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Pollution loads and its impact on Lake Toba

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Abstract: Human activities in Lake Toba area have contributed to the supply of pollutant on these aquatic ecosystems. Organic material and nutrient especially phosphorus component is estimated to be quite dominant of pollutant load. This study aims to recognize the level of organic load (in the form of Chemical Oxygen Demand; COD) and nutrient components (Total Phosphorus; TP) and its influence on the aquatic environment condition. This research was conducted in Lake Toba in November 2017, by observing selected locations in several inlet rivers of the lake and the lake waters area. The pollutant load from the land area, which is organic material (in the form of COD) reaches 90,712 tons/year, while the nutrient load (in the form of TP) reaches 138 tons/year. From aquaculture activities, organic loads released into the waters (in the form of feces and uneaten feed) are estimated at 14,265.4 tons/year, while the phosphorus load (in the form of TP) is 570.33 tons/ year. The phosphorus load that enters the waters of Lake Toba as a whole has exceeded the permissible loading levels and changed the trophic status of the Lake Toba waters. Meanwhile, the organic pollutant load will increase the anoxic column on the hypolimnion area of the lake.

1. Introduction

Lake waters are generally considered as common property resources in Indonesia so that they can be freely exploited without any restrictions. From time to time, the utilization of lake waters has been varied and intensified, both by local people as well as by various sectors. Lake Toba is one of the major lakes in Indonesia that has a multi-sectoral role in local, national and international interest, with various functions and intensive utilization rate. Current utilization of Lake Toba includes tourist destination, fishing areas, fish culture activities in floating net cages (cage aquaculture) and as a source of raw water. Land utilization in the lake catchment is developed not only for settlements but also agricultural activities.

Fisheries activity has been running for a long time and has been recorded since the 1950 [1]. Fish culture in cage system was first tried on Lake Toba in 1988[2] and currently quite widespread along the lakeshore. About 50 villages recorded that have cages, which include 5,158 units owned by local people and those owned by Foreign Companies in five locations[3]. Lake water utilization for raw water is managed by Local Water Company (PDAM; Perusahaan Daerah Air Minum) in Balige, Laguboti, and Pangururan.

Utilization of the mainland area of Lake Toba is settlements area and agricultural activities. Around the banks of lake recorded 147 villages and population densities reached 25,087 heads of households[3]. In the catchment area, agricultural activities are carried out by exploiting the hillsides and plain lands in river valleys. Land use for agricultural activities in the lake catchment reaches 129,448 ha or around 53% of the lake catchment area, with the highest proportion in the Toba Samosir District reaching 56,138 Ha [4].

With various human activities both in the catchment and waters area, the potential threat to the sustainability of the lake ecosystem is very high. This comes from domestic waste and activities that do not consider the impacts on the environment, which ultimately leads to the lake waters.

At present, the lake management is more directed based on Ecosystem Carrying Capacity, which is related to the environment capacity against loading from anthropogenic activities. In determining the spatial plan of the lake catchment area and granting to activity permits that can affect lake water quality, it is necessary to consider the capacity of lake ecosystem to hold pollution loading (Reg. of the Minister of Environment Rep.of Indonesia, No. 28 of 2009).

According to Raghunathan *et al.*[5], the definition of lake environment carrying capacity is the ability to accommodate pollutant load inputs without degrading the quality of the lake's water. The waters carrying capacity conception, meanwhile for the cage aquaculture activities has been stipulated by Beveridge[6] namely the maximum fish production level that can be achieved based on total phosphorus (TP) level that can still be accepted according to the lake waters utilization interests.

Pollutant load from anthropogenic activity covered by waters carrying capacity in this study includes i) pollution load from the catchment area which enters the waters; ii) pollution load from activities in waters area. The purpose of this study was to determine the level of pollutant load in terms of organic (in the form of COD; Chemical Oxygen Demand) and the nutrient component (in the form of TP; Total Phosphorus) and the impact on the environmental conditions of Lake Toba waters.

2. Methods

Primary data collection was carried out in rivers as the inlets of Lake Toba and the waters area of the lake on 12 and 20 stations, respectively (Figure 1) in November 2017.

