Water Quality Status and Pollution Waste Load from Floating Net Cages at Maninjau Lake, West Sumatera Indonesia

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Abstract. Aquaculture has become one of the major causes of Lake Eutrophication due to the lack of direct and efficient technologies for pollution control and remediation. Water samples were collected on February 2018 and March 2019 under floating net cages (depth 4 m) in each farm (Maninjau, Koto Kaciek, Intake PLTA, Sungai Batang areas) using a Kemmerer Water Sampler with the volume is 1200 mL. This tool was used to the determination the water quality parameters which measured based on the standard procedures APHA (1995). Water transparency was measured using a Secchi disk. The Storet method was used to analyze the water quality status. The capacity of water pollution load and the trophic status of Maninjau Lake were analyzed with the formula of the Minister of Environment Regulation No. 28/2009 concerning the capability of Lake and/or Reservoir Water Pollution. The results of the research prove that the water quality status of Maninjau Lake categorize in class one to three, which is heavy pollutant, and class 4 is mild polluted. The capacity of Lake water pollution load based on feed quota in the year 2019 is 9,736.23 tons/year with fish production is 6,490.82 tons/year which is equivalent with 4,327 net cages. While, the trophic status of Maninjau Lake was categorize as hypereutrof.

Keywords: Lakes, water quality index, nutrient, eutrophication, trophic status

1. Introduction

Lakes are very unique ecosystems on the surface of the earth. The Lake does not only provide food, raw materials, and water resources for humanity [1], but also maintains the ecological balance, biodiversity and endangered species resources [2,3]. Other than that, Lakes also play an important role for water conservation, flood control and climate change [4], pollution degradation [5,6,7], maintenance of climate change [8], and groundwater resources [9].

Maninjau Lake is a tecto-volcanic area spanning 99.5 km². It has important roles as a tourist destination and as hydroelectric power plant, also use for floating net cage operations and fisheries activities [10,11]. There was an increase in total floating net cages over the years in 2011, 2012, 2013, 2014 and 2015 of 15,000; 15,860, 16,120; 16,580 and 20,608 units [10,11,12]. Fish species that are...
commonly cultured in Lakes are common carp, *Cyprinus carpio* and Nile tilapia, *Oreochromis niloticus* [13].

Despite the advances that have been made in floating net cages management in Maninjau Lake, such as aquaculture technology improvements [14,15]. The anthropogenic eutrophication of Lakes remains one of the most obvious and prevalent water quality problems. Phosphorus (P) is usually the limiting nutrient for productivity in Lakes, and is thus of key importance in the process of eutrophication [16,3,14]. The aims of this study were analyzed the water quality status of Maninjau Lake, the capacity of Lake water pollution load and trophic status.

2. Materials and Methods

**Study Area:** The study was conducted in Maninjau Lake, which is located in West-Sumatera Province, Indonesia. The geographical position is S: 00°12′26.63"- S: 00°25′02.80" and E: 100°07′43.74"- E: 100°16′22.48", and it is located at an altitude of 461.50 m above sea level. Based on the Schmidt-Ferguson climate classification, Maninjau Lake has the characteristic of climate type A and an annual rainfall of 3,490 mm.

**Water quality analysis:** Water transparency was measured using a Secchi disk. Water samples were collected from 2013 to 2019, under floating net cages (depth 4 m) in each farm (Maninjau, Koto Kaciek, Intake PLTA and Sungai Batang areas) using a Kemmerer Water Sampler (Wildco, USA) with diameter (D) 118 mm and sample volume 1200 mL, and they were used for the determination of dissolved oxygen (DO), chemical oxygen demand (COD) and biochemical oxygen demand (BOD<sub>5</sub>) levels. An oxygen meter (YSI model 52, Yellow Spring Instrument Co., Yellow Springs, OH, USA) was used in situ, and pH values were determined using a pH meter (Digital Mini-pH Meter, 0-14PH, IQ Scientific, Chemo-science (Thailand) Co., Ltd, Thailand). Water temperature was measured using a thermometer (Celsius scale). The TDS, TSS, P levels, N-NO<sub>3</sub>, N-NO<sub>2</sub>, Cu, Fe, Pb, Hg, Cd f the water in each replication were measured according to standard procedures [17]. The data obtained through Storet Method was analyzed and concluded by enclosing the literature as the support. The water quality class 1 to 4 were analyzed with the formula of the Minister of Environment Regulation No.28/2009 concerning the capability of Lake and/or Reservoir Water Pollution [18]. The procedures of water quality determination by using Stored Method as shown in Table 1 were as follow:

1. Collecting the data about water quality periodically.
2. Comparing the data from the measurement results of each water parameters to the threshold value which appropriate to the water class.
3. If the result fulfilled the water quality standard value (measurement result ≤ water quality standard), then it scored 0.
4. If the result did not fulfill the water quality standard value (measurement result > quality standard), then it scored 1.
5. Counting up all the negative scores from each counted parameter and deciding the quality status from the total.

