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Load allocation of nutrients causing eutrophication and their impact to lake: Case study of Menjer Lake, Wonosobo, Indonesia

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Abstract

The purpose of this study was to examine impact of input of nutrients from the catchment to the level of pollution of Lake Menjer Wonosobo. The method was carried out quantitatively by calculating the allocation of pollutant loads from human activities. The water quality status was assessed using the storet method. The highest total P entering Menjer Lake was respectively from agricultural activities, livestock, settlements, and floating net cages. The Menjer Lake was classified as heavily polluted for drinking water, moderately polluted for fish cultivation, and not polluted for irrigation needs.

Keywords*:* Human Activities; Pollutant Load; Menjer Lake; Water Quality; Storet index

1 Introduction

Menjer Lake is formed by the Mount Pakuwaja eruption. This lake is located in Maron Village, Garung District, altitude of 1,300 above sea level and 12 kilometers north of the city of Wonosobo, Indonesia. In the rainy season, this lake occupies a basin area of 70 hectares with a water depth of 45 meters. However, outside the rainy season the water level drops to 20 meters [1]. Menjer Lake is used by local residents for tourism, agricultural irrigation, and floating net cages[2]. In addition, since 1982 it has been used as a Hydroelectric Power Plant.

The sustainability of the ecosystem function of Lake Menjer Wonosobo needs to be considered due to the benefits of the lake for the surrounding community. Human activities often cause eutrophication problems in lakes that cause highly undesirable disturbances of freshwater ecosystems[3], [4]. Currently, there has been a problem of eutrophication in Lake Menjer, marked by the blooming of *Microcystis aeruginosa*[5], [6]. Eutrophication is the enrichment of water nutrients, especially phosphorus, causing the growth of algae and aquatic plants to become uncontrolled, thereby inhibiting the photosynthesis process and reducing the dissolved oxygen content[5], [7], [8]. The main sources of phosphorus come from agricultural fertilizers, fisheries, and household waste[5], and fish culture using floating net cage[9].

Based on Law no. 32 of 2009 and Government Regulation no. 22 of 2021 the aim of water management is to protect the ability of aquatic ecosystems against the pressure of change or negative impacts of human activities so that they are still able to support their functions in accordance with the carrying capacity and carrying capacity of the ecosystem. Carrying capacity is an estimate of the production of certain biological materials to support the metabolic processes of organisms. To assess the carrying capacity of Menjer Lake in receiving inputs of nutrients that cause eutrophication, it is necessary to know the input nutrient P pollutant load that causes eutrophication. Therefore the purposes of this research were to assess the allocation of pollutant load from human activity in the Menjer lake and to observe the level of pollution in Lake Menjer Wonosobo to find the eligibility of water according to its designation.

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2 Material and methods

The research was conducted using a survey method in the catchment area which includes 2 sub-districts of Garung and Kejajar which consist of 3 villages of Sambungan, Tlogo and Maron (Fig.1). The observation was also done in the lake waters ecosystem by taking water samples at 7 (seven) sites inside Lake (Fig. 2).

