

ANALYSIS OF POLLUTION LOAD CAPACITY BASED ON WET, NORMAL AND DRY YEAR'S RESERVOIR OPERATING PATTERNS IN THE SAGULING RESERVOIR, INDONESIA

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Abstract

Saguling Reservoir is one of the Citarum Cascade reservoirs located in the upstream area at an altitude that is 643 meters above sea level in West Java, Indonesia. The Saguling Reservoir functions as a hydroelectric power plant (PLTA), a water supply provider for irrigation, and flood control. This research aims to determine the capacity of the water pollution loading accordance with reservoir operating patterns that consist of dry, normal and wet years, based on Government Regulation No. 37 of 2010 concerning Dams. The pollution load in the reservoir is limited by the Total-P concentration that is caused by the fishery's activities in the water body, especially concerning the Floating Net Cage (KJA) systems. The analysis of water quality status and optimization of reservoir management was carried out by Discrete Markov discharge classification which conducted in 1998-2018. A trophic status analysis of the Saguling Reservoir showed that the waters have entered the hypereutrophic criteria. This study also reveals that the Saguling Reservoir has the lowest pollution load capacity in the dry year, with values of 5,212.7 ton P per year, followed by 6,003.7 ton P per year during normal years, and 6,423 ton P per year during wet years. These results indicate that the value of the carrying capacity of the Saguling Reservoir will be smaller during the dry years. Therefore, based on this research, the ideal number of KJA that can be accommodate by Saguling Reservoir during the dry, normal and wet years, respectively, 22,141 units, 25,500 units, and 27,284 units. Meanwhile, the actual current number of KJA is 35,482 units, which has exceeded the reservoir's carrying capacity, especially in the dry years.

Keywords: Pollution load capacity, Reservoir operating pattern, Saguling Reservoir

Introduction

Saguling Reservoir is one of the reservoirs that form the Citarum cascade reservoir along with Cirata Reservoir and Jatiluhur Reservoir in West Java, Indonesia. Based on the quantity, water discharge from the Saguling Reservoir has the potential to supply the Bandung Metropolitan Area with raw water; the potential use of the Saguling Reservoir water discharge is 1.622 L/s [1]. This reservoir was originally built to supply electricity to the island of Java, but over time, the designation has increased to additional activities that include fish farming, agriculture, and tourism. The change in designation has resulted in an acceleration in the decrease of quality in the Saguling Reservoir waters. The usability of the reservoir depends on the quality of the body of

water. If the water quality decreases through contamination of the water body, its potential will also decrease; and this includes its potential for, fish farming using the floating net cage system (KJA). The presence of KJA in the Saguling Reservoir in West Java, increasingly affects the reservoir's water quality. Phosphorus pollution is primarily caused by the use of KJA in reservoirs, which makes it difficult to meet water quality standards [2]. The principle of the use of reservoir waters for fisheries activities, especially KJA aquaculture, must be based on the carrying capacity of the waters, the amount of which depends on the level of fertility (trophic level). Calculation of the capacity of reservoir pollution load refers to the Minister of Environment Regulation No. 28 of 2009 and is based on the pattern of reservoir management.

The reservoir management pattern is based on Government Regulation No. 37 of 2010 concerning dams that consist of operating patterns for dry years, normal years, and wet years [3]. This can determine the extent to which reservoir management functions optimally and in accordance with its designation, both for drinking and irrigation water sources. The volume of reservoirs during a wet year will be greater, which will affect fish farming in KJA. Therefore, this research is needed to examine reservoir water quality, specifically the capacity of reservoir water pollution load for which calculations are based on reservoir operation patterns during dry, normal and wet years.

Materials and Methods

Research Location

The study was conducted in the Saguling Reservoir area which is located above the Citarum River and acts as a trap for pollutants discharged into the river and around the residential areas of Bandung. The main source of water in the Saguling Reservoir comes from the Upper Citarum River. The Upper Citarum River is a 77-kilometer-long river segment from the upper reaches of the Citarum River, Situ Cisanti in Kertasari District, Bandung Regency to Nanjung, which is the Saguling Reservoir inlet. Saguling Reservoir is one of three reservoirs that block the flow of the Citarum River, which is the largest river in West Java. The location is illustrated in Figure 1. Saguling Reservoir has an effective capacity of 611.5 million m³. The main purpose of the establishment of Saguling is to produce electricity. Saguling Reservoir is a reservoir that uses water to generate electricity and has an output capacity of 700 MW.

