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The linkage of water quality measurement the downstream of the Citarum cascade reservoir management

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Abstract
Cascade Citarum Reservoirs, located in the western part of the island of Java in Indonesia country, cover the main building dams, hydropower, irrigation facilities and other supporting facilities. The study aimed to evaluate the characteristics of the existing condition of the downstream reservoir, including the relation of the water quality and quantity, by using a conceptual model of the Citarum Cascade Reservoir management. The study mostly used the secondary data acquired from Indonesia Power, the Management Bureau of Cirata Dam (BPWC), Perum Jasa Tirta II (PJT) Jatiluhur, the Management Bureau of the Citarum-Ciliwung River Basin (BPDAS Citarum-Ciliwung), and the Water Resource Management Agency of the West Java Province. This research aims to predict the discharge plans R5 and R20 using the Weibull method and the uncertainty of future discharge using the continuous model approach. Furthermore, the multivariate statistical test will analyse the linkage of water quality in reservoir management. To solve the problem of the allocation of the raw water discharge to fulfil the water requirement in the downstream area was developed proportionally in this study, in which the raw water discharge allocations were 46.92 m3/sec, 91.9 m3 /sec and 97.95 m3/sec for Saguling, Cirata, and Jatiluhur, respectively. The tests to determine the relationship between the discharge and water quality using the Discriminant test indicated that the discharge correlates strongly with the parameters such as NH3. BOD and COD.

Keywords:
Citarum Cascade;
Discriminant Test;
Reservoirs management;
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INTRODUCTION

The world's water resources have been developed for centuries to benefit humankind. The construction of the dam to create a reservoir has served many purposes [1, 2, 3, 4] and was built to change natural flow regimes which are the most significant human interventions in the hydrological cycle [2].

Construction of reservoirs in Indonesia began with constructing reservoirs in the Citarum Cascade downstream is Ir. H. Djuanda (Jatiluhur) in 1967, it is one of the most important rivers in West Java with an 8.300-hectare area of inundation and a maximum depth of 107 m. Several reservoirs have been built on the river, namely Saguling, Cirata and Jatiluhur. Each reservoir at a lower elevation receives water that has passed through another at a higher elevation, an arrangement known as a cascade of reservoirs [5]. For example, the Jatiluhur reservoir, associated with a multi-use function, has been a significant proponent of 80% of the raw water to Jakarta at 16.5 m^3/second [6].

The water from the waterfall weir of Jatiluhur is divided into three-channel, namely West Tarum Channel, North Tarum Channel, and East Tarum Channel. Water at the West Tarum channel is used to meet the needs of irrigation, domestic, and industrial. The principal function of these three reservoirs is to provide flood control, water supply, and one of the electricity providers in the area of Java-Madura-Bali [7].

The Jatiluhur multipurpose reservoir, which is used as a Hydroelectric Power Plant (HEPP), the source material for drinking water, flood control, and irrigation, has begun to experience a decrease in environmental carrying capacity and reservoir function [2][8]. In addition, erosion in the upper watershed of Jatiluhur causes the input stream to become increasingly turbid during the wet season [2, 3, 6, 7, 8]. The circumstance is due to the tall request for water for horticulture, urban and mechanical West Tarum along the channel, climate change and land use in the catchment area Jatiluhur, Cirata, and Saguling upstream. The studies of floating net cages in phase II of 2007 showed fluctuations in all measured parameters. Furthermore, an indication of heavy metal pollution was found in the Citarum cascade (i.e., Cirata and Saguling Reservoirs) after research conducted by Cirata Reservoir Management Agency (BPWC) [6]. In the first quarter of 2008, lead levels and copper levels were 0.04 mg/liter and 0.03 mg/liter, respectively. Based on West Java Governor Regulation No. 39 of 2000 concerning Water Quality Standards, the threshold value for drinking raw water, fisheries, and hydropower is 0.02 mg/liter for Copper and 0.03 mg/liter for Lead.

