes using phoslock," *Discrete Continuous Dynamical Systems – Series B*, 26(6), pp. 3143–3175. Available at: https://doi.org/10.3934/dcdsb.2020223.

Vagnetti, R. *et al*. (2003) "Self-purification ability of a resurgence stream," *Chemosphere*, 52, pp. 1781–1795. Available at: https://doi.org/10.1016/S0045-6535(03)00445-4.

Varol, M. *et al*. (2012) "Spatial and temporal variations in surface water quality of the dam reservoirs in the Tigris River basin, Turkey," *Catena*, 92, pp. 11–21. Available at: https://doi.org/10.1016/j.catena.2011.11.013.

Verdegem, M.C.J. (2013) "Nutrient discharge from aquaculture operations in function of system design and production environment," *Review in Aquaculture*, 4, pp. 1–14. Available at: https://doi.org/10.1111/raq.12011.

Wang, C. *et al*. (2020) "Spatial variations of soil phosphorus forms and the risks of phosphorus release in the water-level fluctuation zone in a tributary of the three gorges reservoir," *Science of The Total Environment*, 699, 134124. Available at: https://doi.org/10.1016/j.scitotenv.2019.134124.

Wu, T. *et al*. (2019) "Spatial distribution of sediment nitrogen and phosphorus in Lake Taihu from a hydrodynamics-induced transport perspective," *Science of The Total Environment*, 650(1), pp. 1554–1565. Available at: https://doi.org/10.1016/j.scitotenv.2018.09.145.

Wu, Y. *et al*. (2016) "The fate of phosphorus in sediments after the full operation of the three gorges reservoir, China," *Environmental Pollution*, 214, pp. 282–289. Available at: https://doi.org/10.1016/j.envpol.2016.04.029.

Zhong, J. *et al*. (2021) "Nitrogen budget at sediment–water interface altered by sediment dredging and settling particles: benefits and drawbacks in managing eutrophication," *Journal of Hazardous Materials*, 406, 124691. Available at: https://doi.org/10.1016/j.jhazmat.2020.124691.