There are 10 water quality monitoring stations in different locations (Figure 2). Water quality data in Saguling Reservoir is obtained from monitoring regularly every 3 months from 1998-2018. Water quality data is used to determine water quality status, trophic status (especially total phosphorus and total nitrogen), and the capacity of water pollution load with total phosphorus being a limiting factor. Overall water quality is determined by comparing data with criteria from Government Regulation No. 82 of 2001 concerning the Management of Water Quality and Water Pollution Control [4]. This regulation is commonly used to determine the water class in nationwide that consists of four water quality criteria based on class, which each of class have different criteria that fit to its purpose. In this case, the designation to be used is the classification of class II water quality, the designation of which can be used for the cultivation of freshwater fish, livestock, water for irrigating agriculture, and other allotments that require the same water quality that is used by these.



Figure 3. Administrative Boundary in the Project Area

Figure 1. The location of Saguling Reservoir and Citarum Cascade (Source: BBWS Citarum, 2012)

Data Analysis

Data analysis consisted of several stages; the first stage is a quantity analysis that uses historic mainstay debit determinant and the Class Markov Discrete classification methods that are more focused on dry years. Analysis then, proceeds with the method for determining the path of the plan discharge guidelines. In determining the dry, normal and wet years using the Discrete Markov method, according to the flow of water entering the reservoir, stochastic matrices are created for each month to classify historical data. To form a transition matrix, water discharge data must be completed with data welding, while determining class intervals for each class division is obtained by dividing the probability curve of the selected population distribution into 3 equal parts namely 0.333, 0.6667, and 1 [5].

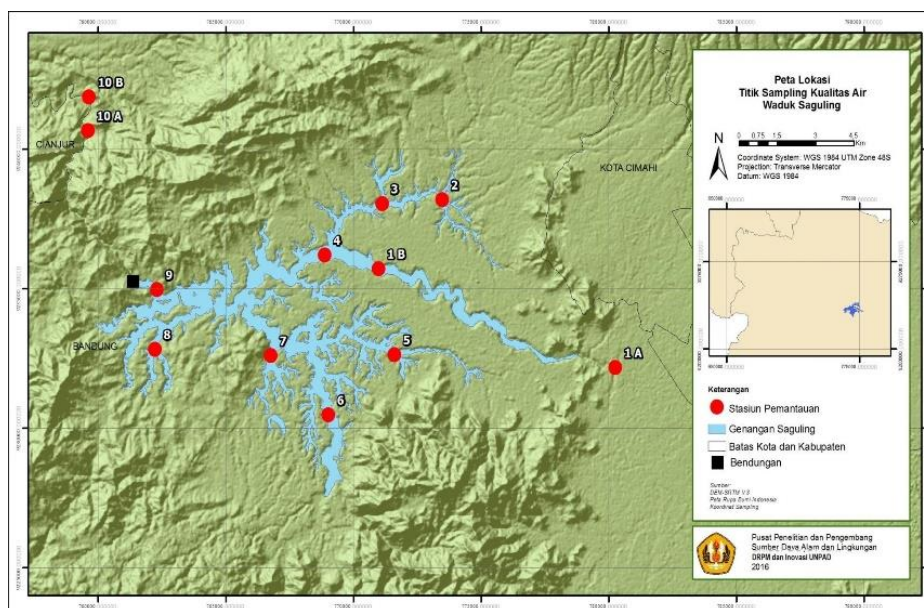


Figure 2. Monitoring location point of water quality (Source: PT. Indonesia Power UP Saguling)

The middle value of each class that is determined based on the cumulative distribution curve (Figure 3) was used. Determination of the trajectory of the guidelines with the concept of plan discharge is done by examining the behavior of historical water discharge to determine the threshold for the magnitude of future water flow events. The probability of reliability of a data point (from many data points) is the probability value of an event in which the value that occurs is equal to or more than the value of the data, or written as $P(X \geq x)$ [6]. To calculate the reliability probability of a data point, the Weibull reliability probability formula was used. The Weibull probability formula shows the probability value (after the data is sorted from large to small) that the event is greater than that value [7]. Weibull probability formula:

$$P(X \geq x) = \frac{m_x}{n+1} \quad (1)$$

where, $P(X \geq x)$ = value of probability occurrences of all events 'X' greater or equal to data 'x', m_x = the ranking of data x, after being sorted large to small, and n is the total amount of data.