Climate change significantly impacts water resources in sub-tropical and tropical regions on the continent of Africa and Asia both in quantity and quality [1][5]. The impact of climate changes on the design of hydrological infrastructure of water resources and their management can be a new challenge for hydrologists and water resource managers. Rain and discharge are hydrological components which are random variables with stochastic characteristics, and discharge is influenced by rainfall variations [9]. Considering the various factors previously mentioned that greatly influence the performance of the reservoir in supporting the livelihoods of the people in the surrounding area [10]. The study aimed to evaluate the characteristics of the existing condition of the downstream reservoir, including the relation of the water quality and quantity, using a conceptual model of the Citarum Cascade Reservoir management.

METHOD

Material

Jatiluhur dam or supply is found in West Java Area. The body dam is at 6°31' south scope and 107°23' east longitude based on geographic facilitates. The Citarum supply framework comprises three stores, Jatiluhur, Cirata, and Saguling, as shown in Figure 1. The Jatiluhur Dam was built in 1957 and authoritatively started working in 1967. It is the lowermost and biggest supply of the Citarum store framework and gives a net multipurpose capacity of almost 2,448 m^3. The dam's administration has experienced numerous changes reflecting Indonesian macroeconomic changes and different interfaces in profiting from water to the dam.

The measuring instrument is used to measure water quality and data source directly in the field and in the laboratory. Measuring instruments consist of Global Positioning System (GPS), Thermometers, Secchi Discs, Water Samplers, pH Meters, TDS Meters, DO Meters, Plankton Net, and Conductivity Meters. Heavy metal concentrations were measured in water samples using concentrated acid extraction and spectrophotometry with the Atomic Absorption Spectophotometry (AAS) tool. Heavy metal concentrations in water (mg/l) analysis are based on the procedure from ASTM-STP 1997 [11][12]. Secondary data is obtained from the Saguling Reservoir Management Agency, namely Indonesia Power, BPWC Cirata as Cirata Reservoir manager and Perum Jasa Tirta II (PJT) Jatiluhur as manager of Jatiluhur Reservoir with observation years from 2009 to 2011. Data uniformity is needed to assess the accuracy and significance of data processing with discriminant statistical tests. Quality parameters used in the discriminant test are TDS, COD, BOD, NH_3, NO_2, and temperature parameters with a period of observation from 2009 to 2011, and sampling is carried out on the water surface.

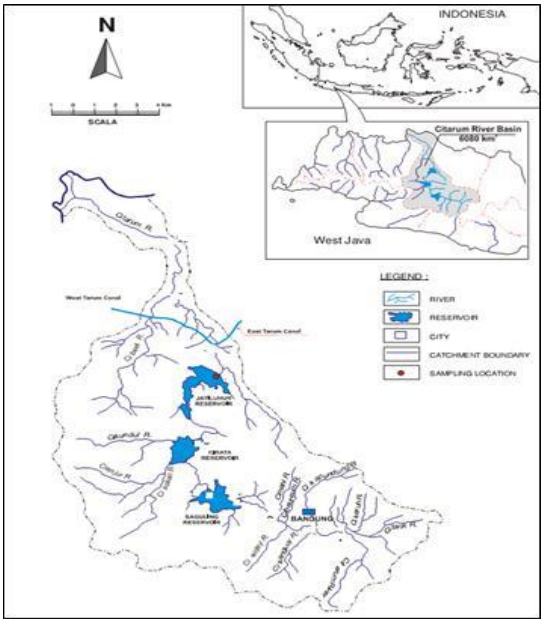

Figure 1. Research Location

Discharge Analysis in The Citarum Cascade Reservoir

Analysis of river discharge is often associated with the dependability of water availability and is often referred to as a dependable flow. For example, activities that require reliable water availability are the supply of raw water and hydropower [7]. Dependable flow is determined by a certain minimum amount with a probability of meeting the needs. For example, drinking water for raw water requirements is usually at 90% or 95%, while irrigation is 80%. This research uses the Weibull method (calculating 80% probability for R5 plan discharge and 95% probability for R20 plan discharge). Discharge observations have been widely carried out in the research on The Saguling reservoir over two periods, 1950-1985 (planning development and management of the Saguling reservoir period) and 1986-2008 (Saguling reservoir station-construction period) [1]. The forecast discharges model using the continuous model approach is used to predict the uncertainty of future discharges. The continuous discharge forecast model has principles based on a statistical analysis of correlation and multiple regression [5]. Multiple regression is done by the beginning method, meaning all variables are included in the study. The multiple regression equation is formulated as (1).

$$Y = a + b_1X_1 + b_2X_2 + ... b_nX_n + E \qquad (1)$$

Where Y is the value of the independent variable (dependent variable); a constant is the value of Y when X = 0; b_n is the n^{th} regression coefficient; X_n is the value of the n^{th} independent variable, and E is an error.