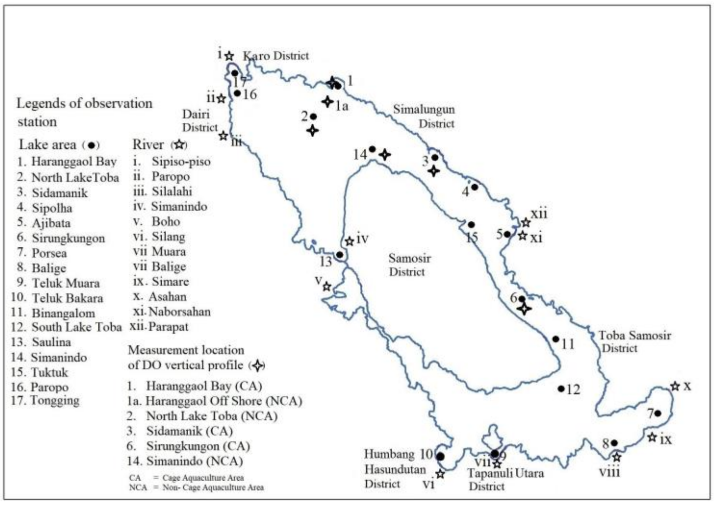

Figure 1. Distribution of sampling locations and water quality parameters measurements in the lake area and rivers as Lake Toba inlets.

The river's physical parameters measured were flow rate using the velocity-area method. Water quality parameters which were measured include temperature, pH, dissolved oxygen (DO), conductivity, turbidity, and Total Dissolved Solid (TDS) using water quality checker (WQC). In waters area, Secchi depth was measured using Secchi disc apparatus and dissolved oxygen profiles using Rinko profiler. Oxygen profile was observed in six locations namely in Haranggaol Bay, Sidamanik and Sirungkungon (representing cage aquaculture area; CA), and Haranggaol Offshore, North Lake Toba and Simanindo area (representing non-cage aquaculture area; NCA).

2.1. Study of anthropogenic pollutant loads impact

Water samples for measuring COD were taken from eight rivers as the lake inlets and several locations in lake waters. Analysis of COD using the closed reflux method spectrophotometrically with permanganatmetric method[7]. The COD value is compared to the water quality standard based on the water grade criteria referring to Government Regulation of the Republic of Indonesia number 82/ 2001.

For TP observation, water samples were taken using the *niskin water sampler* in eight rivers as lake inlet and ten locations in lake waters, then analyzed using destructive methods followed by the ascorbic acid method[7]. Observation of nutrient input from the catchment area by using a moment nutrient load which then used for calculation of river load by conforming to flow rate. The loading of TP from cage aquaculture is calculated based on the level of fish production from secondary data.

Evaluation of TP load (which represent phosphorus) is by paying attention to the equation from[8]:

$$J_N = J_E + J_{PR} \quad \text{(mg/year)} \tag{1}$$

where

J_N = Natural input
J_E = Catchment input
J_{PR} = Precipitation input

and total input of [P] to the lake

$$J_T = J_N + J_A \quad \text{(mg/year)} \tag{2}$$

where

J_T = Total input to the lake
J_A = Artificial input

for calculation of total loading (L_T) of TP we used equation:

$$L_T = J_T/A_o \quad \text{(mg/m}^2\text{/year)} \tag{3}$$

where

A_o = Lake volume

Evaluation of the dissolved oxygen vertical profile is to observe cage aquaculture impact by knowing unsafe oxygen condition (≤ 2.0 mg/L) for fish life and anoxic (0 mg/L) depth.

3. Results

3.1. Water quality parameter conditions of Lake Toba inlet and its waters

The condition of Lake Toba's inlets generally has low flow rate, maximum 3.8 m^3/sec, except for Silang River which reaches 10 m^3/sec. Silang River is known as the main water supplier of Lake Toba which reaches 10% of all water incoming to the lake[9].

The temperatures were still in the natural range, water pH level generally > 7.5 and tends to be alkaline, conductivity ranged from 0.010 - 0.104 mS/cm and dissolved oxygen were generally still quite high. The high turbidity was recorded in Sipiso-Piso (60.6 NTU) and Simare (63.9 NTU), and TDS concentration recorded in Boho River (0.067 mg/L) besides in Silang River (0.063 mg/L) were relatively high compared to other rivers (Table 1).

Table 1. Condition of several inlet river water quality.