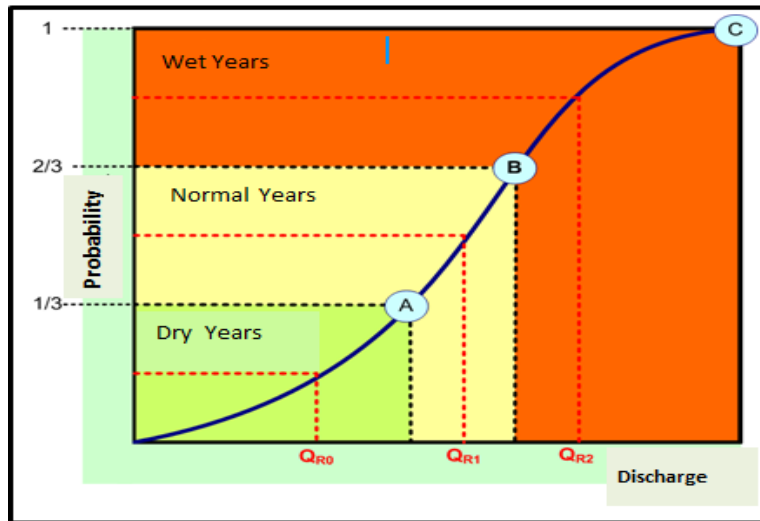


Figure 3. The curve of Chain Markov 3 Classes (Source: Modified by Sabar, 2009)

Water quality, which is the main reference, is trophic in status. The water quality parameter chosen as a limiting factor is phosphate in the form of Total-P, and, given the basic calculation, is the trophic status of the lake and/or reservoir, and is categorized into three classes (wet, normal, and dry years) according to the Markov Discrete calculation. The analysis of the pollution load capacity of fish culture in the KJA is calculated based on the Regulation of the Minister of Environment No. 28/2009 [8] concerning the capacity of the lake and/or reservoir water pollution load. The general formula for calculating the capacity for aquaculture is determined based on the amount of aquaculture waste, which is as follows:

- Lake Morphology and Hydrology

$$Z = 100 \times V/A \quad (2)$$

Where: Z = average depth of reservoir (m); V = water volume of reservoir (million m^3); A = wide area of reservoir (ha).

$$\rho = Q/V \quad (3)$$

Where: ρ = turnover rate of reservoir water (per year); Q = amount of water discharge from the reservoir (million $m^3 \cdot year^{-1}$).

- Allocation of Phosphorus (P) Pollution Load

$$[P]_d = [P]_{STD} - [P]_i - [P]_{DAS} \quad (4)$$

Where: $[P]_d$ = allocation of total-P concentration of waste activities in reservoirs ($mg \cdot m^{-3}$); $[P]_{STD}$ = maximum total-P level in accordance with the water quality standard or water class ($mg \cdot m^{-3}$); $[P]_i$ = observed total-P level of the reservoir ($mg \cdot m^{-3}$); $[P]_{DAS}$ = total-P concentration from the watershed ($mg \cdot m^{-3}$).

- Capacity of Fish Aquaculture Wastewater Pollution

$$L_{fish} = \Delta[P] Z \rho / (1 - R_{fish}) \quad (5)$$

$$R_{fish} = X + [(1-X)R] \quad (6)$$

$$R = 1 / (1 + 0,747 \rho^{0,507}) \quad (7)$$

$$La_{fish} = L_{fish} \times A \quad (8)$$

Where: L_{fish} = total-P waste storage per unit area of the reservoir ($mg \cdot m^{-2} \cdot year^{-1}$); La_{fish} = total P waste in reservoir waters ($kg \cdot year^{-1}$); R = total-P left with sediment; X = proportion of total P that is permanently in sediment (~50%); La_{fish} = total P waste in reservoir waters ($g \cdot year^{-1}$).

Results and Discussion

Quantity Analysis of Input Discharge Saguling Reservoir

Saguling Reservoir input discharge analysis was carried out to determine the reliability of raw water quantity using the historical method by sorting and interpolating the discharge data between 1998 and 2018 and also Markov Discrete in dry, normal, and wet (three classes) years, which was also adjusted to the availability water quality monitoring data. The Markov Discrete discharge analysis in this study results in the classification of the three classes that consist of dry, normal and wet years (Table 1).