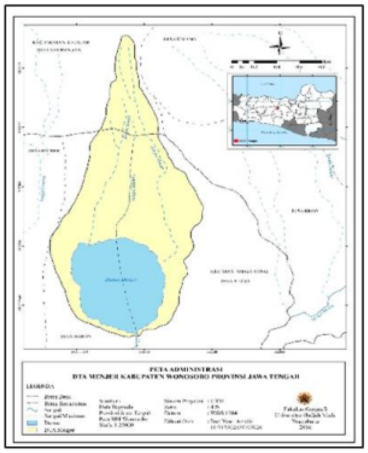

Figure 1 Sampling sites in the Menjer Lake catchment area

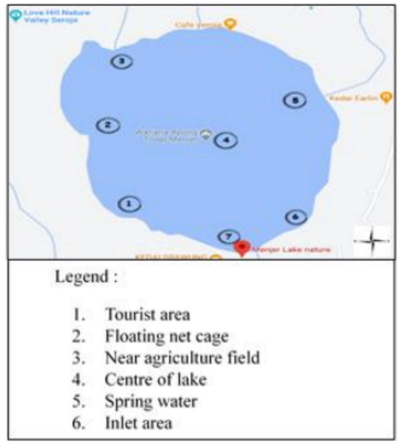

Figure 2 Sampling Sites inside Lake

Data obtained were in the form of quantitative on P load that enters the lake and the level of lake water pollution using Storet Method. Total P load from the catchment area is calculated based on the total amount of P generated from each human activities based on the statistical data of Wonosobo Regency of 2020. The concentration of phosphorus (P) in the waters is also measured to determine the current water class based on Indonesian Government Regulation no 22 year 2021.

Calculation of load P of the floating net cage is calculated using the equation 1 [10] as follows:

$$PLP = FCR \times PF - PB \qquad (1)$$

Description: PLP = load P entering the lake (kg P ton of fish^{-1})
FCR = Food Conversion Ratio (tons of feed tons of fish^{-1})
PF = P total content in fish feed (kg P ton of feed^{-1})
PB = P total fish biomass (kg P ton Fish^{-1})

The calculation of P load coming from livestock was carried out by identifying the amount of waste generated from livestock activities based on Statistical Data of Wonosobo Regency of 2020, then multiplied by the pollution load unit represented in Table 1.

Table 1 Unit of pollution load for livestock waste

Activities	Unit of P Load (g ind^{-1}day^{-1})*
Beef cattle	31.39
Sheep	18.06
Chicken	0.15
Duck	0.60
Rabbit	0.82

* Minister of Environment Regulation No. 1 of 2010

The P load coming from settlement was determined based on the number population in the Statistical Data of Wonosobo Regency, Central Java Province of 2020 multiplied by the type of pollution load unit represented in Table 2.

Table 2 Unit of pollution Load from settlement

Specification	P total (g ind^{-1} day^{-1})*
Settlement without septic tank	3.8
Settlement with septic tank	0.9

* Minister of Environment Regulation No. 1 of 2010

Agricultural P load (Total P) is determined based on the area of agriculture the study area of Wonosobo Regency of 2020 multiplied by the total P-producing coefficient of each agricultural activity for both food crops and horticultural crops. The P coefficient of total food crop (calculated three times of planting season) is 10 kg P ha^{-1} planting season, while the total P coefficient for horticultural agriculture is 1.5 kg ha^{-1} year^{-1} [11].

To determine the level of pollution in Lake Menjer Wonosobo and to determine the suitability of the waters according to their designation, they were analyzed using the Storet Index. Storet index is a tool to measure the quality of pollution of a water body by using comparative data between water quality data and water quality standards that are adjusted to their designation. Furthermore, the results of the calculation of the storet index are used to determine the status of water quality based on the Decree of the Minister of the Environment Number 115 of 2003 concerning Guidelines for Determining Quality Status as follows: Storet Score = 0 meets the quality standard, very good (Class A); score = -1 to -10, lightly polluted, good (Class B); score = -11 to -30 moderately polluted, moderately (Class C); score > -31 heavily polluted, poor (Class D). Furthermore, to determine the eligibility of water based on its designation, the water quality is compared with the water quality standard according to Government Regulation No 22 of 2021 to obtain the water feasibility classification as follows: Class I, for drinking water raw water; Class II, for water recreation facilities; Class III, for fish farming; Class IV, for irrigating crops

3 Results and discussion

3.1 Phosphorus Load

The Phosphorus load from human activities in the water catchment area to Lake Menjer reaches 12.45 tons year^{-1} which comes from the following activities

3.1.1 *Floating net cage*

Lake Menjer is used for Tilapia cultivation in floating net cages fed with pellets for 0.5 kg plot^{-1} day^{-1} for a period of 18 months. The number of cages were 42 plots. It is stated that only 70% of feed given was eaten by fish[12], the remaining 30% became waste that settles at the bottom of the waters[13]. During cultivation 18 months that the amount of fish production in the lake is 6.3 tons. Based on these calculations, the Food Conversion Ratio (FCR) of fish in the Menjer Lake was 1.49. Therefore the P load discharged into lake from fish was up to 45.47 kg ton^{-1} (Table 3).