Parameters	Silang River*)	Range value in other rivers	Asahan River**)
Temperature (°C)	25.88	20.59 - 23.70	26.74
pH	8.20	7.13 - 8.08	8.33
Conductivity (mS/cm)	0.106	0.010 - 0.104	0.103
Dissolved Oxygen (DO) (mg/L)	7.47	6.27 - 8.42	7.75
Turbidity (NTU)	3.9	7.5 - 102.2	3.6
Total Dissolved Solid (TDS (g/L)	0.069	0.006 - 0.067	0.067
Flow rate (m^3/sec)	10***)	0.67 - 3.40	Nd

Note: *) The largest river; **) Outlet of lake; ***) Lukman[9]

Lake water quality was characterized by temperature on natural conditions, pH tends to be alkaline (> 8.0), conductivity was relatively uniform (0.106 - 0.110 mS/cm), turbidity was relatively low (max. 7.7 NTU) and Secchi depth between low to moderate (max.7.1 m) (Table 2).

Table 2. Condition of Lake Toba water quality.

Parameters		Range value
Temperature	(°C)	24.46 - 28.65
pH		7.94 - 8.85
Conductivity	(mS/cm)	0.106 - 0.110
Dissolved Oxygen (DO)	(mg/L)	2.67 - 11.26
Turbidity	(NTU)	0.00 - 17.7
Total Dissolved Solid (TDS)	(mg/L)	0.00 - 0.07
Secchi depth	(m)	4.1 - 7.1

Based on the physicochemical parameters, the lake waters generally were still on the natural condition, except for the Sechi depth which characterizes oligo-mesotrophic waters and the dissolved oxygen in Sidamanik area (Station 3) was relatively low (2.67 mg/L).

3.2. Impact of anthropogenic activity

3.2.1. River water quality standard condition based on COD. River water quality conditions can be reflected by water quality standard related to its utilization for human need. Criteria for water quality standards based on Government Regulation of the Republic of Indonesia number 82 of 2001 referred to COD level, namely the water oxygen needed for organic degradation process chemically.

The value of COD provides a figure of organic content contained in water as a reflection of the organic pollution level which is associated with human activity or known as domestic pollution. The COD level recorded at inlets of Lake Toba ranged between 28.17 – 70.42 mg/L, and based on their COD values have water grades of III and IV (Table 3). Sipiso-Piso River, Silang River, Naborsahan River, and Parapat River have water quality standards on grade IV. It suggested that human activity has been quite intensive in the four river watersheds and reflects that domestic pollution was high.

3.3. Conditions of phosphorus nutrients

One of the parameters for determining aquatic productivity and one of the determining factors for trophic status is phosphorus [P][10], which originates from natural activity namely from weathering of rocks[11] and from the effects of various anthropogenic activities both from agricultural and domestic waste.

Human activities in Lake Toba and the surrounding area have occurred quite intensively, both in the land and in its water bodies. Agriculture activities in the catchment area of the lake include dryland agriculture and rice fields. Whereas in the waters area the most important activity is the fish culture on the cage, known as cage aquaculture.

Based on the field observations, the quantity of TP from the catchment area was 138.498 kg/year totally which came out through the Asahan River 131.372 kg/year, so that TP accumulation in Lake Toba from land activities was about 7.125 kg/ year (7.1 tons/year) (Table 4). The highest TP concentration was obtained from Parapat River (0.203 mg/L), while the highest TP supplier was from the Silang River which reached 32.4 tons/year.

Table 3. Water grade based on COD of Lake Toba inlets.

Stations	Rivers	Water grade
1	Sipiso-piso	IV
2	Paropo	III
3	Silalahi	III
4	Simanindo	III
5	Boho	III
6	Silang	IV
7	Muara	III
8	Balige	III
9	Simare	III
10	Asahan	III
11	Naborsahan	IV
12	Parapat	IV

Note: Water grade criteria based on COD (Govern. Reg. Rep.of Indonesia. No. 82/2001) Grade I (10 mg/L); Grade II (25 mg/L); Grade III (50 mg/L); Grade IV (100 mg/L)

Referring to Regulation of the Minister of Environment Republic of Indonesia No. 28/2009, the trophic status criteria of Lake Toba based on TP levels, show that some areas of the lake were in eutrophic conditions, except in the Porsea (Station 7) and Saulina (Station 13) area were in mesotrophic conditions (Figure 2).

The cage aquaculture activity in Lake Toba has contributed 14.265.4 tons/year of organic load, referring to fish production level (62.023 tons) and feed given (76.228.7 tons). With the release of the organic cage aquaculture activity will supply a large enough TP which is estimated to reach 570 tons (Table 5).

Table 4. A moment Total Phosphor [TP] load from rivers as inlet and outlet of Lake Toba.

