Trophic Status Assessment of Saguling Reservoir, Upper Citarum Basin, Indonesia

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Trophic Status Assessment of Saguling Reservoir, Upper Citarum Basin, Indonesia

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ABSTRACT: This study examined the water quality of Saguling Reservoir as potential raw water for Bandung metropolitan area. Determination of water quality in this study consisted of trophic status determination based on total phosphorus, total nitrogen (ammonia and nitrate), and water clarity. Data were obtained 4 times a year for 16 years (1999-2013). We determined the overall water quality status by comparing data with criteria specified in Ministerial Regulation (Permen) of the Environment Number 28 of 2009 on the Water Pollution Load Capacity of Lakes or Reservoirs. Data from 11 stations were analyzed, which indicated a hypertrophic state with very high pollution. Nanjung Post (upstream of the reservoir) had the highest levels of total P, total N, and chlorophyll a compared with the Muara Ciminyak Post and Muara Intake Post (the middle and downstream regions of the reservoir). Seasonal changes had no effect on the trophic status, regardless of dry, normal, or wet conditions.

KEYWORDS: Eutrophication, monitoring, pollution

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Introduction

Bandung metropolitan area (BMA) is in the upper watershed of the Citarum River and classified as a National Strategic Area from the perspective of economic interests (Appendix Government Regulation No. 26 of 2008). This condition certainly has an impact on increasing the need of raw water in BMA. One of the alternatives to fulfill the raw water needs in BMA is Saguling Reservoir.

Actually, Saguling Reservoir is located in the Upper Citarum Basin. Upper Citarum Basin is one of the largest and important watersheds in Indonesia especially in West Java. In the Citarum Basin, there are cascade reservoirs, namely, Saguling Reservoir, Cirata, and Jatiluhur, that serve as hydropower, water supply providers for irrigation, and flood control.

In terms of quantity, water discharge of Saguling Reservoir is potential for the raw water supply of BMA; the potential use of water discharge of Saguling Reservoir was 1622 L/s.[1] However, in terms of quality, further studies will be needed to ensure Saguling water quality in accordance with regulation for drinking water standard including the study of the determination of the tropical status of the Saguling Reservoir.

The trophic or fertility status of the waters indicates an effect of nutrient waste loads entering the lake water. The fertility level of a lake or reservoir can be calculated based on several influential parameters in accordance with the trophic status index. The parameters include the levels of total phosphorus, total nitrogen, chlorophyll a, and clarity. Trophic status classifications include the following: hypertrophic, eutrophic, mesotrophic, oligotrophic, and dystrophic.[2]

The water quality of the reservoir is determined not only by natural processes, such as weathering and soil erosion, but also by anthropogenic activities. Assessing the human impact on water quality requires considering variations in space and time, as well as the biological, physical, and chemical processes of the natural system.[3,4] The water quality of the reservoir is classified based on the status of eutrophication process which is caused by increased nutrient content in the water.

In general, water plants typically contain 0.7% nitrogen and 0.09% phosphorus by wet weight. Phosphorus limits eutrophication if nitrogen levels are more than 8 times the phosphorus level. Chlorophyll a is a pigment in green plants that is needed for photosynthesis. The chlorophyll a parameter indicates algae biomass content, which has an estimated average weight of 1% of the total biomass.

Eutrophication is caused by increased nutrient content in a lake or reservoir, especially nitrogen and phosphorus. Eutrophication is classified into 4 categories of trophic status. An oligotrophic status indicates low levels of nutrients and that the water quality is still natural and not yet contaminated. Mesotrophic status involves moderate nutrient levels. This status indicates an increase in nitrogen and phosphorus levels but still within tolerable limits with no indications of water pollution. Eutrophic status involves high levels of nutrients due to contamination by increasing levels of nitrogen and phosphorus. Hypereutrophic or hypertrophic status indicates very high levels of nutrients and heavy pollution by nitrogen and phosphorus.