Table 3 The Calculation of P Load from Floating Net Cage

Parameter	P Conc. (kg ton-1)	FCR	P load (PLP) (kg ton-1)
P of fish	1.83	1.49	45.47
P of feed	30.7		

3.1.2 *Livestock*

The number of livestock were calculated based on statistical data of Wonosobo Regency in 2020, consisting of large (beef cattle, sheep) and small livestock (rabbits, chickens, and ducks). Livestock waste is a source of nitrogen (N) and phosphorus (P), as well as other sources of nutrition for plant. However, if the levels of these nutrients excess will be a pollutant in in water bodies[14]. It is stated that the waste from livestock activities carried into water bodies through surface water flows was 20% [15]. Based on the calculation the potential of livestock waste from catchment area entering to Menjer lake was 25.17 tons year^{-1} (Table 4)

Table 4 The calculation of P Load from livestock

Livestock	P Load (ton year^{-1}) each village			Total
	Sambungan	Tlogo	Maron	
Beef cattle	5.00	2.00	18.00	25.00
Sheep	1.25	1.43	1.04	3.72
Rabbit	0	58.00	0	58.00
Chicken	1.48	1.95	1.99	5.41
Duck	14.00	81.00	162.00	257.00
Load (ton/year)	8.39	9.60	7.17	25.17

3.1.3 Settlement

The potential for resident waste to pollute waters is calculated based on the number of residents who has septic tanks and those who do not. The coefficient of pollutant load generation (Total P) with a septic tank per person is 0.9 g person^{-1} day^{-1}, while the total pollutant load generation without a septic tank is 3.8 g person^{-1} day^{-1} (WHO, 2006 in PerMenLH No.1/2010). It is stated that the more people use septic tanks, the lower the burden of water BOD contamination[16] and the pollutant load that enters water bodies from resident waste is 30%[17]. Based on the calculation the potential P load from settlement activities was 4,324 tons year^{-1} (Table 5). The load might be supplied from the residential waste. Detergents used in washing activities in the household can increase nutrients, especially total P which can accelerate eutrophication[17],[18].

Table 5 Phosphorus Load from Settlement

No	Village	Number of Population	Residents With septic tank	Residents Without septic tank	P load With Septic tank (ton year-1)	P Load Without septic tank (ton year-1)
1	Sambungan	1.374	0	1.374	0	1,906
2	Tlogo	1.931	1916	15	0,629	0,021
3	Maron	4.031	3612	419	1,187	0,581
	Jumlah	7.336	5.528	1.808	1.816	2,508
Total					4,324	

3.1.4 Agriculture

The agricultural pollutant load is calculated based on the agricultural area in the Menjer catchment area which includes food crop farming and horticultural agriculture. The amount of P of food crop waste (calculated three times of planting season) is 10 kg P ha^{-1} planting season^{1-}, P for horticultural agriculture is 15 kg ha^{-1} year^{-1}. The land area for food crops is 1,504 ha, while the area for horticultural crops is 94,365 ha year^{-1}, so the potential pollutant load from agricultural waste is 186.66 tons year^{-1} (Table 6).

Table 6 Area of Food Crops and Horticulture and Pollution Potential

No.	District	Food Plant field (Ha)	P Load (ton year^{-1})	Hortic. plant field (Ha)	P Load (ton year^{-1})
1.	Garung	1,504	45.12	21,032	31.55
2.	Kejajar	-	-	73,333	109.99
Total		1,504	45.12	94,365	141.54
P Load (ton year^{-1})		186.66			

The unit of pollutant load of food plant waste entering water bodies is 10% and the pollutant load of horticultural plant waste is 1%[11]. However based on the calculation, the total P entering Menjer Lake from food plant waste is 45.12 tons year^{-1} and from plant waste horticulture of 141.54 tons year^{-1}. Fertilizer is one of the contributors to phosphate compounds in waters in addition to other agricultural wastes such as straw and remaining rice stalks[19]. Not all of the fertilizers used in agriculture are absorbed by plants because some of the fertilizers will oxidize, especially those in contact with the air.