Table 2 shows the average value of monthly discharges in the dry year (three classes), which is $52.60 m^3/sec$. Saguling Reservoir monthly input discharge in a dry year (three classes) has characteristics analogous to the dry R5 plan discharge required for raw water planning. The existence of regulation and classification of Saguling Reservoir discharge affects the condition of the Saguling Reservoir guidelines (volume) based on Government Regulation number 37 of 2010. The Saguling Reservoir pathway is based on class 3 class classification in Figure 4.

Table 1. Distribution of 3 Classes Discrete Markov (1998-2018)

Dry Years	Normal Years	Wet Years
2000	1999	1998
2002	2005	2001
2003	2007	2010
2004	2008	2013
2006	2009	2014
2011	2012	2016
2018	2015	2017

Table 2. Average Discharge Discrete Markov Saguling Reservoir (3 Classes) (1998-2018) (m³/sec)

Average Discharge	Jan	Feb	Mar	Apr	May	Jun	Jul	Ags	Sep	Okt	Nov	Dec	Average
Q2 Wet	141.14	195.97	216.66	206.81	151.13	98.74	70.36	39.64	64.23	96.19	182.29	171.74	136.24
Q1 Normal	105.50	132.36	157.42	151.32	103.12	54.75	29.95	14.15	17.49	37.03	105.35	115.51	85.33
Q0 Dry	64.71	94.42	91.46	112.88	58.73	25.42	13.94	8.45	9.98	15.79	46.83	88.63	52.60

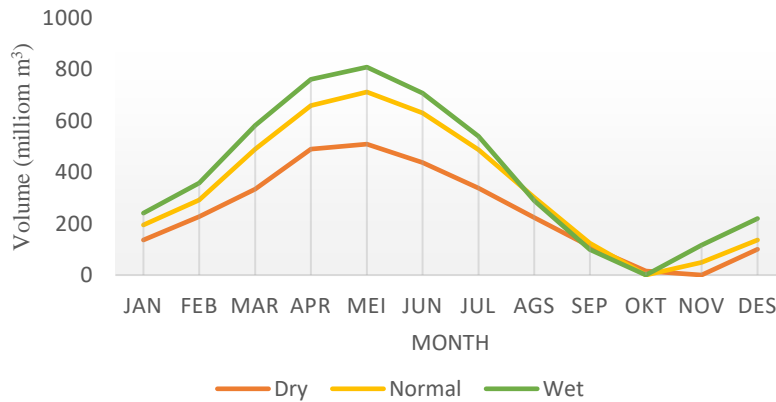


Figure 4. Saguling Reservoir guidance trajectory dry, normal and wet years (three classes) 1998-2018 (million m³)

Based on Figure 4, there is a fluctuation in Saguling Reservoir water volume where the lowest point occurs during October-November or during the time of water quality monitoring period IV sampling. In addition, there are differences in the amount of volume in each class so that the analysis of water quality needs should be conducted in the condition of the reservoir volume along with the classification of the appropriate discharge year, that is, on the classification of dry years (three classes), which is analogous to the mainstay discharge R5 dry years.

Analysis of Trophic Status of Saguling Reservoir

Analysis of reservoir water quality to determine trophic status based on parameters of total Phosphorus and total Nitrogen, was adjusted to the lake trophic status criteria based on State Minister of Environment Regulation No. 28 of 2009. Lake and/or reservoir water quality

conditions are classified based on eutrophication due to an increase in the nutrient content of the water. The limiting factors, used as determinants of eutrophication are the elements Phosphorus (P) and Nitrogen (N). In general, the average water plant contains Nitrogen and Phosphorus levels of 0.7% and 0.09%, respectively, of the wet weight. Phosphorus limits eutrophication if the Nitrogen level is more than eight times the level of Phosphorus; Nitrogen limits the eutrophication process if the level is less than eight times the level of Phosphorus [9].

The entry of the amount of excess Phosphorus pollutant load into the body of water will result in the eutrophication of waters, which can be found the assessment of water criteria based on the Total-P and Total-N values, that is, the waters have entered the eutrophic criteria towards hypereutrophic. This is suggested by the results of the trophic status calculations, which are based on Nitrogen and Phosphorus compounds, and shows that the Saguling Reservoir has a hypereutrophic trophic status, which is already heavily polluted (Figure 5, Table 3). This can be seen from the amount of Total-P levels that are far above the standard criteria.