This study determined the water quality status of the Saguling Reservoir by determining its trophic status. The determination of reservoir trophic status is regulated by the State Ministry of the Environment under regulation number 28 of 2009 on the Water Pollution Load Capacity of Lakes or Reservoirs. Research on the trophic status of the Saguling Reservoir is needed to determine policies related to the use of

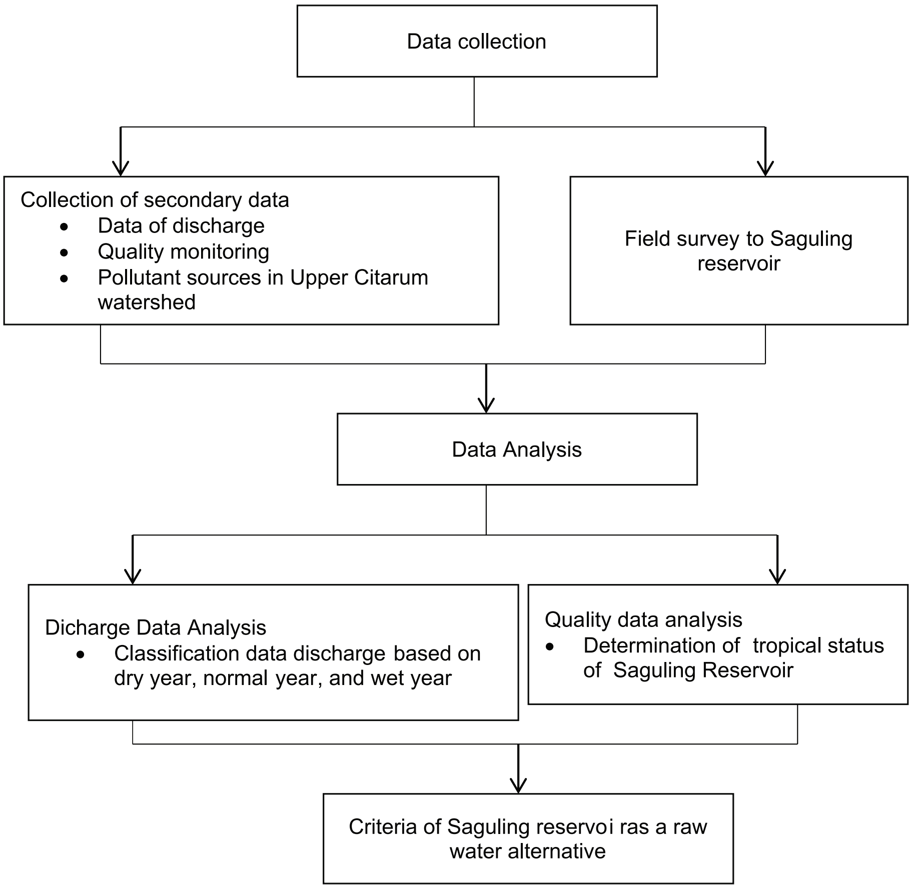

Figure 1. Flowchart of research procedure.

water for drinking, irrigation, and other needs, as well as potential use as a source of raw water for the BMA.

This research is a preliminary study of Saguling water quality to develop the use of Saguling Reservoir as a raw water resource in BMA. Currently, the use of Saguling reservoir is concentrated as a hydroelectric power plant, but it is also used for the cultivation of floating net cages which contributes to nutrient pollution.[5] In this research, we can see the correlation between the water quality status of the reservoir and the hydrological conditions occurring in the watershed in the dry, normal, and wet seasons.

Methods

Flowchart of this research can be seen in Figure 1. The initial and important stage in this study was the collection of water quality data at each monitoring station and data of discharge or data that occur in the Saguling Reservoir.

Study location

The location of the study was Saguling Reservoir, which is located upstream of the Citarum watershed in West Java Province, Indonesia. Saguling is part of the Citarum Cascade Reservoir, which also comprises the Cirata and Jatiluhur Reservoirs. Saguling is located on the upper Citarum River and acts as a trap for pollutants discharged into the river and around the residential areas of Bandung. The main purpose of the Saguling establishment is to generate electricity. The location is illustrated in Figure 2.