The Summary of Phosphorus Load for Catchment Area into Menjer Lake was representing in Table 7.

Table 7 The Summary of Phosphorus Load for Catchment Area into Menjer Lake

No	Source of P	Load P to lake (ton year^{-1})*	P Load Prosentase (%)
1	Agriculture	5.93	47.6
2	Livestock	5.03	40.43
3	Settlement	1.30	10.44
4	Fish cultur using floating net cage	0.19	1.53
	Total	12.45	100

*The calculation based on World Health Organization (WHO) standard.

It is showed that the total P that enters Lake Menjer is 12.45 tonnes year^{-1}, the highest coming from agriculture (5.93 tonnes year^{-1}), followed by animal husbandry (5.03 tonnes year^{-1}), settlements (1.30 tonnes year^{-1}), net cages (0.19 tons year^{-1}). Agricultural activities contribute the highest pollutant load (Total P) to Lake Menjer (Figure 3). Therefore, a government policy or regulation regarding environmentally friendly agricultural activities is needed considering that agricultural activities are very important for humans in meeting economic needs. On the other hand, if agricultural activities are allowed to run freely without regulation, it will have a negative impact on the Lake Menjer ecosystem, especially its water quality.

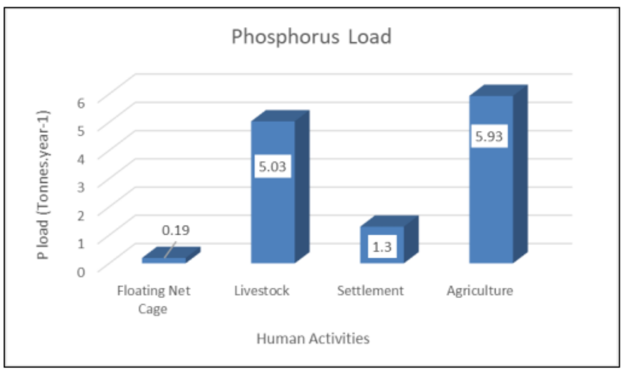

Figure 3 Orders of Magnitude Input Phosphorus Load

3.2 Level of Pollution

Most human activities produce waste, then consequently will affect the quality and quantity of water. The main problems of water quality that are affected by human activities include nutrition load especially N and P into water[20]. This nutrients have a negative impact on the lives of biota and downstream users[21]. In order to effort preserving the functions and prevent water pollution in Indonesia, there has been Government Regulation No. 22 of 2021 to protect the ability of aquatic ecosystems against changes and negative impacts on its ecosystem integrity and function.

The level of water pollution based on the amount of contaminants contained that should not exceed the planned water quality standard. If it is exceeded means that this condition can cause harm to living things that use the waters[5]. The level of water pollution or the water quality status of Menjer lake is determined using the storet index[22]. Based on the index, it shows that Menjer Lake cannot be used for drinking water (class I) because it is heavily polluted (Table 8).

Table 8 Level of Pollution of Class I (Drinking Water)

No	Location	Storet Index	Level of pollution
1	Tourist Activity Area	-69	High polluted
2	Floating Net Cage area	-69	High polluted
3	Near Agriculture Field Area	-69	High polluted
4	Centre of Lake Area	-69	High polluted
5	Spring Water Area	-69	High polluted
6	Inlet Area	-69	High polluted
7	Outlet Area	-69	High polluted

If the Menjer Lake water was used for recreational facilities (class II) as well as for fish farming land (class III) showed that the conditions of all sites were moderately polluted (Table 9 and Table 10). On the other hands, it was not polluted if it was used for the need of agricultural irrigation and/or the equivalent purposes (class IV) (Table 11).

