Alternative Intake Station in Saguling Reservoir for The Needs of Raw Water in Bandung Metropolitan Area

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Abstract. Bandung Metropolitan Area (BMA) region is the upper watershed of Citarum with an area of ± 2338 km^2. The status carried by BMA as a National Strategic Area from the perspective of economic encourage the increasing migration flows to BMA. These circumstances lead to an imbalance between supply and demand, in which on the one hand, demand for clean water is increasing. The potency of Saguling Reservoir as an alternative of raw water of BMA region in terms of quantity in this research was determined based on the determination of mainstay discharge. In this study, the intake site selection 11 monitoring posts will be carried out by reviewing the concentration of all parameters in Government Regulation No. 82 Year 2001 on any division of discharge grade using 5-grade Makov Discrete method (very dry, dry, normal, wet and very wet). In addition, the calculation of the value of Water Quality Index (WQI) was done at each monitoring station for each division of discharge grade that has been done. The series of data flow and concentration parameters used in this study start from the year 1999 to 2014. The allocation of raw water discharge calculation for Saguling Reservoir in order to fulfill the needs of raw water in Bandung Metropolitan Area is 46,92m^3/second (R5 dry for irrigation raw water supply and 29,53 92 m^3/second (R10 dry for drinking water supply). Based on the assessment of the concentration of measured parameters and determination of Water Quality Index, it can be found that around Muara Ciminyak location is the most qualified location to be used as drinking raw water intake for Bandung Metropolitan Area. Based on this study, it also notes that the determination of the concentration of pollutant parameters needs to be done on the each division of discharge grade occurred.

1 Introduction

Bandung Metropolitan Area (BMA) is an upstream of Citarum watershed with an area of 2338 km^2 [6]. The status held by the BMA as a National Strategic Area with the point of economic interest plus various function carried out by Bandung City as the core of the region, turned out to be investors attraction to make investments that encourage the increasing migration flow. The increasing population and economic development and production activities in this region led to successive land conversion and the increasing water demand. This condition triggers an imbalance between supply and demand, were on one hand the demand for clean water increases and on the other hand the water source has suffered from quantity and quality degradation.

The utilization of the potency of Saguling Reservoir as raw water source has an impact on the changing of reservoir operating management from single function reservoir to multi-sector reservoir. Of course this condition needs careful target and preparation. In-depth calculation of Saguling Reservoir capability in terms of quantity and quality as raw water alternatives should be performed. Based on research from Hart et al (2007), Saguling was classifed as a eutropic reservoir.

The potency of Saguling Reservoir as raw water alternative in BMA region in terms of quantity in this research was determined based on the determination of mainstay discharge. Mainstay discharge is the discharge available in a watershed at a certain time which its existence is located to be able to meet the rate of water demand. The amount of this mainstay discharge can be determined by the ranking method (statistic historic) or rational.

The analysis of reservoir water quality was conducted by Water Quality Index method. The analysis of water quality status in this research was conducted by comparing the observation results with the standard values [19], [11], [18]. Evaluation of water quality can be conducted with spatial and temporal approach [1-5], [12], [20], [21]. Therefore, the availability of periodic and regular (time series) data monitoring is the success key in performing the water quality evaluation [14-17], [8], [9]. In addition to historical data series, the selection of appropriate water quality parameters is also a very important variable in evaluating the quality of water source [18], [20].

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WQI shows the relative contamination levels allowed in water quality parameters or water quality parameter standards. Water quality parameter standards used in this WQI analysis refer to Government Regulation No. 82 of 2001 on the designation of water class. Saguling is categorized as class I because it is used for drinking water in downstream cascade Citarum.

Based on this research, it was understood that the mainstay discharge of drinking water of Saguling Reservoir by using the R10 concept as dry (the discharge value is less in one time within 10 years period). Based on the Water Quality Index research conducted, the monitoring location which become the best alternative as region or location of raw water intake can be found.