Station	Rivers	A moment of [TP] loading (mg/L)	A moment flow rate (m^3/sec.) 1]	Loading of TP (ton/year)
Inlets of Lake Toba				
1	Sipiso-piso	0.142	2.79	12.494
2	Paropo	0.083	1.41	3.691
3	Silalahi	0.129	0.81	3.295
4	Simanindo	0.116	0.93	3.402
5	Boho	0.112	3.77	13.316
6	Silang2]	0.097	10.61	32.444
7	Muara	0.041	0.71	0.918
8	Balige	0.095	1.42	4.254
9	Simare	0.103	3.4	11.044
11	Naborsahan	0.110	2.51	8.707
12	Parapat	0.203	0.67	4.289
	Other rivers	0.0263]	49.574]	40.644
		Total	78.606]	138.498
Outlet of Lake Toba				
10	Asahan	0.053	1005]	131.373

Source: 1) Data in November2017; 2) Data in October 2009[12]; 3) The lowest TP in October 2009[12]; 4) Estimation value: Flow rate residual is total flow rate in catchment minus the measured flow rate; 5) Anonymous[13]; 6) Meigh[14]

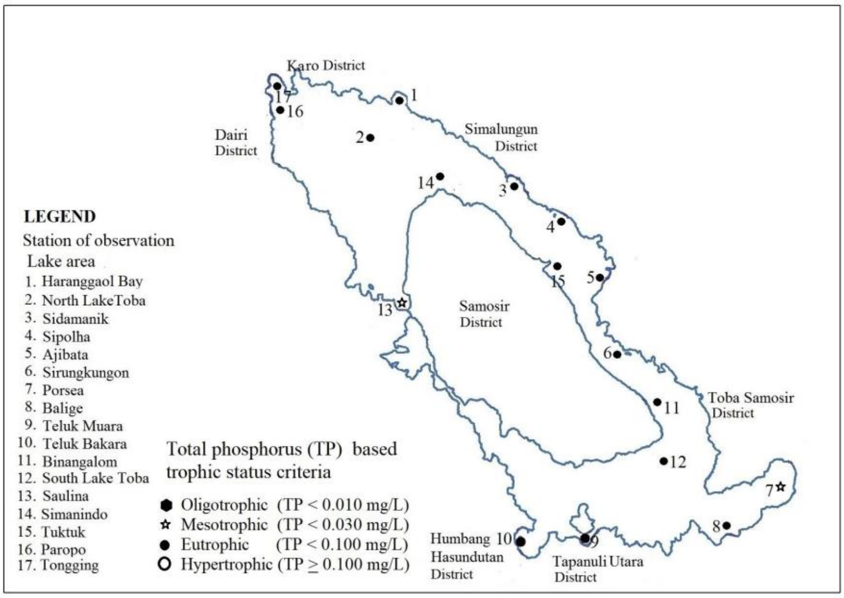

Figure 2. Trophic status condition of Lake Toba (Observation on November 2017).

For the calculation of the loading of [P] in Lake Toba (Equation 1, 2, 3):
J_{PR} = 2047 ton/year (Lukman[9])
J_E = 138.498 ton/year (Table 4)
J_A = 570.33 ton/year (Table 5)

Then: J_T = 138.498+ 2.047 + 570.33
= 710.875 ton/year
= 710.875x 10^9 mg/year
With A_0 = 1.124 x 10^6 m^2 (Lukman & Ridwansyah[15])
So that L_T = $\frac{710.875\text{x } 10^9 \text{ mg/year}}{1.124 \text{ x } 10^6 \text{ m}^2}$
= 632.45 mg/m^2 /year
Thus the total load of TP to Lake Toba is 632.45 mg/m^2/year.

Table 5. Phosphor [P] loading prediction from cage aquaculture in Lake Toba.

