The Influence of the Physicochemical Parameters on the Ortho Phosphate and Total Phosphate Concentrations of Maninjau Lake

P S Komala, B Primasari and Q Ayunin
Department of Environmental Engineering Andalas University, Sumatera Barat - Indonesia
Corresponding author: putisrikomala@eng.unand.ac.id

Abstract. The study was conducted in order to examine the relationship between the physicochemical parameters (temperature, DO and pH) with the orthophosphate (OP) and total phosphate (TP) concentrations based on the depth of Maninjau Lake. Samples were taken at the center of the lake near to a domestic area, endemic fisheries and a hydropower site. The OP concentration ranged from 0.182 - 0.570 mg/L and the TP of 0.265 - 0.603 mg/L indicated that Maninjau Lake was hypertrophic. This does not meet the quality standards regulated by the Indonesian Government. The physicochemical parameters of temperature, pH, and DO have a strong negative correlation with OP and TP concentrations with a correlation value of 0.828-0.982. ANOVA showed that depth stratification affects the OP and TP concentrations while the variation of sampling time does not affect the concentrations. The highest total phosphate concentration value was at the aquaculture cage location which exceeded the second class quality standard based on Government Regulation No. 82 of 2001. It shows that the aquaculture activities result in excess phosphate loads that can trigger lake eutrophication.

Keywords: eutrophication, lake maninjau, orthophosphate, physico-chemical parameters, total phosphate

1. Introduction

As a multifunctional lake which serves the hydropower, fishery, irrigation and tourism facilities [1], Lake Maninjau has experienced a decrease in its water quality. The uncontrolled use of the waters and areas around Lake Maninjau has increased the lake pollution load [2]. Syandri observed that in 2013, Maninjau Lake contained a total phosphate concentration (TP) of 470 µg/L, a total nitrogen (TN) of 1,250 µg/L, chlorophyll-a of 1,320 µg/L and a maximum brightness of 1.75 m. In 2015, this increased to 510 µg TP/L, 710 µg TN/L, chlorophyll-a 1,364.1 µg/L, and a maximum brightness of 1.5 m [3]. Referring to the tropic status of the waters based on the Minister of Environment Regulation No.28 of 2009, based on the TP and TN levels, Lake Maninjau is in a hypereutrophic state.

Eutrophication can be overcome by limiting the external nutrient input. Phosphorus is generally considered to be a limiting nutrient in freshwater ecosystems. High P concentrations often occur together with severe cyanobacterial blooms in water [4]. Cyanobacterial blooms are harmful to health due to the toxins present for both humans and animals. Massive fish deaths in Lake Maninjau have been reported in 1997 [5]. Deteriorating water conditions accompanied by the uncontrolled development of fish culture results in conditions that are not supportive for aquatic biota. Therefore, reducing the phosphorus levels in the aquatic system is an effective way to overcome eutrophication [6].
Phosphorus is found in either dissolved or particle form. Dissolved phosphorus consists of both inorganic compounds and organic compounds. The inorganic compounds are orthophosphate ions while the organic compounds come from the process of the mineralization of dead matter [7]. Orthophosphate ions play an essential role in the functioning of ecosystems because they are the only biologically available form for plants [7]. Organic-P compounds are essential sources of phosphate for algae and they must be transformed into orthophosphate before being available for algal uptake [8]. The phosphorus in the lake is influenced by several environmental factors, mainly pH, temperature, and DO [9]. Eutrophication and water pollution can change the physical chemicals in the water. Besides, the tropical lakes characteristics, with small temperature differences, can affect the vertical distribution of physicochemical parameters. The nutrient and oxygen concentrations may, in turn, be changed. Few studies have reported on the physicochemical parameters of the Indonesian lakes located in the tropics. Some of the deep, oligomictic and meromictic lakes are subject to stresses due to human activities and climate warming [10]. The purpose of this study was to analyze the spatial distribution of phosphorus compounds based on the location and depth stratification of Maninjau Lake and their correlation of both to the physicochemical parameters i.e. DO, pH, and temperature. The results of this study could improve the understanding of the phosphorus dynamics in a eutrophic lake.