2 Methodology

2.1 Mainstay Dicharge of Saguling Reservoir

The reservoir discharge analysis is often associated with the reliability level of water availability in meeting the needs and is often referred to as mainstay discharge. For example, the activities that require the reliability of water availability is the provision of raw water and hydropower [13]. Mainstay discharge is determined by a certain minimum quantity that has a certain probability in meeting the needs, for example, for the needs of drinking raw water usually set as 90% or 95%, while for irrigation is set as 80%. The return period equation for probability is defined as Tr = (1/P) in which Tr is the return period and P is the expected probability. The design criteria of domestic raw water and irrigation can be seen in Table 1.

Table 1. Design Criteria of Domestic Raw Water and Irrigation

Reservoir Water Source	Raw Water Planning Design Criteria			
	Domestic		Irrigation	
Successive Dry Water Discharge	30 days	T_R=10-20 Years	30 days	T_R=5 Years

Source: Modified by Sabar (2009)

Observation of minimum discharge value and maximum discharge value is expected to provide an explanation for the water potential tendency in Saguling Reservoir. Discharge observation has been done in research by Marganingrum (2013) and Rhamdani (2009) in Saguling Reservoir in two periods, namely 1950-1985 (period of development and management planning of Saguling Reservoir) and 1986-2008 (period after the construction of Saguling Reservoir). An observation was also conducted on the minimum discharge trends from year to year as to provide an explanation on the potential base flow of watershed, while observation on the maximum discharge trends from year to year can provide explanation on floods or runoffs due to land-use changes. Furthermore, the observation of dischager in the research of Citarum Cascade Reservoir was conducted within the observation span of 1986-2013.

2.2 Determinantion of Wet, Norma, and Dry Years with Markov Model

Markov model has a formula as follows (Descombes dan Berthod, 2006):

$$q_i = d_i + e_i \quad (1)$$

where:
di = deterministic component
ei = random component
Otoregresip deterministic component has a linear formula as follows:

$$d_i = \beta_0 + \beta_1 q_{t-1} + \beta_2 q_{t-2} + \dots\dots\dots + \beta_m q_{t-m} \quad (2)$$

where d_i is a linear combination of m previous flow, for a limited m. The simplest model has the following formula:

$$d_i = \beta 0 + \beta_1 q_{t-1} + e_1 \quad (3)$$

The above model assumes that all previous influence to the flow is now reflected in the value of the previous flow. Furthermore, in lag model, the amount of β_0 dan β_1 constants are specified with the exact form of e_i. In the first place, it is considered that the flow follows the normal distribution.

If μ is the middle-value flow, ρ is the correlation of coefficient serial lag and σ is flow diversity, the following equation is established:

$$q_1 = \mu + \rho\,(q_{i-1} - \mu) + e_i \quad (4)$$

Here, it is assumed that the flow of qi is the sum of the median, some of the differences in previous flow q_{i-1} with the mean and random components e_i. If q_i has a normal distribution, then e_i should also have a normal distribution as well. The flow of q_i has median μ, so the suggested form will give the desired middle value. The flow q_i has diversity as follows:

$$E\,[\mu + (q_{i-1} - \mu) + e_i]^2 - \mu^2 = \sigma^2\rho^2 + \sigma_e^2 \quad (5)$$

where σ_e^2 is a diversity of the random components ei. The diversity q_i is related with σ_e^2 which expressed in the following formula:

$$s_e^2 = \sigma^2\,(1-\rho^2) \quad (6)$$

If t_i is a random variable that has a normal distribution, but does not serially rely on 0 median and has 1 value of standard deviation, then:

$$ti\ \sigma\,((1 - \rho 2\,))^{0,5} \quad (7)$$

also, a normally distributed variable does not depend serially, on median 0 and variance σ2 (1-ρ2). Thus the model is as follows:

$$q_i = \mu + \rho\,(q_{i-1} - \mu) + t_i\,\sigma\,((1 - \rho^2\,))^{0,5} \quad (8)$$