After the regression equation is obtained, a correlation test is done to determine the strength of the relationship between the independent and dependent variables (correlation coefficient = R). R values range between -1 and 1. R = -1 states that the relationship between the independent and dependent variables is very strong (perfect) only in a reverse direction. For R = 1, it states that the relationship between the independent and dependent variables is very strong, but it is in the same direction.

Observations on the trend of minimum discharge were carried out at a certain time to explain the watershed potential base flow. On the other hand, the trend of maximum discharge can explain floods or runoff due to changes in land use. In addition, discharge observation in the Citarum Cascade Reservoir research was carried out in the 1994-2011 observation span considering the uniformity of the rainfall data. The availability of rainfall data will be correlated later with the discharge data to make a forecast of future discharges. The following formulas can determine the calculation of allocation for raw water in each Citarum Cascade Reservoir.

$$Q_{raw\ water\ Saguling\ Dam} = Q_{\hat{R}5\ Saguling\ Discharge} = Q_{out\ Saguling} \qquad (2)$$

$$Q_{raw\ water\ Cirata\ dam} = Q_{out\ Saguling\ dam} + Q_{local\ discharge\ \hat{R}5\ Cirata} = Q_{out\ Cirata\ dam} \qquad (3)$$

$$Q_{raw\ water\ Jatiluhur} = Q_{out\ Cirata\ dam} + Q_{local\ discharge\ \hat{R}5\ Jatiluhur} \qquad (4)$$

Reservoir intake flow forecasting can be done with a time series modelling approach that predicts specific characteristic values in the future period [5, 13, 14]. The condition happens because that time series modelling is the basis of rational, effective and efficient forecasting. One of the time series modelling techniques that can be used is the moving average method [15][16].

The Discriminant Test

The statistics are used to analyse the relationship of water quality parameters in the Citarum Cascade Reservoir with the quantity of water in the reservoir. The statistical test used in analysing the relationship is discriminant and factor analysis, which is included in the type of multivariate statistics [17, 18, 19]. The benefits of using the discriminant test are the first, namely, the ability to predict the occurrence of the dependent variable with independent variable data input; the second is the ability to choose which independent variables significantly affect the dependent variable and which ones do not. The software to analyse the discriminant test used SPSS IBM Statistic 19.

The main objectives of discriminant analysis in general are:

1. To know if there is a clear difference between groups in the dependent variable, or is there a difference between groups 1 and 2?
2. Which independent variable in the discriminant function makes the difference if there is a difference?
3. Create a discriminant function or model which is basically similar to the regression equation,

The basic process of discriminant analysis is as follows:

1. Separating the variables into dependent and independent variables.
2. Determine the method to create the discriminant function, namely the simultaneous estimation method, where all variables are entered together. Then, the discriminant process is carried out. The variables are entered into the discriminant model in the step-wise estimation method. In this process, some variables remain in the model, and there is a

possibility that one or more independent variables are discarded.
3. Testing the significance of the discriminant function that has been formed using Wilks Lambda, Pilai, F test and others.
4. Testing the classification accuracy of the discriminant function, including knowing the classification accuracy individually with Casewise diagnostics.
5. Interpreting the discriminant function.
6. Perform discriminant function validation test.

Model of Discriminant Analysis

Discriminant analysis is included in the Multivariate Dependence Method with the model as (5).

$$Y_1 = X_1 + X_2 + \cdots + X_n \quad (5)$$

The independent variable (X_1 and so on) is metric data, namely the interval or ratio type data. The dependent variable (Y_1) is categorical or nominal data, which in this study is the type of wet year category (2), normal year category (1) and dry year category (0).