2. Materials and Method

2.1. Study Area

Lake Maninjau is located in Tanjung Raya Subdistrict, Agam Regency, West Sumatra Province at 0°19’S 100°12’E with an altitude of 461.5 meters above sea level. The Lake Maninjau region has a slope of land ranging from flat to hilly or mountainous with a very steep area >40%. Lake Maninjau’s temperature averages a maximum of 31.27 °C and a minimum of 22.66 °C. The average humidity is 95.20%. The average wind speed around the lake is 23.5 km/hour. There are 88 large and small rivers with a maximum width of 8 meters that flow into the lake. Most of the rivers (61.4%) are dry during the dry season, while the rivers that run all year round total only 34 with a relatively small discharge. The aquaculture cages are spread over almost all of the surface of Lake Maninjau and even now, some of the cages are located towards the middle of the lake.

The study was conducted in the February - May period of 2018 with a sampling frequency of three times at two week intervals. The sampling location was determined based on SNI 6989.57:2008 [12]. The water sampling locations can be seen in Figure 1. The sampling locations were in the center of the lake (1), the location with polluted water (near to the domestic) area (2), at the aquaculture cages (4), at the lake utilization location (hydropower) (3) and where the endemic fisheries were (5). The sampling locations can be seen in Figure 1.

2.2. Sampling

Sampling was carried out during dry and sunny weather conditions. Based on SNI 6989.57:2008, the samples were taken from 5 observation locations. At the center of the lake with a maximum depth of 130 m, 5 depth variations were taken, namely at 0 m, 22 m, 40 m, 100 m, and 130 m. This is in addition to near the domestic area with a maximum depth of 30 m with samples taken at depths of 0 m, 15 m, and 30 m; around the endemic fisheries with a maximum depth of 5 m and samples taken at depths of 0 m and 5 m; at the hydropower site with a maximum depth of 2.5 m, and samples taken at depths of 0 m and 2.5 m; and around the floating net cages with a maximum depth of 19 m, with samples taken at 3 depths, namely 0 m, 9 m, and 19 m. The water sampling used a vertical water sampler with the help of a boat to get to the observation location. The water samples were analyzed immediately by measuring the environmental parameters in the field using the Lutron DO-5510 DO-meter for the DO parameters and temperature and using the HI 9813-5 pH-meter for the pH parameters. The samples were placed in
the cooler box to be analyzed in the laboratory. The flow rate was measured using a current meter at a depth of 50 cm.

Figure 1. Map of the Sampling Locations.
1. Center of the lake (lat 00°22'17"S, long 100°11'22.3" E);
2. Domestic (lat 00°18'59.9"S, long 100°09'53.3" E);
3. Hydropower (lat 00°17'24.1"S, long 100°08'58.8" E);
4. Aquaculture cage (lat 00°13'13.3" S, long 100°10'08.8 E);
5. Endemic Fisheries (lat 00°15'33.2" S, long 100°10'50.5" E).

2.3. Laboratory Analysis
The samples that have been taken were placed in a cooler box (coolbox) for analysis in the laboratory. Laboratory analysis for the parameters of total phosphate and orthophosphate refers to the Standard Methods for the Examination of Water and Wastewater [13]. The reagents used are a mixture of potassium antimonyl taratat, ammonium molibdat and ascorbic acid. The mixture was added to the sample and then heated with a hotplate until the remaining volume of the solution was only 2 mL. The solution was measured with a wavelength spectrophotometer at 660 nm.

2.4. Data Analysis
The total phosphate and orthophosphate analysis results were then compared with the quality standards of the Government Regulations No. 82 of 2001 on Water Quality Management and Water Pollution Control for Class 2 Standard Quality [14]. Correlation analysis was used to determine the relationship between the total phosphate and orthophosphate concentrations for temperature, pH, and DO.
significance of both concentrations with depth at each sampling location and sampling frequencies at different times used analysis of variance (ANOVA) with SPSS Statistics 22 at a 0.05% level of significance.

3. Results and discussion

3.1. Water Characteristics

The characteristics of Maninjau Lake were measured at the center of the lake. The results can be seen in Table 1. The pH values were generally alkaline and close to a neutral pH, which is equal to 6.73. The temperatures ranged from 28.1 to 32.8 °C. The DO values ranged from 6.8-7.7, which shows a relatively high photosynthetic activity caused by phytoplankton.