Saguling has been heavily polluted, particularly by domestic sewage and industrial waste. Most of the contaminants in Saguling (such as organic matter, nutrients, and heavy metals) come from Bandung, the reason why Saguling has been identified as a very trophic reservoir.[6]

Monitoring quality stations in Saguling Reservoir

The water quality in Saguling was monitored regularly every 3 months (in March, June, September, and December). There were 11 quality monitoring stations at different locations: Nanjung (the input), Batujajar, Muara Cipatik, Muara Ciminyak, Cimerang, Cihaur, Muara Cijere, Muara Cijambu, Muara Cihaur, Turbine Intake, and Tailrace. A total of 44 water quality parameters were monitored, which consist of physical and chemical parameters. The main study locations were Nanjung Station, Muara Ciminyak Station, and Turbine Intake Station, as shown in Figure 3.

The water quality data were used to determine the trophic status, especially the total phosphorus, total nitrogen (ammonia and nitrate), and water clarity. Data were regularly obtained 4 times a year for 16 years (1999-2013). The overall water quality was determined by comparing the data with the criteria from Ministerial Regulation (Permen) of the Environment Number

Figure 2. Location of Saguling and Citarum watershed.

Figure 3. Locations of monitoring quality stations at the Saguling Reservoir.

28 of 2009 on the Water Pollution Load Capacity of Lakes or Reservoirs. The chlorophyll a parameter was also considered but it was not measured from the reservoir and instead calculated as follows[7]:

$$\text{Log}(\text{chlorophyll a}) = -1.09 + 1.46 * \log(P_t)$$

Determination of wet, normal, and dry years with a Markov model

A Markov model was used to determine wet, normal, and dry years by dividing them into 3 classes according to the water discharge that entered the reservoir. Based on the water division, a stochastic matrix can be created for each month to divide the historical data into 3 classes. The stages of the process are as follows.[8]

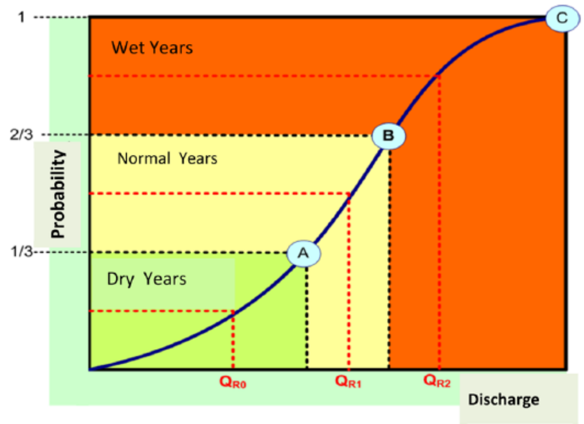

Figure 4. Class divisions based on the probability in the Markov model.

Frequency distribution analysis. The frequency distribution of water discharge per month was analyzed for the period of 1999-2013. The frequency distribution of historical data was then matched with 2 frequency distribution models: normal and lognormal. The most suitable distribution of the 2 alternative types was chosen for each month.

Class division. The second phase was the classification of water discharge levels. A first-order process was investigated for 3 classes. The amount of discharge was divided as follows:

1. Dry discharge (represented by 0);
2. Normal discharge (represented by 1);
3. Wet discharge (represented by 2).

Class intervals for each class divisions were obtained by dividing the probability curve of the distribution of the selected population into 3 equal parts at 0.333, 0.667, and 1, as shown in Figure 4. The range value of each class was the middle value of each one at 0333, 0.667, and 1 in the probability curve. The probability of each of the data was determined using the Weibull method as follows:

$$P(Xm) = \frac{m}{N+1} \quad (1)$$

where $P(Xm)$ is the probability of a set of values that are expected during the observation period, N is the number of observations of variate X, and m is the rate of events.