RESULTS AND DISCUSSION

The Analysis of Plan Discharge Allocation for Raw Water in the Citarum Cascade Reservoir

Design discharge is a discharge value that is available in flow at a certain time and is calculated to have an existence that exceeds or equals a value based on specific probabilities and distributions that represent the characteristics of the flow [20][21]. This research uses the Weibull method (calculating 80% probability for R5 design discharge and 95% probability for R20 design discharge). The existing random observation values require calibration for certain probability functions to understand probabilistic or stochastic phenomena such as river water discharge [5][22]. From the research, it can be said that the best distribution that can be used for all discharges is never obtained. The condition is caused by water discharge with different statistical characteristics in space and time.

Table 1, Table 2, and Table 3 show the value of R5 year discharge at Saguling Post, Cirata local discharge, and Jatiluhur local discharge with 1994-2011 data observations. After the monthly R5 plan discharge value is obtained, the average discharge is calculated to be used as a raw water discharge plan in the Citarum Cascade Reservoir. The Saguling Reservoir's raw water discharge is 46.92 m^3/s, Cirata local discharge is 44.98 m^3/s, and Jatiluhur local is 6.05 m^3/s. The results of the planned discharge calculation at the Citarum Cascade Reservoir can be seen in Table 4. The discharge plan for raw water in the Citarum Cascade Reservoir becomes a constraint that must be considered in the reservoir operation to ensure the availability of raw water downstream. The allocation of drinking water that must be provided in the Saguling Reservoir, Cirata, and Jatiluhur is based on the planned discharge R20, which can be seen in Table 5.

Table 1. R5 Discharge Plan at Saguling Station (m^3/s)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
61.03	98.04	73.09	101.07	56.69	24.81	14.07	7.44	8.22	8.62	30.12	78.91

Table 2. R5 Local Discharge Plan at Cirata Station (m^3/s)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
70.43	83.64	56.15	89.59	54.19	22.38	12.09	6.62	10.49	20.96	48.16	65.17

Table 3. R5 Local Discharge Plan at Jatiluhur Station (m^3/s)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5.93	21.83	8.64	16.55	5.39	2.35	0.00	1.88	0.34	0.14	3.01	6.61

Table 4. The Discharge Calculation Results for the Raw Water Allocation Plan in CCR

The Location	$\hat{Q}R5$ (m^3/s)	Accumulate Discharge (m^3/s)
Saguling Dam	46.92	46.92
Cirata Dam	44.98	91.9
Jatiluhur Dam	6.05	97.95

Table 5. The R20 Discharge Plan Calculation for The Drinking Water in CCR

The Location	$\hat{Q}R20$ (m^3/s)	Accumulate Discharge (m^3/s)
Saguling Dam	29.53	29.53
Cirata Dam	28.51	58.04
Jatiluhur Dam	0.98	59.02

The allocation of drinking water is needed to ensure the availability of drinking water discharge used downstream of the Citarum Cascade Reservoir (i.e., DKI Jakarta and surrounding areas). The allocation of raw water availability calculation results in the Citarum Cascade Reservoir is 59.02 m^3/s. Compared to the results of the Citarum Cascade Reservoir SOP study conducted by BBWS Citarum in 2013 regarding the minimum raw water requirements in the Jatiluhur Reservoir downstream, which is 115.9 m^3/sec, the results of the allocation of raw water availability calculation in this study provides a value of discharge R5 with a difference of 15%. The situation can be caused by several factors, i.e., differences in the use of historical discharge data, calculation of local discharge allocation, and the method of calculating discharge plans. Therefore, this study used the discharge method R5 for allocating raw water and R20 for drinking water.

The obtained value of drinking water allocation in the Citarum Cascade Reservoir is proportional to 59.02 m^3/sec, calculated based on the planned discharge of R20. Therefore, the allocation of drinking water can be sufficient to fulfil the planned drinking water needs for the DKI Jakarta area until 2030 in the amount of 20.214 m^3/sec [1][5].