Table 1. Water characteristics of Maninjau Lake.

| Parameters       | Center | Quality Standard* (mg/L) | Description |
|------------------|--------|--------------------------|-------------|
| Temperature °C   | 28.1   | 25-32                    | fulfill     |
| pH               | 6.73   | 6-9                      | fulfill     |
| DO               | 6.8    | > 3                      | exceed      |
| Orthophosphate   | 0.361  | -                        | exceed      |
| Total Phosphate  | 0.464  | 0.2                      | exceed      |
| Sulfate          | 23.6   | -                        | exceed      |
| Sulfide          | 16     | 0.002                    | exceed      |
| BOD              | 47     | 3                        | exceed      |
| COD              | 74     | 25                       | exceed      |
| TDS              | 288    | 1000                     | fulfill     |
| TSS              | 850    | 50                       | exceed      |
| Nitrite          | 0.157  | 0.06                     | exceed      |
| Ammonium         | 0.461  | -                        | exceed      |
| Nitrate          | 0.289  | 10                       | fulfill     |
| Total Nitrogen   | 0.927  | -                        | exceed      |
| Oil and fat      | 0.016  | 1000                     | fulfill     |

*Government regulations of the Republic of Indonesia Number 82 of 2001 on Water Quality Management and Water Pollution Control; Quality standards Class 2

The water quality monitoring carried out by the Indonesian Institute of Sciences showed that the pH data from Maninjau Lake ranged from 6.6 to 8.7 with the DO around 2.5 - 7.9 mg/L. The temperature parameters ranged from 27.6 - 29.5 °C [15]. Compared to the water characteristics observed by the Indonesian Institute of Sciences which were measured in May 2018, for the pH, DO, and temperature parameters, they have increased. The orthophosphate concentrations ranged from 0.211 to 0.495 mg/L with the highest concentration being at the aquaculture cage location. The Total Phosphate (TP) concentration ranged from 0.374 to 0.523 mg/L where the highest TP concentration was also at the same location. The OP, sulfate, ammonium, total nitrogen concentration is not regulated by government quality standards while the TP, BOD, COD, sulfide and TSS concentrations have exceeded the quality standard according to the government regulations of the Republic of Indonesia Number 82 of 2001. Specifically for the TP concentrations, they have also exceeded the Lake Trophic Status Criteria of the Regulation of Environment State Minister No. 28 of 2009 of 100 μg/L[16]. The trophic status of the lake has reached a hypereutrophic condition.

The high parameter concentrations indicate that the lake has been polluted by the anthropogenic activity around the lake. The organic and inorganic materials present in the water bodies coming from domestic, agricultural, and aquaculture wastes are the main contributors to the high level of pollutants in the lakes. The high sulfide content showed an increase compared to the Henny's research in 2009, which was 400 μg/L [17]. The sudden rise in sulfide concentrations in the surface water during the
bloom is likely to result from the reduction or inhibition of sulfide oxidation due to a decrease in the dissolved oxygen or sulfur oxidizer inhibition. This is in addition to the changes in the physicochemical conditions and ecological communities during the bloom that favor sulfate reducers [18]. A natural phenomenon known as a "sulfur tubo" was reported to have occurred in 1998, where the water smelled of sulfur and the anoxic conditions rose to the surface and caused massive fish death [19].

3.2. Total Phosphate (TP) and Orthophosphate (OP) with Depth
The measurement of the TP and OP concentrations carried out at the five sampling locations on Maninjau Lake has proved that the activity carried out around the sampling point greatly affected both levels. The TP and OP concentrations at various depths in the center of the lake, domestic area, hydropower, endemic fisheries, and aquaculture cage locations can be seen in Figures 2a-2d.

![Figure 2a](image1.png)  **Figure 2a.** Concentration of TP to Depth at the center of the lake  

![Figure 2b](image2.png)  **Figure 2b.** Concentration of OP to Depth at the center of the lake

![Figure 2c](image3.png)  **Figure 2c.** Concentration of TP to Depth: Hydropower, Aquaculture cage, Endemic Fisheries  

![Figure 2d](image4.png)  **Figure 2d.** Concentration of OP to Depth: Hydropower, Aquaculture cage, Endemic Fisheries

The OP and TP concentrations were in the range of 0.182-0.570 mg/L and 0.265-0.603 mg/L respectively. The orthophosphate concentration profile consistently follows the changing profile of the total phosphate concentration. According to Jannson, an orthophosphate is a form of phosphate which
is mostly found in water because it can be used directly by aquatic organisms [8]. The profile of the total phosphate and orthophosphate concentrations was more stratified in the center of the lake compared to the other locations. In the deeper part of the lake, vertical stratification is shown as the gradient of the dissolved substance and temperature which contributes to the difference in density of water [20]. The low-temperature difference in the vertical distribution was 28.47°-31.47°C, indicating a weak temperature stratification. This affects the gradient of the concentration of dissolved compounds in the lake.