**Table 1. The value system determination to decide the water quality status**

| Sample quantity | Score | Parameters |
|-----------------|-------|------------|
|                 |       | Physic     | Chemical | Biology |
| >10             | Maximum | - 2       | - 4      | - 6     |
|                 | Minimum | - 2       | - 4      | - 6     |
|                 | Average | - 6       | - 12     | - 18    |
After that, the classification was done based on the obtained value as follows:
1. Class 1: Excellent, Score = 0 fulfilled quality standard
2. Class 2: Good, Score = -1 s/d -10 lightly polluted
3. Class 3: Moderate, Score = -11 s/d -50 moderately polluted
4. Class 4: Bad, Score = ≥-51 badly polluted

The capacity of water pollution load and the trophic status of Maninjau Lake were analyzed with the formula of the Minister of Environment Regulation No. 28/2009 concerning the capability of Lake and/or Reservoir Water Pollution (Table 2 and 3). The total floating net cages in Maninjau Lake and those operated for fish farming from 2013 to 2019 are recorded using the census method. The total floating net cages and fish that are active for fish farming in each year (2013 to 2019) are conducted by census method.

Table 2. Capacity of Maninjau Lake

| No | Parameter                                                                 | Formula                                                                 | information                                                                 |
|----|---------------------------------------------------------------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| A  | The morphology and hydrology of the Lake                                 | \[ \bar{Z} = 100 \times \frac{V}{A} \]                                  | \( \bar{Z} \): The average depth (m) \( V \): The volume of water (m\(^3\)) \( A \): The surface area (Ha) |
| A  | The rate of turnover Lake water                                           | \( \rho = \frac{Q_o}{V} \)                                             | \( \rho \): The rate of turnover Lake water (year\(^{-1}\)) \( Q_o \): Total a debit out (billion m\(^3\)/year) |
| B  | The allocation of load pollution Phosphorus (P)                          | \[ \Delta \{P\}_{d} = \{P\}_{f} - \{P\}_{i} \]                        | \( \Delta \{P\}_{d} \): The allocation of the total P load from FNC (mg P/m\(^3\)) \( \{P\}_{f} \): Requisite levels of P-total max. In accordance with the Farmed fish species (mg P/m\(^3\)) \( \{P\}_{i} \): levels of P-total monitoring results (mg/m\(^3\)) |
| C  | Capacity of P-total pollution load of wastewater fish farming            | \[ L_{\text{fish}} = \frac{\Delta \{P\} \bar{Z}}{\rho (1 - R_{\text{fish}})} \] | \( L_{\text{fish}} \): Capacity of P-total waste of fish per unit area of the Lake (gr P/m\(^2\)/year) |
| D  | Feed and P waste from fish farming FNC                                   | \[ PLP = FCR \times P_{\text{feed}} - P_{\text{fish}} \]                | \( PLP \): P-total entering the Lake from fish waste (kg P/ton fish) \( FCR \): Feed Conversion Ratio(ton feed/ton fish) \( P_{\text{feed}} \): levels of P-total in feed (kg P/ton feed) \( P_{\text{fish}} \): P-total levels in fish (kg P/ton fish) |
| E  | Aquaculture                                                              | \[ LI = \frac{L_{\text{fish}}}{PLP} \]                                | \( LI \): FNC fish production (tons / year) \( LP \): Total feed the fish with FNC (ton /year) |
|    | Total fish production of FNC                                             | \[ LP = LI \times FCR \]                                               | \( L_{\text{fish}} \): The total capacity of P-total waste fish in the waters of the Lake (g P / year) |
|    | The total feed to the fish in FNC                                        |                                                                         |                                                                             |
Table 3. Lake trophic status criteria

| Status of trophic | Average Total-N (µg/l) | Average Total-P (µg/l) | Average Klorofil-a (µg/l) | Average water tranperancy (m) |
|-------------------|------------------------|------------------------|---------------------------|-------------------------------|
| Oligotrof        | ≤ 650                  | < 10                   | < 2.0                     | ≥ 10                          |
| Mesotrof         | ≤ 750                  | < 30                   | < 5.0                     | ≥ 4                           |
| Eutrof           | ≤ 1900                 | < 100                  | < 15                      | ≥ 2,5                         |
| Hypereutrof      | > 1900                 | ≥ 100                  | ≥ 200                     | < 2,5                         |

Sources: Ministry of Environment, 2009, Modification OECD 1982, MAB 1989; UNEP-ILEC, 2001

3. Results

The water quality status in each year at Maninjau Lake based on the Storet Method are recorded in Table 4. Based on water quality data 2013 to 2019, and compared with water quality standards based on the Government of the Republic of Indonesia regulation No. 82/2001 concerning management of water quality and water pollution. The water quality status of Maninjau Lake was classified in class 1, 2 and 3 were as bad (heavily polluted), whereas the class 4 in 2013 to 2016 was classified as moderate (medium polluted), while in 2017 to 2019 was classified as bad.