District	Fish producti on (ton)1)	Feed used estimati on (ton)2)a)	Content of [P] on feed (ton)3)c)	Retentio n of [P] by fish (ton)4)d)	Release [P] through faeces (ton)e)	Release of dissolve d [P] metabol ite residues (ton)f)	Release of [P] total yang to the waters (ton)
Simalungun	17518.9	21548.2	258.58	97.48	54.30	106.79	161.09
Toba Samosir	8989.2	11056.7	132.68	50.02	27.86	54.80	82.66
Tapanuli Utara	78	95.9	1.15	0.43	0.24	0.48	0.72
Hbg. Hasundutan	536.6	660.0	7.92	2.99	1.66	3.27	4.93
Samosir	33508.5	41215.5	494.59	186.46	103.86	204.26	308.13
Dairi	943	1159.9	13.92	5.25	2.92	5.75	8.67
Karo	449.1	552.4	6.63	2.50	1.39	2.74	4.13
TOTAL	62023.3	76288.6	915.46	345.13	192.25	378.09	570.33

Source: 1) Anonymous[16]; 2) Lukman *et al.*[17]; 3) Garno & Adibroto[18]; 4) Rismeyer (1998) *in* Azwar *et al.*[19]. a) FCR nile = 1.23; b) 1.2% of feed weight; c) 37.7% from [P] content on feed; d) 21.0% from [P] content on feed; e) 41.3% from [P] content on feed

3.4. Condition of some anthropogenic determinant of water quality parameters

Condition of some anthropogenic determinant of water quality parameters shows variation (Table 6). The trophic status of Lake Toba based on the TP content was eutrophic and based on Secchi depth, the waters conditions were mesotrophic-eutrophic. While the organic matter content is reflected by the COD level, there is a tendency in the cage aquaculture area to show water quality in grade III and IV while in non-cage aquaculture area was in grade III.

Table 6. Water quality condition of Lake Toba.

Station	Area	Total P (mg/L)	Sechi depth (m)	COD (mg/L)	Note
1	Haranggaol Bay	0.078	4.0	30.28	CA
3	Sidamanik	0.054	3.8	72.31	CA
6	Sirungkungon	0.090	6.1	30.06	CA
2	North Lake Toba	0.054	4.8	24.27	NCA
12	South Lake Toba	0.047	7.1	30.62	NCA
14	Simanindo	0.062	3.7	36.59	NCA

Water grade based on COD (Govern. Reg. Republic of Indonesia No. 82/2001)
Grade I (10 mg/L); Grade II (25 mg/L); Grade III (50 mg/L)
Grade IV (100 mg/L)

Trophic status of lakes (Ministry Environment Reg. of Republic Indonesia No. 28/2009) based on TP criteria
Oligotrophic Mesotrophic Eutrophic Hypertrophic

Oligotrophic ≤ 0.010 mg/L; Mesotrophic < 0.030 mg/L; Eutrophic < 0.100 mg/L; Hypertrophic ≥ 0.100 mg/L
CA : Cage aquaculture Area; NCA : Non Cage aquaculture Area

Vertical dissolved oxygen profile is strongly influenced by waters utilization. Especially the presence of cage aquaculture. Critical (unsafe) dissolved oxygen condition (≤2 mg/L) in cage aquaculture area was found at depths of 55 - 65 m, but in non-cage aquaculture areas found at depths of 43 - 103 m. The anoxic depth (DO ≈ 0 mg/L) layer was found at 74 - 77 m depth in cage aquaculture area and 61 - 417 m depth in non-cage aquaculture area (Table 7).

Table 7. Some selected locations with varying depth of critical oxygen content (≤ 2 mg/L) and starting anoxic conditions (≈ 0 mg / L).

Station	No.of Station	Water depth (m) of critically dissolved oxygen content		Note
		≤ 2 mg/L*)	≈ 0 mg/L*)	
Haranggaol Offshore	1a	82	100	NCA
North Lake Toba	2	103	417	NCA
Simanindo	14	80	>114 m**)	NCA
Haranggaol Bay	1	60	Shallow waters	CA
Sidamanik	3	58	74	CA
Sirungkungon	6	55	75	CA

*) Based on Rinko profiller measurement;**) On 114 m depth DO was 1.8 mg/L
CA : Cage aquaculture Area; NCA : Non Cage aquaculture Area

4. Discussion

The process of lake aging is marked by, among others, eutrophication that takes place naturally. Goldman & Horne[20] stated that lake eutrophication goes through stages from oligotrophic (nutrient-poor) to mesotrophic (has a moderate nutrient content) and eutrophic (very rich in nutrients), which is also commonly known as a trophic status of the lake. At present globally, lakes are facing cultural eutrophication phenomenon[21].

The eutrophication of lake is related to input loads which also comes from the catchment area. River Silang and River Boho are two of the rivers that act as Lake Toba inlets were characterized by relatively high TDS. This reflects that the level of the material dissolution process, both from natural sources and human activity are relatively high. Silang River, which is located in Humbang Hasundutan District, is known to have the largest watershed compared to other rivers that drain to Lake Toba. The catchment area has been known to play a role in the condition of lake waters, mainly related to sedimentation rates, as the model developed by Akrasi[22].