Simplification of water discharge that entered the reservoir in Markov model was conducted by dividing them into three classes. Based on the water division, matrix stochastic can be created each month that divides the historical data into three classes. The stages of Markov model processing in dividing discharge category are as follows:

a. Frequency distribution analysis

An analysis of the frequency distributions of water discharge per month in the period 1999-2013 was conducted. Then the frequency distribution of historical data was matched with the two frequency distribution models: Normal and LogNormal. Each month, the most suitable distribution of the two alternative types was chosen

b. Class division

The second phase after the selection of frequency distribution was the distribution of water discharge class. The process investigated in this study was the first order for three classes. Therefore, the amount of discharge was divided into three classes 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 was obtained by dividing the probability curve of the distribution of the selected population into 3 equal parts, namely 0.333, 0.667, and 1 as shown in Figure 1. Range value of each class was the middle value of each class which is in probability curve 0333, 0.667, and 1. The probability determination of each data was conducted by using Weibull method as follows:

$$P\ (Xm) = \frac{m}{N+1} \quad [9]$$

with:

P (Xm) = probability of a set of values that are expected during the observation period
N = number of observation of X variate
m = serial number of events or rate of events

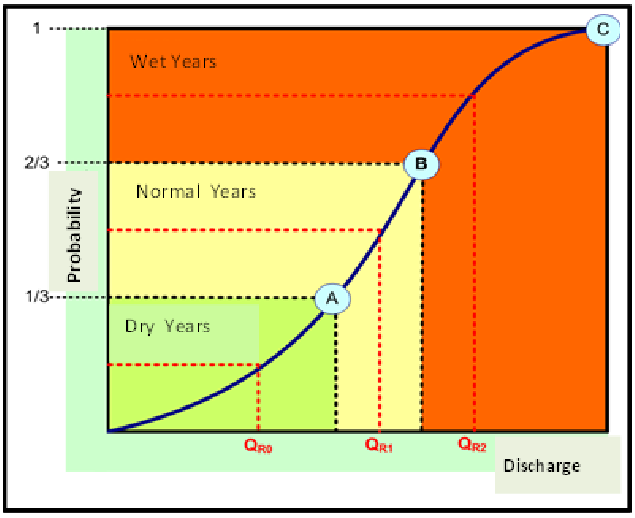

Fig. 1. Class division based on probability in Markov model

2.3 Monitoring Quality Station in Saguling Reservoir

Monitoring of water quality in Saguling was conducted regularly every three months within one year span, with each taken in March, June, September, and December respectively. There were 11 locations of Saguling quality monitoring stations: Nanjung Station (input), Batujajar, Cipatik Muara, Muara Ciminyak, Cimerang, Tjihaur, Muara Cijere, Cijambu Muara, Muara Tjihaur, Turbine Intake and Tailrace. The monitoring was conducted on forty-four (44) water quality parameters which consist of physical and chemical parameters. Main study location in this research was Nanjung Station, Muara Ciminyak Station, and Intake Turbine station as shown in Figure 2.

Fig. 2. Location of Monitoring Quality Station in Saguling Reservoir

2.4 The Measurement of Saguling Water Quality Index

WQI method does not distinguish between physical, chemical, and biological contaminants. All types of contaminants are given equal value [18]. WQI method is quite easy and simple with the following equation:

$$WQI = (\sum[Ci/Pi])/n \quad (10)$$

WQI = quality index (water quality index)
Ci = concentration of the variable i
Pi= quality standards for variable i
n = number of variable

Source or basis for determining the water quality was based on WQI which was based on research by Altansukh and Davaa that conducted in Tuul River, Mongolia. Determination of water quality based on WQI value can be seen in Table 2.

Table 2. Determination of Water Quality Based on WQI Value

No	WQI Value	Water Quality		Recommendation
		Class	Status	
1	WQI ≤ 0.30	1	Very clean	No treatment necessary. Suitable for all kind of water usage.
2	0.31 ≤ WQI ≤ 0.89	2	Clean	After treatment, it can be used for drinking and agriculture. Without treatment, can be used for fishery.
3	0.90 ≤ WQI ≤ 2.49	3	Slightly polluted	Unsuitable for drinking and agriculture. If there's no choice, use it after treatment. Without treatment, can be used for livestock, recreation, and sports purposes.
4	2.50 ≤ WQI ≤ 3.99	4	Moderately polluted	Can be used for irrigation and industrial purposes after a proper treatment.
5	4.00 ≤ WQI ≤ 5.99	5	Heavily polluted	After an appropriate treatment can be used for heavy industrial activities without human body contact.
6	WQI ≥ 6.00	6	Dirty	Unsuitable for any purpose. Requires an extensive treatment.