The carrying capacity of water pollution load of Maninjau Lake based on fish production, feed quota equivalent to the total active floating net cages which presented in Table 5. Furthermore, the trophic status of Maninjau Lake is presented in Table 6.

Table 4. Water quality status of Maninjau Lake

| Year | Score  | Classification | Score  | Classification | Score  | Classification | Score  | Classification | Score  | Classification |
|------|--------|----------------|--------|----------------|--------|----------------|--------|----------------|--------|----------------|
| 2013 | -148.75| Bad            | -148.75| Bad            | -105.50| Bad            | -28.00| Moderate       |
|      | ±8.54  |                | ±8.54  |                | ±22.17 |                | ±2.60 |               |
| 2014 | -151.25| Bad            | -151.25| Bad            | -108.25| Bad            | -28.00| Moderate       |
|      | ±6.29  |                | ±6.29  |                | ±17.06 |                | ±1.26 |               |
| 2015 | -153.75| Bad            | -153.75| Bad            | -112.05| Bad            | -29.00| Moderate       |
|      | ±7.50  |                | ±7.50  |                | ±18.90 |                | ±5.03 |               |
| 2016 | -157.50| Bad            | -157.50| Bad            | -115.25| Bad            | -28.50| Moderate       |
|      | ±5.00  |                | ±5.00  |                | ±13.60 |                | ±5.26 |               |
| 2017 | -163.75| Bad            | -163.75| Bad            | -117.05| Bad            | -34.00| Bad            |
|      | ±4.79  |                | ±4.79  |                | ±11.90 |                | ±1.63 |               |
| 2018 | -166.25| Bad            | -166.25| Bad            | -125.75| Bad            | -37.00| Bad            |
|      | ±4.79  |                | ±4.79  |                | ±4.35  |                | ±2.58 |               |
| 2019 | -167.50| Bad            | -167.50| Bad            | -129.75| Bad            | -37.00| Bad            |
|      | ±5.00  |                | ±5.00  |                | ±8.02  |                | ±2.58 |               |

Note:
1. Excellent, Score = 0 fulfilled quality standard
2. Good, Score = -1 s/d -10 light polluted
3. Moderate, Score = -11 s/d -30 moderately polluted
4. *Bad, Score = \geq -31* badly polluted

Table 5. Fish production, quota of feed, total of floating net cages and the capacity of the pollution load

| Year | Fish production (ton/year) | Quota of feed (ton/year) | Total active floating net cages (net) |
|------|---------------------------|--------------------------|--------------------------------------|
|      | Reality at Maninjau Lake  | recommendatio ns according to capacity | Reality at Maninjau Lake | recommendatio ns according to capacity |
| 2013 | 24,180.00                 | 6,393.94                | 38,688.00                          | 9,590.92                |
| 2014 | 24,870.00                 | 11,044.08               | 39,792.00                          | 16,566.13              |
| 2015 | 32,972.00                 | 5,037.65                | 49,458.00                          | 7,556.48               |
| 2016 | 25,101.00                 | 12,691.01               | 40,161.00                          | 19,036.51              |
| 2017 | 28,381.50                 | 9,300.28                | 45,408.00                          | 13,950.42              |
| 2018 | 19,795.50                 | 8,331.50                | 31,671.00                          | 12,497.25              |
| 2019 | 16,496.25                 | 6,490.82                | 26,394.00                          | 9,736.23               |

Note: *Operated as much as 80% of the total floating net cages,*
**Operated as much as 60% of the total floating net cages,**
***Operated as much as 50% of the total floating net cages.***

Table 6. Trophic status of Maninjau Lake

| Tahun | Total-N (µg/L) | Total-P (µg/L) | Chlorophyll-a (µg/L) | Water transparency (m) | Trophic status |
|-------|----------------|----------------|----------------------|------------------------|----------------|
| 2013  | 1,697.50±305.76 | 380.00±82.87   | 0.91±0.46            | 1.90±0.29              | Hypereutrof   |
| 2014  | 1,187.25±132.54 | 577.50±63.97   | 0.94±0.35            | 1.60±0.42              | Hypereutrof   |
| 2015  | 1,972.50±126.85 | 490.00±96.95   | 1.38±0.59            | 1.30±0.18              | Hypereutrof   |
| 2016  | 2,100.00±367.42 | 465.00±99.83   | 0.52±0.16            | 1.18±0.10              | Hypereutrof   |
| 2017  | 1,650.00±449.48 | 517.50±164.60  | 0.44±0.31            | 1.50±0.08              | Hypereutrof   |
| 2018  | 1,835.00±347.61 | 425.00±5.0     | 0.29±0.05            | 1.55±0.06              | Hypereutrof   |
| 2019  | 1,885.00±290.11 | 337.50±61.85   | 0.29±0.05            | 1.95±0.13              | Hypereutrof   |