Discussion and Results

Fertility level of Saguling Reservoir water

The trophic status is determined from 4 parameters: total phosphorus, total nitrogen, water clarity, and chlorophyll a. The trophic status of the reservoir was determined by comparison with the criteria shown in Table 1.

The data in Table 2 show average of the parameters from 11 monitoring posts in 15 years (1999-2013). The data indicated that the reservoir is in a hypertrophic state. Thus, the water in

Table 1. Trophic status criteria for a lake or reservoir.[9]

TROPHIC STATUS	AVERAGE LEVEL OF TOTAL N, MG/L	AVERAGE LEVEL OF TOTAL P, MG/L	AVERAGE LEVEL OF TOTAL CHLOROPHYLL A, MG/L	AVERAGE CLARITY, *M*
Oligotrophic	≤650	<10	<2	≥10
Mesotrophic	≤750	<30	<5	≥4
Eutrophic	≤1900	<100	<15	≥2.5
Hypertrophic	>1900	≥100	≥200	<2.5

Adapted with permission from Ministerial Regulation of the Environment Number 28 of 2009 on the Water Pollution Load Capacity of Lakes or Reservoirs.

Table 2. Trophic status data of Saguling Reservoir.

PARAMETER	AVERAGE OF 11 MONITORING POSTS OF SAGULING RESERVOIR	STATUS	CONCLUSION
Transparency	0.3	<2.5	Hypertrophic
Total P	280	≥100	
Total N	1914.4	>1900	
Chlorophyll a	8075	≥200	

the reservoir has a high level of organic matter contamination, which can cause algal blooms.

Table 3 indicates the trophic status of 3 monitoring posts, representing the upstream reservoir areas with the Nanjung Post, the middle of the reservoir with the Muara Ciminyak Post, and the downstream area of the reservoir at the Turbine Intake Post. The parameters showed fluctuations every year during the study period. The transparency, total phosphorus, and chlorophyll a parameters appeared to be in a fixed hypertrophic range from year to year at all 3 stations. However, the total nitrogen showed varying ranges. The overall average for all 4 parameters was consistent with the hypertrophic status. This indicates that the reservoir is heavily polluted by a very high nutrient content. The government actually has some plans and strategies to solve the problems in Saguling Reservoir. Hence, we suggest government with all stakeholders to work together to implement those immediately because Saguling Reservoir's condition is critical.

Figure 5 shows that Nanjung Post had the highest total P, total N, and chlorophyll a compared with the Muara Ciminyak Post and Turbine Intake Post. Nanjung Post shows that the highest pollution occurs upstream of the reservoir, which receives pollution from the upper Citarum watershed, as shown in Figure 6. The watershed is dominated by industrial activities from 542 companies, as well as domestic waste from the population of ±8.6 million people, 79.8 hectares of rice fields, livestock, and other activities.[10]

The Muara Ciminyak Post represents the mid-reservoir area, which is widely used as a location for floating net cages. This increases the concentration of reservoir nutrients. Fish waste and fish feed residues containing phosphorus and nitrogen stimulate the growth of phytoplankton or algae and increase aquatic productivity. An increase in air temperature, sunlight warming, and strong wind can stir the water levels of the lake. This causes the current to rise from the bottom of the lake and lift up the settling water mass. The water mass carries toxic compounds from the bottom of the lake and causes the oxygen content in the body of water to decrease. The low oxygen level can lead to the sudden death of fish.

Some of the impacts of eutrophic conditions are reduction in water clarity, anoxic hypolymnetic zones, the occurrence of aquatic plants problems, the survival of only fish that can live in warm water, and dominance of blue-green algae. Around 10% of the phosphorus that causes eutrophication comes from natural processes in the water environment itself (background source), whereas 7% comes from industry, 11% from detergents, 17% from agricultural fertilizers, 23% from human waste, and 32% from livestock waste, which is the largest source. These percentages show the enormous extent that populations and the diverse activities of modern societies contribute to the release of phosphorus to the aquatic environment.[11]

The water fertility of the Saguling Reservoir is greatly influenced by the high phosphorus content. Some studies have illustrated how phosphorus is an important element that causes eutrophication. Its presence contributes to the growth of algae, a phenomenon that was first discovered in 1968.[12] Another compound that also affects the fertility of the water is nitrogen. The usage of nitrogen fertilizer in the upper Citarum watershed continues to increase from year to year. The nitrogen component is highly soluble and easily migrates in the soil, and plants are less able to absorb all of the nitrogen fertilizers.