3 Discussion

3.1 Raw Water Dicharge Allocation at Saguling Reservoir

Discharge analysis in Citarum Cascade Reservoir started from the discharge observation data at Saguling Reservoir, namely Nanjung discharge station as primary station and Safuling discharge station as secondary station. Figure 3 shows that the average monthly discharge of Nanjung Station and Saguling Station have the same monthly pattern in both data series of 1920-1980 and 1986-2013.

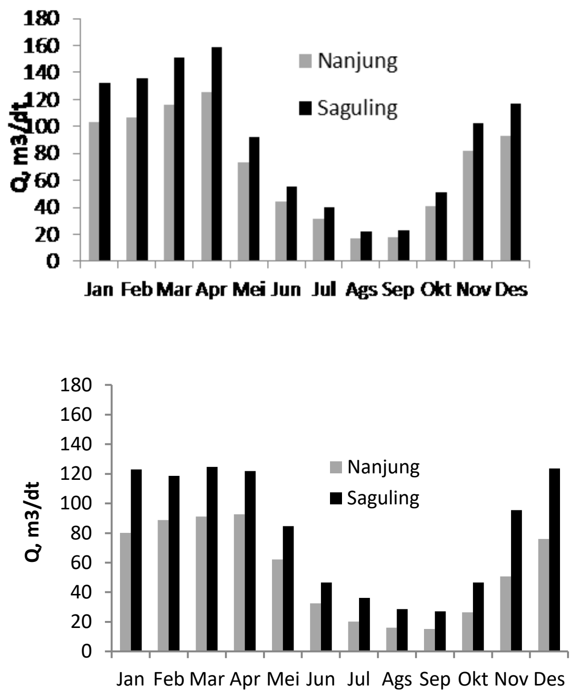

Fig.3. Monthly Average Discharge Fulucation in Nanjung Statin and Saguling Station Within Two Different Time Periods

Drinking water allocation that the Saguling Reservoir can provide is based on the discharge plan of dry R5 or dry R10 which can be seen in Table 3.

3.2 Division of Discharge Class of Saguling Water by Year

Distribution of research observation year (1999-2013) was conducted by Markov Discreet Method. It was divided into dry, normal, and wet years. The class divisions were performed in Nanjung, Muara Ciminyak, and Turbine Intake Stations. The class divisions in dry, normal, and wet years in each station can be seen in Table 4.

Table 4. Determination of Dry, Normal, Wet Years according to Markov Discreet Method based on Discharge Data of Saguling Reservoir

Dry Years (0)	Normal Years (1)	Wet Years (2)
2002	1999	2002
2003	2000	2003
2004	2008	2004
2006	2009	2006
2011	2012	2011

3.3 The Average Value of WQI of Overall Monitoring Post in Saguling Reservoir

Based on Figure 4, it was found that based on the average value of WQI for each monitoring location station in Saguling Reservoir. Monitoring location that has the smallest WQI value was Muara Ciminyak Station with WQI value of 3,05. The monitoring location that has the highest WQI in this case showed the highest pollution level was Nanjung monitoring location.