Table 3. Trophic Status of Saguling Reservoir in 3 Classes

Year	Total-N ($\mu\text{g/l}$)	Total-P ($\mu\text{g/l}$)	Category
Wet	795	284	Hipereutrof
Normal	1024.95	795.60	Hipereutrof
Dry	422.86	199.40	Hipereutrof

Fish culture with the KJA system is one of the economic activities that has the potential to reduce the quality of the reservoir waters environment [10]. The content of fish feed, fish droppings, and waste disposal from KJA activities are waste for reservoirs if not managed properly. This is supported by the results of research by Nastiti, et al. [11], which showed that in the waters of the Saguling, Cirata and Jatiluhur Reservoirs, the largest total N and P total drainage (83.63-99.93%) originated from fish farming.

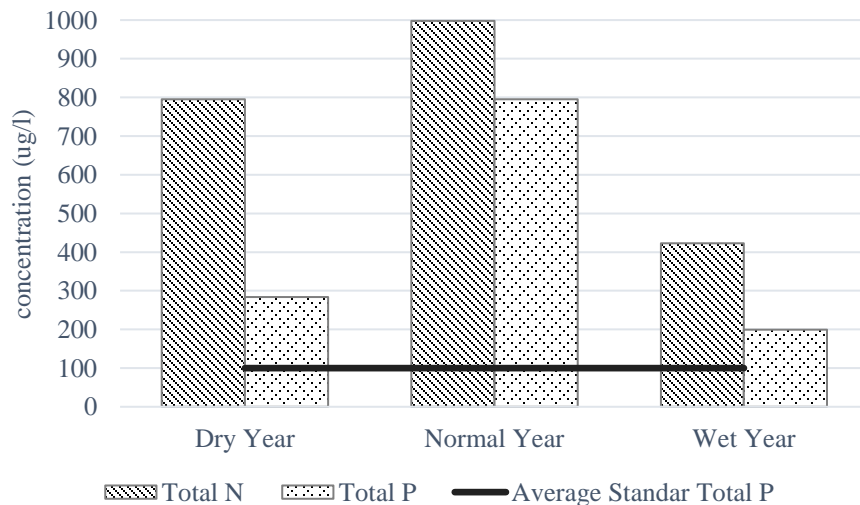


Figure 5. The concentration of Total-N and Total-P based on dry, normal, and wet years in Saguling Reservoir (1998-2018)

The trophic state not only refers to the nutrient status of the water, but also to the biological production that occurs in the water and to morphological characteristics of the lake basin itself. A eutrophic lake may not only be a lake with high levels of nutrients, but also a very shallow pond, full of rooted aquatic plants, that may or may not have high levels of nutrients [12]. Water quality impairment caused by nutrient enrichment remains a major concern [13]. Harmful algal blooms can cause its drinking water supply to be disturbed for the time being, refocusing on the link between nutrient enrichment, particularly phosphorus (P), and water quality impairment [14], with many of these nutrients being agriculturally derived. To control agriculture nutrient loading to surface waters, multiple control strategies are necessary at the source and during transport into the receiving water resources.

Analysis of Pollution Load Capacity of Saguling Reservoir

The analysis of the capacity of pollution load in the Saguling Reservoir is based on the formula for calculating the capacity of lake and/or reservoir water pollution loads according to the Minister of State and Environment Regulation No. 28/2009. Analysis of pollution load capacity in the reservoir is conducted based on reservoir operation patterns which consist of dry years, normal years and wet years according to Government Regulation No. 37 of 2010 concerning Dams.