Referring to the COD level, most of the rivers observed showed water grade of III, except Sipiso-piso River, Silang River Naborsahan and Parapat had water grade of IV. These rivers also supply significantly high TP as Parapat River has the highest TP content (0.203 mg /L) while the Silang River is the highest TP supplier to Lake Toba (32.4 tons/year).

Water quality in inland waters is influenced by geomorphological, climate, vegetation structure and land use conditions in its watershed. The linkage of land use and water quality, from a confirmed water body in South New Zealand, show that nutrient concentrations and other components of water quality are positively correlated with the intensity of catchment modification[23]. Concentration levels of TP in Southern Finland lakes, apparently greatly influenced by agricultural activities in its catchment[24].

It is undeniable that domestic activities play a significant role in the condition of the water grade and the level of TP in the rivers which is the inlets of Lake Toba. Naborsahan and Parapat rivers cross the Parapat region which is a tourism center in Lake Toba, and based on data from Sitompul*et al*.[3] the population of Parapat City reached 1.292 households. Meanwhile, the Silang River is the river with the largest watershed in Lake Toba catchment area.

Supply of TP other than from lakes inlets, which is very significant, is from cage aquaculture activities which reached 570.3 tons/year or four times the TP supply from catchment area (138.5 tons/year). The input loading of TP from cage aquaculture activities was generally quite high, as happened in Lake Rupanco Chile, where there were cages aquaculture activity for salmon (*Oncorynchus mykiss; O. salar*) culture. At the fish production of 1626 tons between August 2008 and July 2009, the rate of TP solid and dissolved loss annually was 12.1 tons of TP estimated from the unconsumed feed, feces, and urine[25]. In Lake Maninjau where cage aquaculture fish production was 36 217 tonnes in 2011, the potential loss of phosphor into the waters can reach 387 ton/year, consist as those wasted through feces (130.5 ton/year) and wasted as dissolved with greater proportion (256.6 ton/year)[26].

The total load of TP to Lake Toba is 632.45 mg/m2/year (0.63 g/m2/year) exceeded the allowed limit based on *Vollenweider's permissible loading levels*[27]. In waters with an average depth of 200 m (Note: The average depth of Lake Toba = 228 m[15]), the total load which can be permitted is 0.6 g/m2/year. The actual phosphor loading currently in Lake Toba is thought to be higher than calculation, related to the supply of [P] from the land which can be directly through small streams of domestic waste sourced from residential areas and from agriculture area. Sitompul *et al*[3] recorded at 42 villages around Lake Toba that flowed domestic waste directly into lake waters with a population of 8.537 households.

Estimating external and internal [P] content is important information in the lake restoration management plan. For estimating the [P] loading it is necessary to know the complete information about water mass balance and [P], although not all of them are necessary and can be measured. Specific management models of a lake can help to complement these data gaps in both water balance and nutrient[28]. In this paper, only the simple mass balance model was used.

Inputs of allochthonous organic matter is rarely noticed to their role in determining limnetic area primary production and hypolimnetics dissolved oxygen, in contrast to TP. However, organic matter can be an important determinant in waters that have human influence. It was also stated that hypolimnion can be a system associated with its catchment area[29].

Allochthonous input especially TP, has formed the current Lake Toba trophic status, which is generally in eutrophic conditions. In a previous report based on TP level[12], water trophic status of

Lake Toba was between oligotrophic to hypereutrophic, but on average was in mesotrophic range. Allochthonous input of organic has caused several waters of Lake Toba to have water grade III based on the COD criteria and even IV in cage aquaculture area. On the other hand, organic allochthonous input will greatly affect the distribution and conditions of dissolved oxygen in the hypolimnion area. According to Wetzel[30] the distribution of oxygen in water from stratified lakes is controlled by a combination of solubility conditions, hydrodynamics, input from photosynthesis, and loss for metabolic and chemical oxidation.

This paper stated that the depth of critical oxygen conditions (≤2 mg/L) and anoxic conditions in the existing of cage aquaculture had been recorded at a lower depth while in the non-cage aquaculture area it is much deeper. Previous observations[15] reported that the dissolved oxygen levels on the surface were relatively high (6-7 mg/L), but decreased even drastically at a depth of 100 m and generally showed very minimal conditions (<2 mg/L) at a depth of 200 m and so on.