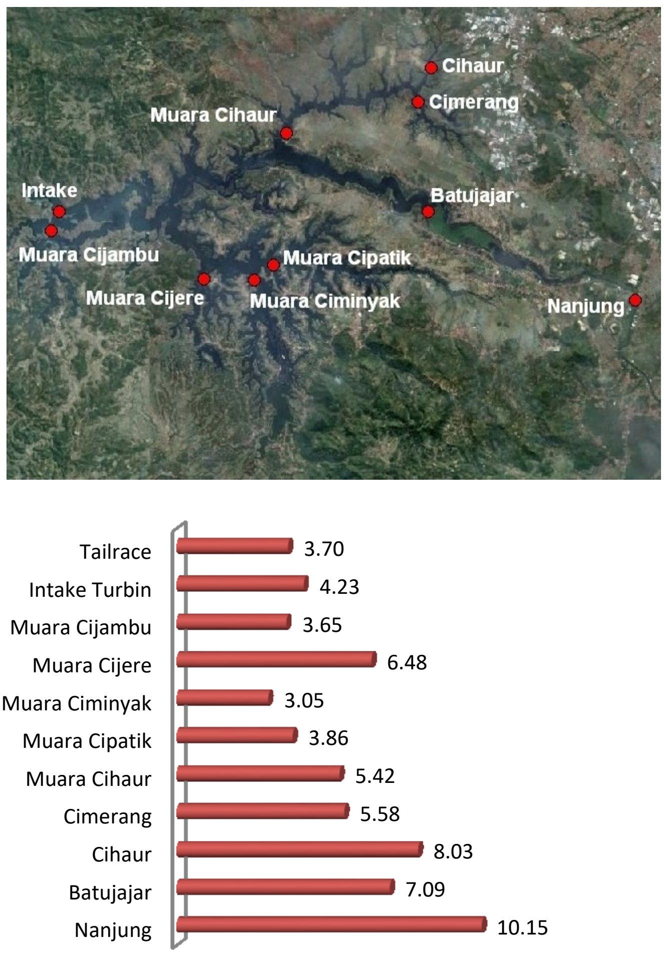

Fig.4. The average WQI value of each monitoring station in Saguling Reservoir

Determination of water quality based on WQI value (Altansukh & Davaa) can be seen in Table 5.

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Table 5 Water Quality Status of Each Monitoring Station in Saguling Reservoir

Monitoring Location	WQI Value (Average)	Status
Nanjung	10,150	Dirty
Batujajar	7,092	Dirty
Cihaur	8,035	Dirty
Cimerang	5,575	Heavily polluted
Muara Cihaur	5,416	Heavily polluted
Muara Cipatik	3,858	Moderately polluted
Muara Ciminyak	3,046	Moderately polluted
Muara Cijere	6,482	Dirty
Muara Cijambu	3,650	Moderately polluted
Intake Turbin	4,227	Heavily polluted
Tailrace	3,704	Moderately polluted

The high value of WQI or the high pollution in Nanjung Station is caused by the land-use in Nanjung watershed which is dominated by industry and household. The previous surveys informed that the main types of industry in Citarum watershed are textile industry, leather tanning industry, food industry, and electroplating industry. Based on a study conducted by Environmental Agency of West Java Province in 2007, there were 359 companies that are divided into 11 different industry sectors, located in four administrative areas along the upstream of Citarum River. Among those industrial sectors, textile industry is one of the sectors that need to be considered because of its most dominant number. Other industrial sector such as electroplating, pharmaceuticals, metals, food/beverages also need attention. Detailed data on the number of industry of inventory result of Environmental Agency of West Java Province (2007) can be seen in Table 6.

Table 6 Data of the Number of Industry

No	Industry Sector	Municipality/City				
		Sumedang Regency	Bandung Regency	Bandung City	Cimahi City	Total
1	Textile	10	152	54	46	262
2	Electrop lating	0	5	9	5	19
3	Leather	1	0	1	0	2
4	Chemic al	0	4	0	0	4
5	Pharmac eutical	0	3	3	3	9
6	Paper	0	2	1	0	3
7	Paint	0	1	0	2	3
8	Integrat ed IPAL	0	2	0	0	2
9	Food/Be verage	1	3	10	10	24

No	Industry Sector	Municipality/City				
		Sumedang Regency	Bandung Regency	Bandung City	Cimahi City	Total
10	Garment	0	0	2	0	2
11	Metal	0	0	1	6	7
	Total	15	176	93	75	359