The Quality of Aquatic Environment in the Citarum Cascade Reservoir

The Jatiluhur reservoir has diverse water quality estimations at each perception station [1, 2, 5, 6]. The temperature within the Jatiluhur releases ranges from 26.5°C to 30.5°C. The lowest temperatures happen within the Parung Kalong zone (upstream of the Jatiluhur), and the most noteworthy temperatures happen within the Cilalawi Stream outlet. The degree of acidity (pH) ranges from 7.0 to 9.0. The degree of pH portrays the capacity of a body of water to kill hydrogen particles entering the body of water [23]. Most sea-going biota is sensitive to pH changes and survives in pH values extending from 7 to 8.5. The perceptions of pH are moderately the same as those of waters in 1983, 2004, 2005, and 2006 [8].

To compile the linkage of the conceptual model to aspects of water quality, uniform secondary data is needed. It starts from the upstream cascade, the Saguling strikethrough, and the Jatiluhur Reservoir downstream. The water quality condition in the Citarum Cascade Reservoir is shown in Figure 2, Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7. Sampling has been done four times a year to illustrate strikethrough of the condition of water quality sampling in the Citarum Cascade Reservoir. Where most of the highest parameter values belong to The Saguling Reservoir, this shows that the water quality condition in the Saguling Reservoir is worsening or categorised as more polluted than other reservoirs.

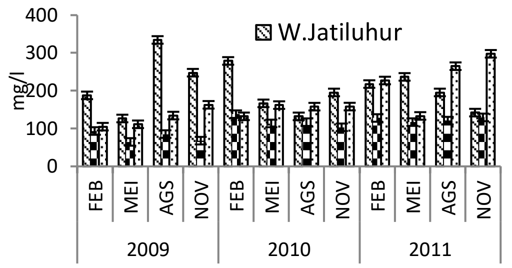

Figure 2. The Average TDS parameters in the Citarum Cascade Reservoir in the 2009-2011 period

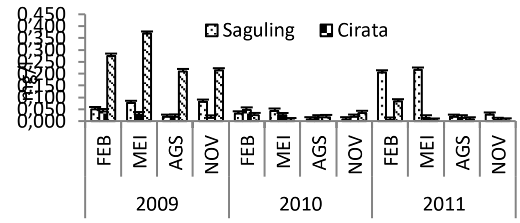

Figure 3. The Average NH_3 parameters in the Citarum Cascade Reservoir in the 2009-2011 period

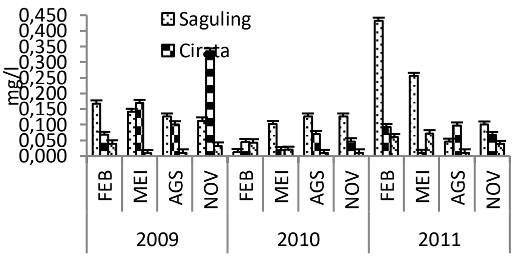

Figure 4. The Average NO_2 parameters in the Citarum Cascade Reservoir in the 2009-2011 period

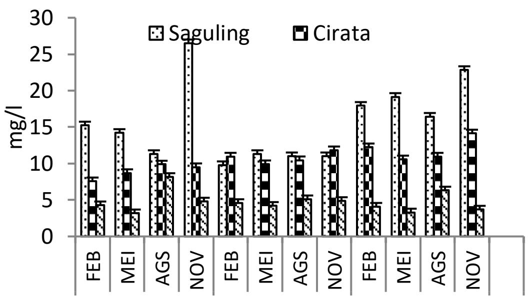

Figure 5. The Average BOD parameters in the Citarum Cascade Reservoir in the 2009-2011 period

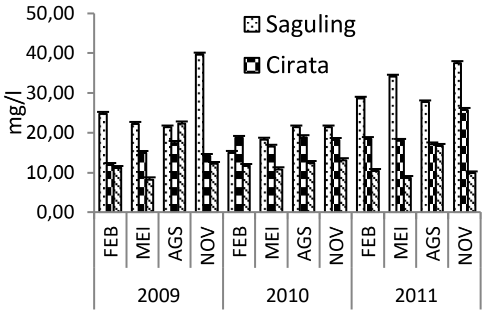

Figure 6.The Average COD parameters in the Citarum Cascade Reservoir in the 2009-2011 period