Dissolved oxygen level in the hypolimnion layer is possible to be lower than that in the epilimnion because respiration in sediment area will be more intensive and the water mixing from the surface to deeper part is limited by heat stratification[31]. The sinking and further degradation of organic material stimulate oxygen depletion in the bottom waters. Oxygen is consumed during organic matter respiration, remineralization, nitrification and redox reactions. Organic matter remineralization consumes oxygen both directly through the oxic respiration and indirectly through the oxidation of various metabolites (eg Mn (II). Fe (II). S (-II)[32].

5. Conclusion

It could be explained that the eutrophication of the lake is related to input loads which come from the catchment area. In case for Lake Toba, River Silang and River Boho are two of the rivers that act as Lake Toba inlets were characterized by relatively high TDS. This reflects that the level of the material dissolution process, both from natural sources and human activity are relatively high.

The pollution load from activities on land and the waters of Lake Toba has had an impact on the condition of the lake itself. The phosphorus load that enters the Lake Toba waters as a whole has exceeded the permissible loading levels and has caused the trophic status of the lake waters changed. Meanwhile, the organic pollutant load will increase the anoxic column on the hypolimnion area of Lake Toba.

Acknowledgments

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References

[1] Soerjani, M., S. Wargasasmitha, A. Djalil, & S. Tjitrosoedirdjo, 1979. Survey Ekologi Danau Toba. *Laporan Akhir*. Thn.1978 – 1979. Univ. Indonesia Dep. PU. 24 hal
[2] Dharma, L. 1988. Percobaan pemeliharaan ikan mas dalam jaring terapung di Ambarita-Danau Toba, Sumatera Utara. Bull. Penel. Perik. Darat, 7(2): 32 – 40.
[3] Sitompul. R. L.U. Sitanggang. H.D. P. Roswita, R. Sagala, & D. Y. Mulyati. 2007. Profil Pantai dan Perairan Danau Toba. BPBPEKDT. Medan.
[4] Lukman, 2013. Danau Toba. Karakteristik Limnologis dan Mitigasi Ancaman Lingkungan dari Pengembangan Karamba Jaring Apung (Characteristic of Limnology. Mitigation to Environment Threaten from Cage Aquaculture Development). LIPI Press. 106 hal
[5] Reghunathan, V.M., S.Joseph, C.U. Warrier, A.S. Hameed, S.A. Moses. 2016. Factors affecting the environmental carrying capacity of a freshwater tropical lake system. *Environ Monit Assess*. 188:615.
[6] Beveridge, M.C.M. 1987. Cage Aquaculture. Fishing News Books. Ltd. Farnham- Survey-

England. 352 p

[7] Eugene, W.R., R.B. Baird, A.D. Eaton and L.S. Clesceri. 2012. Standard Methods for the Examination of Water and Wastewater, 22nd Edition.Washington, DC: American Public Health Association., pp. 4-118-119. 2012

[8] Dillon, P. J., & F. H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on trophic status. J. Fish. Res. Bd. Canada 32: 1519 – 31

[9] Lukman, 2012. Evaluasi keseimbangan fosfor di Danau Toba (Evaluation of phosphor balance in Lake Toba). Prosiding Seminar Nasional Limnologi VI tahun 2012. 423-431

[10] Vollenweider. R.A & J. Kerekes. 1980. The loading concept as basis for controlling eutrophication phylosophy and preliminary result of the OECD Programme on eutrophication. Eutrophication of Deep Lakes Proceedings of a Seminar held in Gjovic. Norway. June 1978. Pergamon Press. Oxford. New York. p. 5 - 38

[11] Lewis. W. M. Jr. 2000. Basis for the protection and management of tropical lakes. Lake & Reservoir: Research and Management 5: 35 – 48

[12] Nomosatryo & Lukman. 2011. Ketersedian hara di perairan Danau Toba. Sumatera Utara. Limnotek, 18(2): 127 -137

[13] Anonymous, 2008. Studi Pengelolaan Keseimbangan Air sehubungan dengan Pemasukan dan Pengelolaan air Danau Toba. Laporan Hidrologi. Dep. PU, Dirjen Sumber Daya Air, Satuan Kerja Balai Wilayah Sungai Sumatera II. 38 hal.

[14] Meigh. J., M. Acreman, K. Sene & J. Purba. 1990. The wáter balance of Lake Toba. International Conference on Lake Toba. May 1990. Jakarta – Indonesia.