Table 3. Trophic status parameters (transparency, total phosphorus, total nitrogen, and chlorophyll a).

STATION	PARAMETER	UNIT	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	AVERAGE	SD
Nanjung (upstream)	Transparency	m	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	1.0	0.2	0.1	0.2	0.3
	Total P	µg/L	330.8	418.8	500.5	748.5	220.5	712.0	202.3	304.3	318.0	137.0	266.5	205.0	288.0	675.3	257.5	361.2	186.1
	Total N	µg/L	1157.5	1147.8	1896.3	2713.5	2266.3	2953.8	1879.3	3737.7	1600.4	5526.0	3785.0	5123.5	2809.0	4302.0	2076.5	3231.1	1293.7
	Chlorophyll a	µg/L	953.9	1207.7	1443.4.	2158.7	635.9	2053.4	583.3	877.4	917.1	395.1	768.6	591.2	830.6	1947.4	742.6	1041.8	5367.8
Trophic status																			Hypertrophic
Muara Ciminyak (middle)	Transparency	m	0.0	0.0	0.0	0.0	0.7	0.5	0.0	0.0	0.2	0.2	0.9	1.1	0.5	0.4	0.9	0.4	0.3
	Total P	µg/L	307.3	488.3	524.0	231.8	175.5	304.8	222.8	265.0	237.3	377.0	229.5	219.8	285.0	450.3	165.0	263.6	166.7
	Total N	µg/L	1305.5	1295.3	2101.3	1216.0	1179.6	1989.8	1415.0	1720.5	777.0	1241.0	2071.8	1484.8	2179.3	992.8	395.3	1388.5	570.0
	Chlorophyll a	µg/L	886.1	1408.1	1511.2	668.3	506.1	878.9	642.4	764.2	684.2	1087.2	661.8	633.7	821.9	1298.5	475.8	760.3	4808.6
Trophic status																			Hypertrophic
Turbin Intake (downstream)	Transparency	m	0.1	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.3	0.2	0.6	0.7	0.5	0.2	0.4	0.3	0.2
	Total P	µg/L	235.0	424.8	381.8	198.0	181.3	289.3	186.5	188.8	139.5	530.0	225.8	221.5	485.3	247.5	173.8	255.6	147.0
	Total N	µg/L	1171.0	1161.3	2524.5	1088.3	1127.0	1406.5	1523.5	2313.1	766.5	1708.0	2544.3	2669.3	2065.8	1194.0	407.3	1567.8	653.0
	Chlorophyll a	µg/L	677.7	122.5	1100.9	571.0	522.7	834.2	537.8	544.3	402.3	1528.5	651.0	638.8	1399.4	713.8	501.1	737.1	4238.9
Trophic status																			Hypertrophic

Division of Saguling Reservoir according to climate (1999-2013)

The research period (1999-2013) was divided into dry, normal, and wet years using a discrete Markov method. The class divisions were performed for Nanjung, Muara Ciminyak, and Turbine Intake Stations. The results are shown in Table 4.

Analysis of trophic status based on dry, normal, and wet years

The trophic status of Saguling Reservoir which was analyzed based on dry, normal, and wet years is shown in Table 5. The overall averages indicate a hypertrophic status. However, in dry years, the highest concentrations of total P, total N, and chlorophyll a occur in the upper reservoir. This indicates that the concentration of pollutants is higher in dry years, including total P and total N. In wet years, the 3 parameters appear to have the greatest concentration downstream of the reservoir due to the accumulation of pollutants in this area. Pollutants more rapidly flow downstream in wet years. In normal years, total P and total N are high in the middle of the reservoir due to the use of floating cage nets that dominate in the area.