3.4 The Average WQI Value Based on Grouping of Monitoring Station Location

Distribution of Monitoring Station based on Location of Saguling Reservoir	
Inlet	Nanjung
	Batujajar
North of Reservoir (Middle)	Cihaur
	Cimerang
	Muara Cihaur
	Muara Cipatik
	Muara Ciminyak
	Muara Cijere
	Muara Cijambu
Outlet	Intake Turbin
	Tailrace

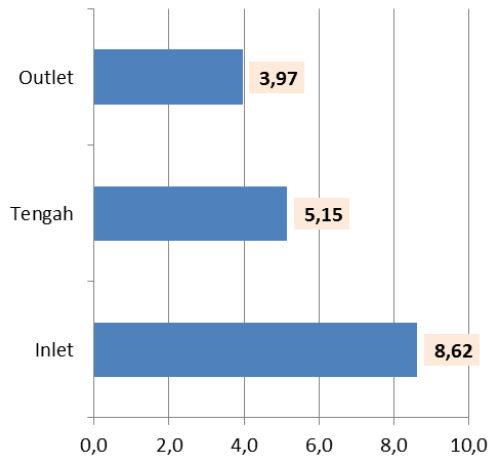

Fig.5. The average value of EQU based in the Location Grouping of Monitoring Station

Grouping of the entire monitoring station into three main location of Reservoir (inlet, middle, and outlet) and WQI value based on the location division can be seen in Figure 5. Based on Figure 5, it can be seen that the highest pollution is in the inlet area of Saguling Reservoir discharge, in this case from the upstream Citarum watershed and the lowest pollution is in outlet location. This is in accordance with the dilution phenomenon occurs along the reservoir or water body which is the increasingly away from the inlet location with high pollution, the pollution can decrease.

3.5 WQI value based on the Discharge Class Division (Dry, Normal, and Wet)

Water quality of each monitoring location cannot be separated from the volume condition occurred in Saguling Reservoir. In obtaining the actual status of reservoir, it is necessary to determine the quality of reservoir with the scenario of year condition or the volume occurred, in this case the dry, normal, and wet year. The WQI value of each monitoring location the condition series of dry, normal, and wet year can be seen in Table 7. The specific WQI value in the year condition of wet, normal, and dry for all monitoring station of Saguling Reservoir can be sen in Figure 6, Figure 7, and Figure 8.

Table 7. WQI Value of Each Monitoring Station in the Discharge Class Division of Wet, Normal, and Dry Year

Year Division Based on Discharge Class	Nanjung	Batujajar	Cihaur	Cimerang	Muara Cihaur
Drw	14,277	10,893	11,681	6,494	9,041
Normal	8,383	5,689	7,781	5,206	4,053
Wet	7,792	4,693	4,642	5,025	3,154

Table 7. WQI Value of Each Monitoring Station in the Discharge Class Division of Wet, Normal, and Dry Year (Cont.)

Year Division Based on Discharge Class	Muara Cipatik	Muara Ciminyak	Muara Cijere	Muara Cijambu	Intake Turbin	Tailrace
Dry	5,818	4,051	7,244	5,397	6,270	4,074
Normal	3,058	2,734	6,675	2,785	3,587	3,811
Wet	2,697	2,353	5,526	2,768	2,823	3,227

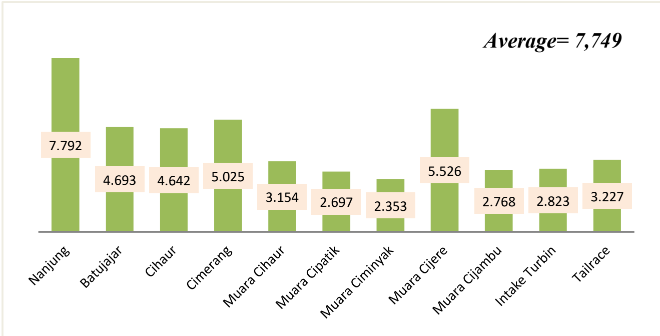

Fig. 6. WQI Value of Each Monitoring Station in the Discharge Class Division of Wet Year