Meanwhile, in the shallow depth locations, i.e., in the hydropower, aquaculture cage, and endemic fisheries locations, the concentration is unstratified and shows insignificant differences. Mixing and turbulence occur in a water body and this determines the stability of the water column [21]. Maninjau Lake, with wind speeds faster than 10.4 m s⁻¹[10], can lift the hypolimnetic water in order to bring the existing dissolved compounds to the surface. The phosphate concentrations at the bottom are generally higher than those at the surface. The internal cycling processes contributed to the P changes in the water column [22]. The concentration of phosphate in the surface layer of the aerobic part is lower than that in the bottom anoxic part. P can be released from the sediment into the overlying water in both aerobic and anoxic conditions. However, the P release quantities were different [23]. The relatively low concentration of dissolved oxygen in the overlying water usually increases the rate of phosphorus released from the sediment [24].

The highest OP and TP concentration was found at the aquaculture cage location at a depth of 19 m, of 0.570 mg/L and 0.603 mg/L respectively. The spatial distribution of TP in the overlying water was similar to that of the sediment with a few notable differences [25]. The high TP concentration in the region of the sediment corresponds to the high concentrations measured in water. This indicates that the exchange and diffusion of P between the water and the sediment took place. The main pathway through which the phosphorus enters the aquatic environment from the fish cage is through the feed given to the fish [26]. High concentrations of TP and OP are also shown at the endemic fisheries and near to the domestic locations. Improper domestic wastewater treatment causes high levels of phosphorus at the location. Overall, in all locations, the phosphorus content is relatively high and distributed evenly throughout the lake as evidenced by the high phosphorus level in the center of the lake. Both the incoming external load and the internal phosphorus formed from the sediments under certain environmental conditions contribute to determining the level of phosphorus in the water column.

The ANOVA test showed that the different sampling times showed there to be no significant effect on the TP and OP concentrations. It obtained significance values of 0.88 and 0.99 respectively, as shown in Table 2. The significance value of >0.05 indicates that the sampling frequency did not significantly influence the TP and OP concentrations. The ANOVA used to determine whether depth and location influence the TP and OP concentrations show that except for the hydropower and endemic fisheries, location and depth affects the TP and OP concentrations. In all of these locations, the significance values ranged from 0.000 - 0.015 as can be seen in Table 3.

The significance value of less than 0.05 indicates that depth has a significant effect on the total phosphate and orthophosphate concentrations. Otherwise, at the hydropower location, both the TP and OP concentrations were not affected by depth. At <5 m depth, the shallow depth is influenced by the wind. The wind is more effective at re-suspending the sediment in the shallow lake areas than in the deep lake areas [21]. The highest phosphorus content is at the bottom of the lake. The high wind speed in the shallow part of the lake can lift the phosphor to the surface, meaning that the concentration increases. The hydropower located near the lake outflow is where the TP and the OP concentrations fluctuated during sampling. One possible reason for this is that the increase in phosphorus concentration in the lake outflows due to the release of phosphorus from the sediments. The leakage from the sediment results in internal phosphorus loading [4]. The same results obtained in previous studies showed that BOD5 and COD did not show significant changes in the hydropower and endemic fishery areas [1].
3.3. Correlation between TP, OP and physicochemical parameters with depth

From the previous studies, it is known that the physicochemical parameters that affect the TP and OP concentrations in the waters are mainly temperature, DO, and pH [27]. In this observation, the correlation of the physicochemical parameters in all sampling locations and depth with the TP and OP concentrations was analyzed. The relationship of the TP and OP concentrations to temperature, DO, and pH has been shown in Figures 3a to 3f.