Figure 5. Trophic status of Nanjung, Muara Ciminyak, and Turbine Intake Posts.

Conclusions

The results of this study show that the Saguling Reservoir is in a hypertrophic state, which means that the reservoir is very highly polluted. The trophic status at Nanjung Post shows that the highest contamination occurs upstream of the reservoir. This area receives pollution from the upper Citarum watershed from industrial activities, domestic waste, and agriculture. Eutrophic conditions can cause reduction in water clarity, anoxic hypolymnetic zones, aquatic plant problems, the survival of only fish that can live in warm water, and dominance of blue-green algae. The results also revealed that there is no effect of seasonal changes on the trophic status of the reservoir, with the hypertrophic status persisting regardless of dry, normal, or wet conditions.

Determination of tropical status of Saguling Reservoir in this research is very important because the actual condition of Saguling as hydropower and floating net cages certainly

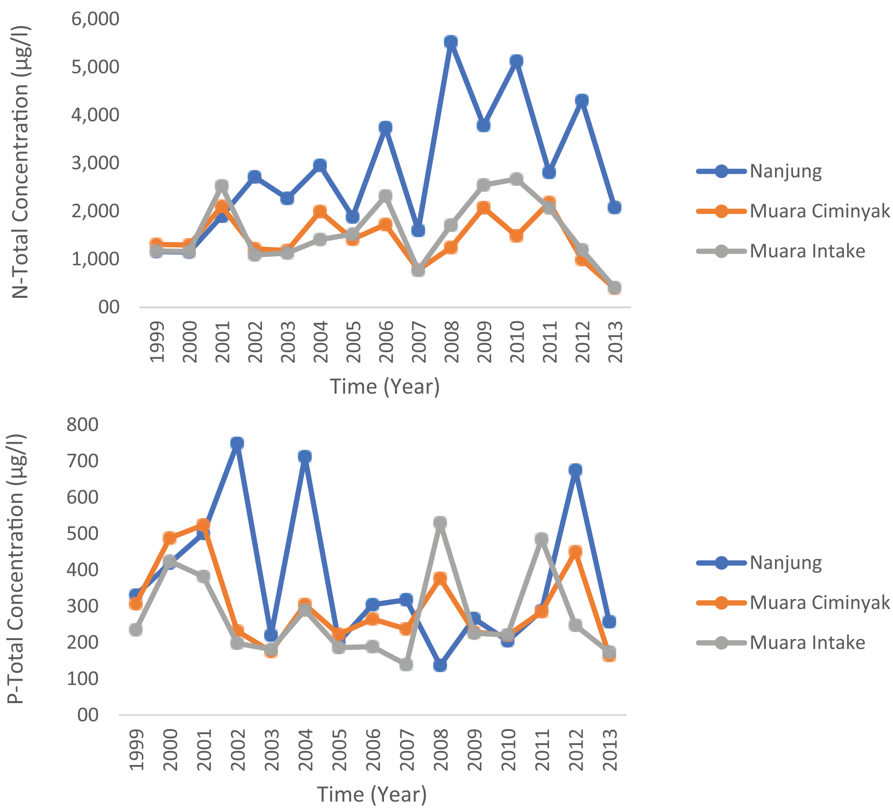

Figure 6. Comparison of N-Total Concentration and P-Total Concentration of Nanjung, Muara Ciminyak, and Muara Intake in 1999-2013.

Table 4. Determination of dry, normal, wet years according to discrete Markov method.

DISTRIBUTION OF OBSERVATION YEARS (1999-2013) INTO DRY, NORMAL, AND WET YEARS	DRY YEARS (0)	NORMAL YEARS (1)	WET YEARS (2)
Monitoring station in Saguling Reservoir	002	1999	2001
	2003	2000	2005
	2004	2008	2007
	2006	2009	2010
	2011	2012	2013

Table 5. Trophic status of Saguling Reservoir in dry, normal, and wet years.