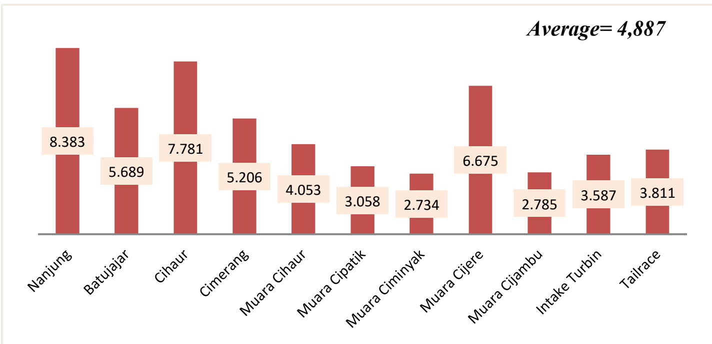

Fig.7. WQI Value of Each Monitoring Station in the Discharge Class Division of Normal Year

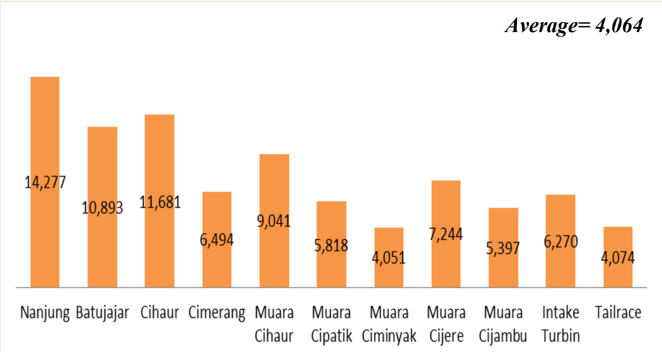

Fig.8. WQI Value of Each Monitoring Station in the Discharge Class Division of Dry Year

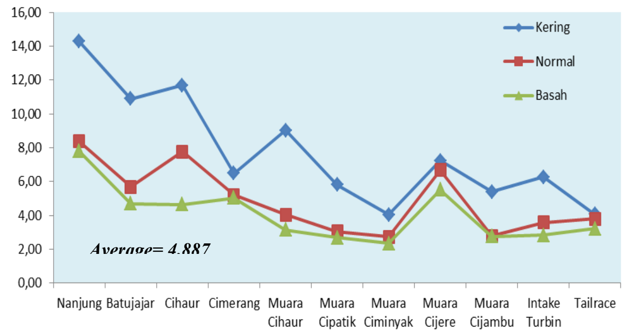

Fig.9. WQI Value Graph in Each Monitoring Station in Dry, Normal, and Wet Condition

Based on Figure 9, the highest WQI value is gained from the dry year, followed by the normal year, then, the wet years. It happened in each monitoring station in Saguling Reservoir. This was in accordance with the consistency of flow rate and concentration where it tend to be low in the dry season and the pollution concentration will increase. On the contrary, the reservoir flow rate increased in the rainy season, therefore the pollution concentration will decrease due to the dilution in the reservoir.

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4 Conclusion

The calculation allocation of raw water discharge for Saguling Reservoir in order to fulfill the needs of raw water in Bandung Metropolitan Area is 46,92 m3/second (R5 dry for irrigation raw water supply) and 29,53 92 m3/second (R10 dry for drinking raw water). The pollution load in Saguling Reservoir is a function of pollutant concentration and quantity or discharge occurred in the reservoir. This is demonstrated by the research of water pollution in Saguling Reservoir with Markov discrete approach and the determination of Water Quality Index (WQI) in the condition of dry, normal, and wet year. Based on the water quality analysis by Water Quality Index (WQI) method, it was found that the WQI Value in Muara Ciminyak Station is 4,051 in the dry year condition; 2,374 in normal year condition; and 2,353 in wet year condition. The monitoring location of this Muara Ciminyak Station is the most qualified as an option in the intake location of raw water supply from Saguling Reservoir. Utilization of Saguling Reservoir as an alternative potency of raw water supply requires careful target and preparation. In-depth calculation of Saguling Reservoir capability in terms of quantity and quality as an alternative of raw water needs to be done.

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