The correlation of all physicochemical components with the phosphorus compounds shows a strong correlation (r>0.9), except for temperature i.e. 0.828 (Figures 3a and 3b). Maninjau Lake’s temperature is in the range of 28.03º - 31.27ºC where the temperature is at the highest at the surface and decreases with depth. Temperature is one of the critical factors to inducing alga bloom, which always occurs between 23 ºC and 28 ºC [28]. The lake temperatures support the occurrence of algae bloom. It can be seen in this moment that the lake is greenish in color. The TP and OP concentrations decrease with the increase in temperature or vice versa, increasing with the decrease in temperature. However, the temperature difference between the surface and the bottom are only about 3ºC, which does not correlate very strongly with the changes in the phosphorus concentration. The high temperature can stimulate microorganism productivity which contributes to the P release from the sediment, meaning that simultaneously, the dissolved P concentrations in the overlying water increase [29]. The OP is a soluble reactive of TP (SRP); at a temperature above 29ºC, the OP/TP ratio is around 0.6 while at temperatures below 29ºC, the OP/TP ratio increases to above 0.7. It indicates that more SRP parts from TP are being released into the water column at a lower temperature.

| Parameters | Center of the lake | Domestic | Hydropower | Endemic fisheries | Aquaculture cage |
|------------|--------------------|----------|------------|-------------------|-----------------|
| TP         | 0.88               | 0.87     | 0.12       | 0.97              | 0.08            |
| OP         | 0.99               | 0.98     | 0.15       | 0.80              | 0.98            |

| Parameters | Center of the lake | Domestic | Hydropower | Endemic fisheries | Aquaculture cage |
|------------|--------------------|----------|------------|-------------------|-----------------|
| TP         | 0.000              | 0.001    | 0.344      | 0.003             | 0.004           |
| OP         | 0.000              | 0.000    | 0.283      | 0.015             | 0.000           |

Figure 3a. Correlation of TP with Temperature. Figure 3b. Correlation of OP with Temperature.
of eutrophication in the lake [30]. High concentrations of nitrate and phosphate in the lake lead to fast growth, as well as the death of both plants and alga. It is generally agreed upon that algal blooms occur in water bodies when the concentration of TP reaches 0.02 mg/L [25]. The TP concentrations obtained in this study have exceeded this critical concentration, which is generally associated with eutrophic/hyper-eutrophic lakes. The carbon dioxide level is one of the major factors controlling water eutrophication [28]. Yang revealed that phytoplankton can utilize low levels of carbon dioxide, which leads to the water becoming alkaline. Natural water is mostly alkaline due to the presence of carbonates in sufficient quantities [31]. Phosphorus solubility is a function of pH and redox potential, being generally lowest at a neutral pH and higher in aerobic conditions [32].

![Figure 3c. Correlation of TP with pH.](image)

![Figure 3d. Correlation of OP with pH.](image)

Figures 3e and 3f show that the correlation between the TP and OP concentrations and DO are very strong. As well as temperature and pH, the TP and OP concentrations increase with the decrease in DO.

![Figure 3e. Correlation of TP with DO.](image)

![Figure 3f. Correlation of OP with DO.](image)

The DO ranges in Maninjau Lake, i.e., 0.01-9.7 mg/L, were the lowest at a depth of 130 m depth at the center of the lake. The highest DO was at the domestic station. The DO values in Maninjau Lake tend to be high. The microbial biodegradation of phytoplankton biomass and humic substances can significantly decrease the DO concentration [32]. It leads to hypolimnetic anoxia. The oversaturated DO values indicate high rates of primary production from the algal blooms nearby [33]. The high organic matter inputs and their subsequent oxidation can also appear to be essential for developing low-oxygen conditions in this region [34].

According to the data recorded in this study, the TP and OP concentrations in the bottom waters are significantly higher than those of the surface waters. While high DOs exceeding the saturated DO found
on the surface of the lake reached 10 mg/L, this decreases as the depth approaches 0, indicating a condition of anoxia. The processes leading to P release in the water column from the underlying sediments include the desorption and dissolution of P bound in both precipitates and inorganic material [24]. The explanation for the release of P from the anaerobic profundal lake sediments is the reduction of phosphate-containing Fe oxides with the resulting diffusion of Fe (II) and phosphate from the sediment pore water into the overlying water [9].

Relatively low dissolved oxygen concentrations in the overlying water usually increase the rate of phosphorus that is released from the sediments [24]. Hou explained that in an aerobic condition, phosphorus can bind with Fe$^{3+}$ to form Fe$_2$(PO$_4$)$_2$. At the same time, dissolved phosphorus in the overlying water can be absorbed by Fe(OH)$_3$, in the sediment so it was difficult for phosphorus to release from the surface sediments in an aerobic condition. Conversely, in the anoxic condition, the bound phosphorus could be easily released from the sediments into the overlying water. These results suggest that the P release from the surface sediments was higher in the slightly alkaline condition with a lower temperature and anoxic state, followed by the strongly alkaline state with a higher temperature and aerobic condition in the overlying water. From the results of this study, it can be concluded that the distribution of vertical and spatial phosphorus is influenced by the physicochemical parameters of temperature, pH, and DO. The process of releasing phosphorus can dramatically affect water quality and result in sustained eutrophication in Lake Maninjau, especially when the external phosphorus source is not controlled. Government policy is needed to limit the number of cages, as well as to control the incoming wastewater.