STATION	PARAMETER	UNITS	AVERAGE		
			DRY	NORMAL	WET
Nanjung (upstream)	Transparency	m	0.3	0.2	0.3
	Total P	µg/L	454.7	365.7	235.7
	Total N	µg/L	2896.0	3183.7	2727.6
	Chlorophyll a	µg/L	1311.2	1054.5	679.7
Trophic status				Hypereutrophic	
Muara Ciminyak (middle)	Transparency	m	0.3	0.3	0.3
	Total P	µg/L	252.4	370.5	273.5
	Total N	µg/L	1657.0	1381.3	1464.1
	Chlorophyll a	µg/L	727.9	1068.4	788.7
Trophic status				Hypereutrophic	
Turbin Intake (downstream)	Transparency	m	0.3	0.2	0.2
	Total P	µg/L	268.5	332.6	323.6
	Total N	µg/L	1600.1	1555.7	1519.1
	Chlorophyll a	µg/L	774.3	959.2	933.2
Trophic status				Hypereutrophic	

increase the pollution of N and P in Saguling Reservoir. Master plan of Saguling Reservoir use as raw water needs to be reviewed and assessed based on water quality status, not only in terms of quantity.

Determination of tropical reservoir status in each classification year (dry year, normal year, and wet year) only has been done in this research because the research of tropical status or water quality was usually done based on average condition of observation year. Based on year classification, the influence of quantity (debit) to the water body quality can be seen.

Author Contributions

MM conceived of the presented idea and developed the theory also verified the analytical method and MB performed the computations. All authors discussed the results and contributed to the final manuscript.

REFERENCES

1. Marganingrum D. *Integrated water resources management "Saguling Reservoir" in order to adapt the development of bandung metropolitan area* (Dissertation). Environmental Engineering Research Program ITB; 2013.

2. Welcomme RL. Fish biodiversity in floodplains and their associated rivers. In: Gopal B, Junk WJ, Davis JA, eds. *Biodiversity in Wetlands: Assessment Function and Conservation*, Vol 1. Leiden, The Netherlands: Backhuys Publishers; 2000:61–87.
3. Aubert AH, Gascuel-Odoux C, Merot P. Annual hysteresis of water quality: a method to analyse the effect of intra and inter-annual climatic condition. *J Hydrol*. 2013;478:29–39.
4. Lai YC, Tu YT, Yang CP, Surampalli RY, Kao CM. Development of a water quality modeling system for river pollution Index and suspended solid loading evaluation. *J Hydrol*. 2013;478:89–101.
5. Djuangsih N. *Eutrophication in Saguling Reservoir: Competitive Grant Research Report*. Bandung, Indonesia: PPSDAL—Research Institute of Padjadjaran University; 1996.
6. Hart BT, van Dok W, Djuangsih N. Nutrient budget for Saguling Reservoir, West Java, Indonesia. *Water Res*. 2002;36:2152–2160.
7. Jones JR, Bachmann RW. *Prediction of Phosphorus and Chlorophyll Levels in Lakes*. Alexandria, VA: Water Pollution Control Federation; 1976.
8. Marselina M. Primary pollutant selection and determination of water quality index in class dischage divison based on three class markov model. *Int J GEOMATE*. 2017;13(38):89–96.
9. Government of Indonesia. *Ministerial Regulation (Permen) of the Environment Number 28 of 2009 on the Water Pollution Load Capacity of Lakes or Reservoirs*; 2009.
10. West Java Environmental Management Agency; 2008.
11. Morse GK, Lester JN, Perry R. The economic and environment impact of phosphorus removal from wastewater in the European Community (APHA, AWWA, WEF (1995)). In: Eaten AD, ed. *Standard Methods for the Examination of Water and Wastewater*. 19th ed. Washington, DC: APHA; 1993: 61.
12. Fried S, Mackie B, Nothwehr E. Nitrate and phosphate levels positively affect the growth of algae species found in Perry Pond. *Grinnell College*. 2003;4:21–24.