Table 4. Calculation Result of Saguling Reservoir Pollution Load Capacity

Parameter	Symbol	Unit	Value in		
			Dry year	Normal year	Wet year
Lake Morphology and Hydrology					
Average depth	Z	m		12.2	
Water volume	V	million m ³	243.41	339.88	393.35
Wide area of reservoir	A	ha	1,975.3	2,758.15	3,192.0
Amount of water discharge	Q	million m ³ /year		2,413.4	
Turnover rate of reservoir water	ρ	per year	9.92	7.10	6.14
Allocation of Phosphorus (P) Pollution Load					
Observed total-P level of the reservoir	[P] _i	mg/m ³	289.4	239.5	213.5
Allocation of total-P concentration of waste activities in reservoirs	Δ [P] _d	mg/m ³	660.5	710.5	736.4
Capacity of Fish Aquaculture Wastewater Pollution					
Total-P waste storage per unit area of the reservoir	L _{fish}	g P/m ² year	263.9	217.6	201.2
Total P waste in reservoir waters	L _a _{fish}	ton P/ year	5,212.7	6,003.7	6,423.6
Total-P left with sediment.	R	-	0.39	0.43	0.45
Proportion of total-P dissolved into sediment after cages	R _{fish}	-	0.69	0.71	0.72

Based on the calculations presented in Table 4, it shows that the maximum Total-P load that can be accommodated by the Saguling Reservoir is 5,212.7 ton P per year during dry years, 6,003.7 ton P per year during normal years, and 6,423.6 ton P per year during the wet years. Total-P load during the wet years has the greatest value compared to other years. Widyastuti, et al. [15] suggested that the P and N elements are the two elements responsible for phytoplankton blooming in an ecosystem and that the phosphorus element is most often the main cause. This situation occurs because of the denitrification of nitrogen compounds, which prevents nitrogen from accumulating in sediments, as is the case with P. compounds. Therefore, the determination of carrying capacity in this study uses the Beveridge formula (1996) which refers to the total P waste load wasted into the aquatic environment.

Carrying capacity analysis using the Beveridge formula (1996) shows the maximum total fish production that can be cultivated [16]. Furthermore, the maximum total fish that can be cultivated can be used to determine the optimal amount of KJA. Calculation of reservoir carrying capacity is carried out for the dry years and, assume the lowest discharge occurs during the dry years. Next, the calculation is using the lower limit of the KJA and operates in accordance with the capacity of the pollution load, which is known.

Table 5. Calculation Result of Saguling Reservoir Pollution Load Capacity and Carrying Capacity Based on 3 Classes Discrete Markov

Parameter	Unit	Value in			Average
		Dry Year	Normal Year	Wet Year	
Observed total-P level of the reservoir ($[P]_i$)	mg/m ³	289.4	239.5	213.5	245.7
Allocation of total-P concentration of waste activities in reservoirs ($\Delta[P]_d$)	mg/m ³	660.5	710.5	736.4	702.4
Total-P waste storage per unit area of the reservoir (L_{fish})	g P/m ² year	263.9	217.6	201.2	227.6
Total P waste in reservoir waters (La_{fish})	ton P/year	5,212.7	6,003.7	6,423.6	5,193.3
Carrying capacity (maximum fish production)	ton/year	47,313	54,492	58,304	53,370
Optimal number of KJA	unit	22,141	25,500	27,284	24,975

Based on the analysis results in Table 5, it can be seen that during the dry year, the amount of pollution load capacity that is indicated by La_{fish} has the lowest value, which is 5,212.7 ton P/year. Also, the carrying capacity of the reservoir during the dry year has the lowest value (47,313 ton/year). This indicates that the maximum total amount of fish that can be produced during a dry year is 47,313 ton/year. But, actually, the total fish production according to the Department of Animal Husbandry and Fisheries of West Bandung Regency (2018) is 75,823 ton/year with the number of KJA during 2018 being 35,482 units. This indicates that the current number of KJA has exceeded the reservoir's carrying capacity, especially during the dry years.

The carrying capacity of reservoirs for KJA cultivation is very much related to changes in water quality. It is clear that the reservoir volume, is declining [15]. To determine the difference in carrying capacity based on reservoir volume, carrying capacity is calculated from four

monitoring periods: monitoring I) March; II) June; III) September; IV) December; where in period IV the lowest reservoir volume occurred based on the Saguling Reservoir guidelines [3].