4. Conclusions

The water quality of Maninjau Lake regarding the TP value does not meet the quality standards regulated by the Indonesian Government under the designation of Maninjau Lake and Trophic State Criteria based on the Ministry of Environment and Forestry regulation. OP ranged from 0.182 - 0.570 mg/L and TP ranged from 0.265 - 0.603 mg/L. These results indicate that Maninjau Lake is hypertrophic. The highest total phosphate concentration value was at the aquaculture cage location. The distribution of spatial phosphorus is influenced by the physicochemical parameters i.e. temperature, pH, and DO. The P release from the surface sediments was higher in the slightly alkaline state with a lower temperature and anoxic condition, followed by a strong alkaline condition with a higher temperature and aerobic conditions in the overlying water. Therefore the parameters of temperature, pH, and DO have a strong negative correlation with the OP and TP concentrations with a correlation value of 0.828-0.982. In addition, ANOVA showed that both the depth stratification and the sampling location were influenced by the physicochemical parameters i.e. temperature, pH and DO.

5. References

[1] Komala P S, Nur A and Nazhifa I 2019 Distribution of organic contamination based on depth stratification in Maninjau Lake, Indonesia IOP Conf. Ser. Mater. Sci. Eng. 602 9–16.

[2] Kementerian Lingkungan Hidup dan Kehutanan 2015 Gerakan Penyelamatan Danau (GERMADAN) Maninjau.

[3] Syandri H 2016 Kondisi Kualitas Air Pada Daerah Pemeliharaan Ikan Keramba Jaring Apung di Danau Maninjau Prosiding Seminar Nasional Tahunan Ke-V Hasil-Hasil Penelitian Perikanan dan Kelautan B3 6 pp 301–10.

[4] Li J, Hansson L and Kenneth M. Persson 2018 Nutrient Control to Prevent the Occurrence of Cyanobacterial Blooms in a Eutrophic Lake in Southern Sweden, Used for Drinking Water Supply Water 10 1–11.

[5] Lukman, Sutrisno and Hamdani A 2013 Pengamanan Pola Stratifikasi di Danau Maninjau Sebagai Potensi Tubo Belerang Limnotek 20 129–40.

[6] Lewis W M, Wurtsbaugh W A and Paerl H W 2011 Rationale for control of anthropogenic nitrogen and phosphorus to reduce eutrophication of inland waters Environ. Sci. Technol. 45 10300–5.

[7] Nemery J 2019 Phosphorus and eutrophication Encycl. Environ. 1–7.

[8] Jansson M 1993 Uptake, exchange and excretion of orthophosphate in phosphate-starved
Scenedesmus quadricauda and Pseudomonas K7 Limnol. Oceanogr. 38 1162–78.

[9] Liu J, Luo X, Zhang N and Wu Y 2016 Phosphorus released from sediment of Dianchi Lake and its effect on growth of Microcystis aeruginosa Environ. Sci. Pollut. Res. 23 16321–8.

[10] Fukushima T, Matsushita H, Subehi L, Setiawan F and Wibowo H 2018 Will hypolimnetic waters become anoxic in all deep tropical lakes? (Scientific Reports (2017) DOI: 10.1038/srep45320) Sci. Rep. 8 1–9.

[11] Pemerintah Kabupaten Agam 2015 Buku Data Lingkungan Hidup Daerah Kabupaten Agam (Lubuk Basung).

[12] Badan Standardisasi Nasional 2008 SNI 6989.57:2008 Mengenai Air dan Air Limbah - Bagian 57: Metode Pengambilan Contoh Air Permukaan.

[13] APHA 2005 Standard methods for the examination of water and wastewater (Washington, D. C.: APHA-AWWA-WEF).

[14] Peraturan Pemerintah Republik Indonesia Nomor 82 2001 Tentang Pengelolaan Kualitas Air dan Pengendalian Pencemaran Air.