Table 9 Level of Pollution of Class II (domestic used)

No	Location	Storet Index	Level of pollution
1	Tourist Activity Area	-69	High polluted
2	Floating Net Cage area	-69	High polluted
3	Near Agriculture Field Area	-69	High polluted
4	Centre of Lake Area	-66	High polluted
5	Spring Water Area	-69	High polluted
6	Inlet Area	-54	High polluted
7	Outlet Area	-54	High polluted

Table 10 Level of Pollution of Class III (Aquaculture)

No	Location	Storet Index	Level of pollution
1	Tourist Activity Area	- 24	Medium polluted
2	Floating Net Cage area	- 24	Medium polluted
3	Near Agriculture Field Area	- 24	Medium polluted
4	Centre of Lake Area	- 24	Medium polluted
5	Spring Water Area	- 24	Medium polluted
6	Inlet Area	- 24	Medium polluted
7	Outlet Area	- 24	Medium polluted

Table 11 Level of Pollution of Class IV (irrigation)

No	Location	Storet Index	Level of pollution
1	Tourist Activity Area	0	Unpolluted
2	Floating Net Cage area	0	Unpolluted
3	Near Agriculture Field Area	0	Unpolluted
4	Centre of Lake Area	0	Unpolluted
5	Spring Water Area	0	Unpolluted
6	Inlet Area	0	Unpolluted
7	Outlet Area	0	Unpolluted

3.3 Water Eligibility Status

The Status of water qualities were represented by the concentration of TSS, BOD, COD, DO, TN, TP and Coliform showed that there were several parameters exceeded the threshold in each class category. It is listed in Table 12).

Table 12 Measurement of water quality parameters compared to standards Class I- IV

No	Parameter	Unit	Measure-ment	Water Quality Status (PP No. 22 of 2021)			
				Kelas I	Kelas II	Kelas III	Kelas IV
1	TSS	mg/l	166.5	No (25)	No (50)	No (100)	Yes (400)
2	BOD	mg/l	4.9	No (2)	No (3)	Yes (6)	Yes (12)
3	COD	mg/l	23.6	No (10)	Yes (25)	Yes (40)	Yes (80)
4	DO	mg/l	3.7	No (6)	No (4)	Yes (3)	Yes (1)
5	TN	mg/l	6.5	No (0.65)	No (0.75)	No (1.9)	Unregulated
6	TP	mg/l	0.3	No (0.01)	No (0.03)	No (0.1)	Unregulated
7	Coliform	(MPN/ml)	2,325	No (1000)	Yes (5000)	Yes (10000)	Yes (10000)

Note :No : Not fulfill (≥) water quality standard; Yes: Fulfill (≤) water quality standard; Number in bracket: the value of water quality standard should be met

For class 1 designation, all parameters do not meet the quality standard (Table 12). This shows that Menjer Lake water is not suitable for use as a raw source of drinking water. Based on the classification of class II water, it shows that there are 2 parameters that are still below the class 2 water quality standard, namely COD and Coliform. For the classification of class III water for use as fish culture, it shows that TSS, TN and TP show concentrations exceeding the quality standard. Enrichment of waters by nutrients, especially nitrogen and phosphorus, resulting in uncontrolled growth of aquatic plants[5], [23]. The sources of nitrogen and phosphorus mainly come from agricultural activities, fisheries, industry, and household waste[24]. Meanwhile, if used for irrigation needs (class IV) all are not problematic due to it is below The total P that entered Lake Menjer was 12.45 tonnes year^{-1}, the highest coming from agriculture (5.93 tonnes/year), followed by Livestock (5.03 tonnes year^{-1}), settlements (1.30 tonnes year^{-1}), and net cages (0.19 tons year^{-1}). Based on the evaluation of the water quality status, the impact of human activities in the watershed on the Menjer Lake makes it only meet the requirements for aquaculture utilization. Land use for agriculture that does not apply conservation principles causes a decrease in Menjer Lake water quality[25].

4 Conclusion

The total P that entered Lake Menjer was 12.45 tonnes year^{-1}, the highest coming from agriculture (5.93 tonnes year^{-1}), followed by Livestock (5.03 tonnes year^{-1}), settlements (1.30 tonnes year^{-1}), and net cages (0.19 tons year^{-1}). Based on the evaluation of the water quality status, the impact of human activities in the watershed on the Menjer Lake makes the water only meet the requirements for aquaculture utilization. Land use for agriculture that does not apply conservation principles causes a decrease in Menjer Lake water quality.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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