[15] Lukman & I. Ridwansyah. 2010. Kajian morfometri dan beberapa parameter stratifikasi perairan Danau Toba. Limnotek. 17 (2): 158 - 170.

[16] Anonymous, 2016.Statistik Perikanan Budidaya Provinsi Sumatera Utara Tahun 2015. Laporan Tahunan. Dinas Kelautan dan Perikanan Prov. Sumatera Utara. 148 hal

[17] Lukman. M. Badjoeri, S.H. Nasution. 2010. Antisipasi Bencana Lingkungan Perairan Danau Toba melalui Penetapan Daya dukung dan Pemintakatan Wilayah Budidaya. Laporan Akhir Tahun 2010 Kegiatan Program Kompetitif – LIPI. Puslit Limnologi – LIPI. 70 hal.

[18] Garno. Y. S & T. A. Adibroto. 1999. Dampak penggemukan ikan di badan air waduk multiguna pada kualitas air dan potensi waduk. Prosiding Semiloka Nasional Pengelolaan dan Pemanfaatan Danau dan Waduk. IPB- Ditjen Pengairan - Men KLH. XVII: 1-10

[19] Azwar, Z.I., N. Suhenda & O. Praseno. 2004. Manajemen pakan pada usaha budi daya ikan dalam karamba jaring apung. Dalam: Sudradjat. A. S.E. Wardoyo. Z.I. Azwar. H. Supriyadi. & B. Priono (Penyunting). Pengembangan Budi Daya Perikanan di Perairan Waduk. Pusat Riset Perikanan Budidaya. BRKP. DKP. Hal.37 - 44

[20] Goldman RC, Horne AJ. 1983. Limnology. Tokyo: Mc-Graw Hill International Book Company.

[21] Smith, V. (2003). Eutrophication of freshwater and coastal marine ecosystems: a global problem. Environmental Science *and Pollution Research*, 10, 126–139.

[22] Akrasi. S.A. 2005. The assessment of suspended sediment inputs to Volta Lake. Lakes & Reservoirs: Research and Management 10: 179 – 186

[23] Galbraith, L.M., & C.W. Burns. 2007. Linking land-use, water body type and water quality in southern New Zealand. Landscape Ecol., 22:231–241

[24] Rantakari, M., P. Kortelainen, J. Vourenmaa, J. Mannio & M. Forsius. 2004. Finnish lake survey: The role of catchment attributes in determining nitrogen, phosphorus and organic carbon concentrations. Water, Air, and Soil Pollution: Focus 4: 683–699, 2004

[25] Munoz, J.L., C. Echeverria, R. Marce, W. Risse, B. Sherman & J.L. Iriarte. 2013. The combined impact of land use change and aquaculture on sediment and water quality in oligotrophic Lake Rupanco (North Patagonia. Chile. 40.8oS). Journal of Environmental Management, 128: 283-291.

[26] Lukman, I. Setyobudiandi, I. Muchsin, & S.Hariyadi. 2015. Impact of Cage Aquaculture on Water Quality Condition in Lake Maninjau, West Sumatera Indonesia. Inter. J. of Sci. Bas.

and Appl. Res. (IJSBAR), 23 (1): 120-137

[27] Vollenweider, R. A. 1975. Input-output models with special reference to the phosphorus loading concepts in limnology. *Schweiz. Z. Hydrol*., 37: 53 -84

[28] Schauser, I., & I. Chorus. 2009. Water and phosphorus balance of Lake Tegel and Schlachtensee – A modelling approach. *Water Research*, 43: 1788 - 1800

[29] Marce, F., E. Moreno-Ostos, P. Lo´pez, & J. Armengol. 2008. The role of allochthonous inputs of dissolved organic carbon on the hypolimnetic oxygen content of reservoirs. *Ecosystems*, 11: 1035–1053

[30] Wetzel, R. G., 1983. Limnology. W. B. Saunders College Publ., Philadelphia. 743

[31] Miranda L.E., J.A. Hargreaves & S.W. Raborn. 2001. Predicting and managing risk of unsuitable dissolved oxygen in a eutrophic lake. *Hydrobiologia*, 457: 177–185

[32] Pena, M.A., S. Katsev, T. Oguz & D. Gilbert. 2010. Modeling dissolved oxygen dynamics and hypoxia. *Biogeosciences*, 7: 933–957.