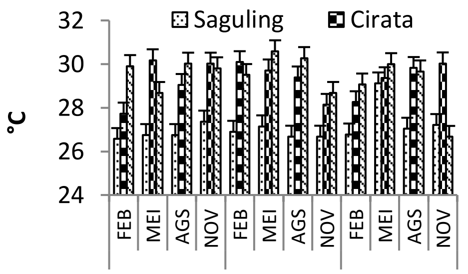

Figure 7. The Average temperature parameters in the Citarum Cascade Reservoir in the 2009-2011 period

Statistical Test Results on the Relation of Quantity Aspects to Water Quality in the Citarum Cascade Reservoir

The first step of statistical testing of the discriminant method is indicated by the feasibility test results of the variable used in the analysis using the Wilks Lambda and F test, as listed in Table 6. It can be seen that the parameters of TDS, NO_2 and temperature have a large significant value > 0.05, indicating that there is no difference between these parameters and the type of annual discharge. Therefore, these three parameters were excluded in the subsequent discriminant analysis. The condition underlies the second step, discriminant analysis, where the parameters used are discharged, NH_3, BOD and COD. The results of the intergroup test with Wilks Lambda showed that the discharge parameters, NH_3, BOD and COD showed differences between groups of annual discharge types, as listed in Table 7. Therefore, the results of the discriminant test result in two-equation functions that can be used to assess the relationship between the type of annual discharge and the water quality parameters as follows:

Function 1 = -1.665 – 0.944 NH_3 - 0.019 BOD + 0.004 discharge
Function 2 = 0.15 +5.27 NH_3 – 0.045 BOD

Function 1 shows the relationship between NH_3, BOD and discharges parameters to the dry and normal year type intervals. In contrast, the second function shows the relationship between NH_3 and BOD parameters to the normal and wet year type intervals. The conclusion obtained from the discriminant test is that the water quality parameters that can describe the different types of dry, normal and wet years that occur in the Citarum Cascade Reservoir are COD and NH_3 parameters. In contrast, the discharge parameters can only show the difference between the types of dry and normal years. The discriminant test has been proven to describe the use of water quality data which varies into several indicators of water quality parameters, namely NH_3 and COD parameters [19, 23, 24, 25, 26, 27, 28].

Table 6. Test Results Between Variables with the Wilks Lambda Method

	Wilks' Lambda	F	df1	df2	Sig.
TDS	0.984	2.830	2	357	**0.060**
Discharges	0.636	102.037	2	357	0.000
NH_3	0.960	7.351	2	357	0.001
NO_2	0.986	2.612	2	357	**0.075**
BOD	0.933	12.846	2	357	0.000
COD	0.953	8.777	2	357	0.000
Temperature	0.989	1.901	2	357	**0.151**

Table 7. Inter-Group Test Results Type of annual discharge using the Wilks Lambda method

	Wilks' Lambda	F	df1	df2	Sig.
Discharges	0.636	102.037	2	357	0.000
NH_3	0.960	7.351	2	357	0.001
BOD	0.933	12.846	2	357	0.000
COD	0.953	8.777	2	357	0.000

CONCLUSION

The allocation of raw water flow calculation for the Citarum Cascade Reservoir to meet the needs of downstream drinking water for the DKI Jakarta area is proportional, whereas the allocation of raw water discharge for the Saguling, Cirata and Jatiluhur Reservoirs. The values are 46.92 m^3/sec, 91.9 m^3/sec, and 97.95 m^3/sec, respectively. The allocation of drinking water availability calculations in the Citarum Cascade Reservoir results is 59.02 m^3/sec, which can be used as a drinking water discharge in the DKI Jakarta and surrounding areas.

Some quality parameters: COD, BOD, and Pb, have exceeded the drinking water quality standard set by the Indonesian Ministry of health. The waters of the Citarum Cascade Reservoir have been polluted by organic matter that is easily biodegradable and unfit for use as a source of raw drinking water. Physical, chemical, and biological treatment is needed if it will be used as a source of drinking water.

Statistical test results with a discriminant analysis show that the discharge variable as a quantitative aspect has a close relationship with the organic parameters of water quality, i.e., NH_3. BOD and COD in the Citarum Cascade Reservoir.

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