[15] Lembaga Ilmu Pengetahuan Indonesia 2017 Program Penyehatan Danau Maninjau dan Pemberdayaan Masyarakat di Sekitar Danau Maninjau Tahun 2017.

[16] Kementerian Lingkungan Hidup dan Kehutanan 2009 Kepmenlh Nomor 28 Tahun 2009 Tentang Daya Tampung Beban Pencemaran Air Danau Dan/Atau Waduk Menteri.

[17] Henny C and Nomosatryo S 2016 Changes in water quality and trophic status associated with cage aquaculture in Lake Maninjau, Indonesia Workshop and International Seminar on Science of Complex Natural Systems 9–10 October 2015, Bogor, Indonesia vol 31.

[18] Achá D, Guédron S, Amouroux D, Point D, Lazzaro X, Fernandez P E and Sarret G 2018 Algal bloom exacerbates hydrogen sulfide and methylmercury contamination in the emblematic high-altitude lake titicaca Geosci. 8.

[19] Henny C and Nomosatryo S 2012 Dinamika Sulfida di Danau Maninjau: Implikasi Terhadap Pelepasan Fosfat di Lapisan Hipolimnion Limnotek 19 102–12.

[20] Boehler B and Schultz M 2008 Stratification of lakes Rev. Geophys. 46 1–27.

[21] Havens K E, Beaver J R, James R T, Lind O T and Qin B 2012 Wind Effects in Shallow Lakes Lakeline 0–3.

[22] Wu Z, Liu Y, Liang Z, Wu S and Guo H 2017 Internal cycling, not external loading, decides the nutrient limitation in eutrophic lake: A dynamic model with temporal Bayesian hierarchical inference Water Res. 116 231–40.

[23] Holdren G C and Armstrong D E 1980 Factors Affecting Phosphorus Release From Intact Lake Sediment Cores Environ. Sci. Technol. 14 79–87.

[24] Hou D, He J, Lü C, Sun Y, Zhang F and Otgonbayar K 2013 Effects of environmental factors on nutrients release at sediment-water interface and assessment of trophic status for a typical shallow lake, northwest china Sci. World J. 2013.

[25] Wang L and Liang T 2015 Distribution Characteristics of Phosphorus in the Sediments and Overlying Water of Poyang Lake PLoS One 10 1–12.

[26] Devi P A, Padmavathy P, Aanand S and Aruljothi K 2017 Review on water quality parameters in freshwater cage fish culture Int. J. Appl. Res. 3 114–20.

[27] Chen M, Ye T R, Krumholz L R and Jiang H L 2014 Temperature and cyanobacterial bloom biomass influence phosphorous cycling in eutrophic lake sediments PLoS One 9.

[28] Yang X, Wu X, Hao H and He Z 2008 Mechanisms and assessment of water eutrophication J. Zhejiang Univ. Sci. B 9 197–209.

[29] Jiang X, Jin X, Yao Y, Li L and Wu F 2008 Effects of biological activity, light, temperature and oxygen on phosphorus release processes at the sediment and water interface of Taihu Lake, China Water Res. 42 2251–9.

[30] Pathak H and Pathak D 2012 Eutrophication: Impact of Excess Nutrient Status in Lake Water Ecosystem J. Environ. Anal. Toxicol. 02 1–5.

[31] Sharma R C, Singh N and Chauhan A 2016 The influence of physico-chemical parameters on phytoplankton distribution in a head water stream of Garhwal Himalayas: A case study
[32] Kim L H, Choi E and Stenstrom M K 2003 Sediment characteristics, phosphorus types and phosphorus release rates between river and lake sediments *Chemosphere* **50** 53–61.

[33] Guo X, Dai M, Zhai W, Cai W J and Chen B 2009 CO2 flux and seasonal variability in a large subtropical estuarine system, the Pearl River Estuary, China *J. Geophys. Res. Biogeosciences* **114**.

[34] Qian W, Gan J, Liu J, He B, Lu Z, Guo X, Wang D, Guo L, Huang T and Dai M 2018 Current status of emerging hypoxia in a eutrophic estuary: The lower reach of the Pearl River Estuary, China *Estuar. Coast. Shelf Sci.* **205** 58–67.

**Acknowledgments**

This study was supported by the Directorate General of Research and Development Strengthening of the Ministry of Research and Higher Education of the Republic of Indonesia through the scheme of Excellent Basic Research of Higher Education (PDUPT) No.051/SP2H/LT/DRPM/2019, fiscal year 2019.