Note: The key factor for tropic status is total-P

**DISCUSSION**
Our results reveal that the water quality of Maninjau Lake was classified as heavily polluted due to cultivation waste of tilapia and common carp fish with floating net cages. Nitrogen and phosphorous is primary sources of loadings waste organic in Maninjau Lake [14,15]. Additionally, the availability of N, P and TOM in the water was significantly higher after fish mass mortality as much as 600 ton in August and September, 2016 and had a negative effect on the water quality of Maninjau Lake [13]. According to Junaidi et al. [12] that the effect of organic matter accumulation has caused the status of heavily polluted lake water quality and mass mortality of fish in floating net cages in every year. Furthermore, the load of waste of floating net cages from the year 2001 to 2013 in Maninjau Lake totaled 111889.84 tons with the average load of 9324.98 tons/year and the average load of 24.60 tons/day.

The capacity of the lake and/or reservoir water pollution load is the ability of Lake water and reservoir water to receive input pollution load without causing lake water and reservoir water be polluted. The present study was conducted to report the capacity water pollution loads introduced by floating net-cages fish farming in Maninjau Lake. Based on the data fish production and quota of feed from aquaculture activities at Maninjau Lake have been exceed capacity water pollution load (Table 5). The capacity of water pollution load largely determined by the level of phosphorous (P) in water bodies. The maximum P concentration that can be accepted by water bodies due to the common carp and tilapia aquaculture activities in floating net cages is 250 μg/L [19]. In contrast, the P concentration in water bodies of Maninjau Lake ranges between 337 to 577.5 μg/L.

Negative environmental impacts of cage aquaculture operations have been reported in many parts of the world [20, 21, 22, 13]. The level of N dan P loads release into water bodies depend on fish species, stocking density, feeding rate and feed types [14,15,23,24,25]. According to Syandri et al.[14] the total N and P load releases into water bodies were different for each ton of fish production such as the Cyprinus carpio (37.93±2.59 and 18.30±0.12), Oreochromis niloticus (49.90±5.17 and 20.01±0.99), Osphronemus gorami (45.90±4.18 and 22.60±0.80) and Clarias gariepenus (20.35±4.12 and 13093±1.47) kg t⁻¹, respectively. The feed composition and apparent food conversion ratio of aquaculture operations primarily had a negative effect on the environment. In addition, the aquaculture integrated model, recirculating aquaculture systems, site selection, size of the farm and species of cultivated fish should also be considered as an important factors [26,27].

The condition of lake and/or reservoir water quality is classified based on eutrophication due to increased levels of nutrients in the water. One of the most pressing problems for lake environments in the past of a few decades is eutrophication problem [28], whereby the release of N and P into excessive water bodies due to aquaculture activities can trigger cyanobacteria blooms, reduce water transparency and dissolve oxygen levels, damage the structure of food webs, and trigger a toxicity effect. Meanwhile, inputs of fish feed residues to Lakes have increased the levels of nitrogen, phosphorous and carbon in the water column and in sediments, which can the abnormal growth of fish.

In this study, the trophic status of Maninjau Lake since 2013 until 2019 is hypereutrof. Anthropogenic development of Maninjau Lake in Indonesia from aquaculture activities has led to considerable pollution of Lake ecosystems. The factor analysis of water quality from nitrogen, phosphorous, Chlorophyll-a and water transparency indicated that the phosphorous might be the main factor affecting the water quality in Maninjau Lake. Meanwhile, in Lake Wuli indicated that N might be the main factor affecting water quality of the most eastern sites in the wet season, and P may be the main factor in the dry season [3]. Additionally, excessive concentrations of P can be harmful to the environment because it is a stimulating nutrient for the growth of phytoplankton, macroalgae, as well as vascular plants [29]. Several studies have shown conclusively that P, not nitrogen (N), is typically the limiting nutrient for freshwater ecosystem [30,31]. Furthermore, the eutrophic lake harbored a higher abundance of methanotrophs [32]. Our results provide a valuable recommendation for government regarding the management of water environments in Maninjau Lake by regulation of Bupati Agam.

4. Conclusion
This study shows that the water quality status of Maninjau Lake was categorized as heavily polluted with trophic status as Hypereutrophic. The data obtained showed that fish production and feed quota from fish culture with floating net cages exceeds the capacity of Maninjau Lake water pollution loads. The findings of this study are relevant for the issuance of the regulation of Agam Regency Regent regarding the determination of trophic status and carrying capacity of Maninjau Lake water pollution load.

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