Table 6. Calculation Result of Saguling Reservoir Pollution Load Capacity Every Period during Dry Years Discrete Markov

Parameter	Unit	Value in Period				Average
		I	II	III	IV	
Monitoring						
Observed total-P level of the reservoir ([P] _i)	mg/m ³	278.44	238.23	410.58	230.39	289.41
Allocation of total-P concentration of waste activities in reservoirs (Δ[P] _d)	mg/m ³	671.56	711.77	539.42	719.61	660.59
Total-P waste storage per unit area of the reservoir (L _{fish})	g P/m ² year	268.28	284.34	215.49	287.47	263.9
Total P waste in reservoir waters (L _{a_{fish}})	g P/ year	5,299.3	5,616.6	4,256.5	5,678.4	5,212.7
Carrying capacity (maximum fish production)	ton/ year	48,099	50,979	38,634	51,540	47,313
Optimal number of KJA	unit	22,508	23,856	18,079	24,119	22,141

Based on the results of the carrying capacity analysis for each period during the dry year (Table 6), it appears that the lowest carrying capacity was during the third period (September monitoring), so that the ideal number of KJA of 18,079 units was obtained. These results can be used as a reference to calculate the amount of KJA in the reservoir, because in this condition the reservoir water volume is very low.

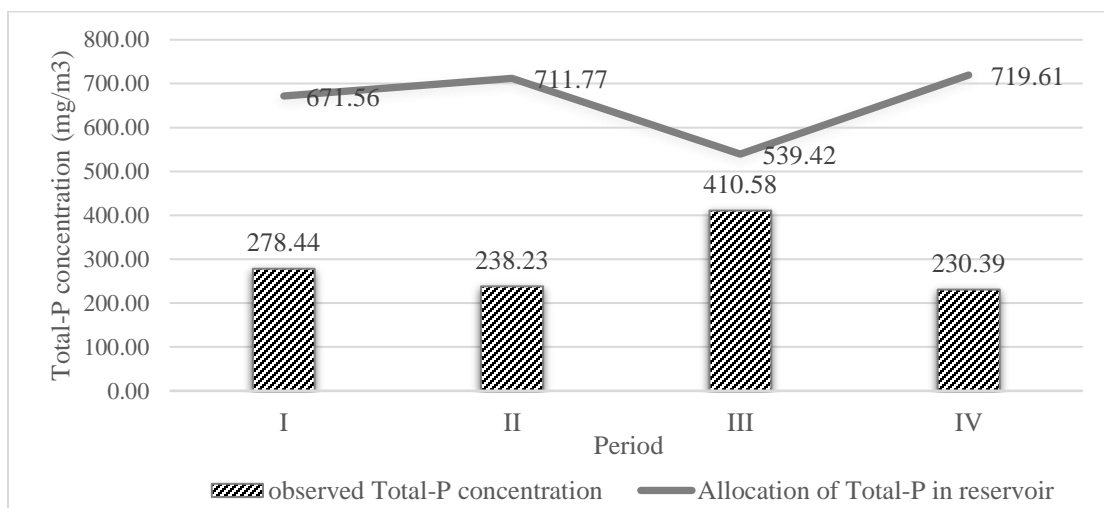


Figure 6. The graph of Total-P concentration during the dry years per period in Saguling Reservoir

Based on Table 6, it appears that the higher the Total-P level results of monitoring ([P]i), the lower the allocation of phosphorus pollution load in reservoirs ([P]d). The most critical allocation of phosphorus load in reservoirs ([P]d) was measured during period III (September monitoring), which had the lowest value of 539.42 mg/m³ during September, known as the peak during the dry years.

Conclusions

The results indicate that the trophic status of the Saguling Reservoir has entered the hypereutrophic category. This is based on the assessment of the Total-P and Total-N criteria, which included as heavily polluted. Based on the analysis of pollution load capacity, the Saguling Reservoir has a total Total-P load of 5,212.7 ton P per year during dry years, 6,003.7 ton P per year during normal years, and 6,423 ton P per year during wet years. The pollution load capacity of the Saguling Reservoir has the lowest value during dry years. Based on the calculation of the reservoir carrying capacity during dry, normal, and wet years, respectively, it measured 47,313 tons/year, 54,492 tons/year, and 53,370 tons/year. Based on this research, the ideal number of KJA in Saguling Reservoir during the dry, normal and wet years, respectively, 22,141 units, 25,500 units, and 27,284 units. These results indicate that the value of the carrying capacity of the Saguling Reservoir will be smaller during the dry years.

Recommendation

It is necessary to do calculations based on Markov Discrete 5 classes consisting of very wet, wet, normal, dry, and very dry years. Pollution control during very dry years needs to be analyzed further to compensate for the extreme dryness to meet drinking water source requirements.

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