Performance Evaluation of Jatibarang Reservoir Due to Land Use Changing

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Abstract. Jatibarang Reservoir is located on the Kreo River. These reservoir functions are flood control, water supply, and hydroelectric power. The total capacity is around 20.4 million m³. The spillway is designed at elevation +148.9 with a width of 15 m, capacity Q₅₀ = 240 m³/s, and an emergency spillway at +151.80 m, the width of 60 m with a capacity of 1350 m³/s. This paper aims to evaluate the performance of reservoirs in their function as flood control, due to land-use changes in upstream of the reservoir catchment area. The method which was used is the HEC HMS. Land use map data is used for the 2016 and spatial planning map of Central Java province for 2011-2031. The results were obtained are the hydrological parameters increase in CN and imperviousness, decrease in initial storage, and initial abstraction which increasing flood discharge. The impact of this, an emergency spillway that was designed for discharges higher than Q₅₀, must function at discharge that smaller than Q₅₀. The initial design, Q₅₀ water level elevation below +151.8, but with the change in hydrological parameters, water level elevation of Q₅₀ increase up to +152.2.

1. Introduction

Land-use change, potentially, has a significant impact on hydrological behaviour and ecological processes at temporal and spatial scales. Thus, obtaining information on land-use change in catchments is very important for integrated land use planning and water resource management. This is because a slight modification of land cover can affect runoff formation and flow patterns through modification of interception, infiltration, surface runoff, and the evaporation process [1].

A better assessment and understanding of the impact of land-use change on the water catchment hydrological process also helps in predicting the potential for flooding and the level of reliability of water resource infrastructure.

The Garang watershed is vital in the management of water resources in Central Java. Garang River is the primary source of raw water for the people in Semarang City. Aside from being a provider of water for life, the Garang watershed also stores potential disasters, especially flooding. This condition is indicated by the number of floods in Semarang that is not only caused economic losses, but also social losses in the form of fatalities.

To overcome this problem, efforts to control water damage have been carried out. One of the flood control efforts is to normalize the Garang river downstream or commonly called the western canal.
flood. In addition to the upstream effort, efforts are also needed to control overflow runoff, one of which is by building the Jatibarang reservoir.

The aim of this study was to evaluate the performance of reservoirs in their function as flood control, due to land-use changes in upstream of the reservoir catchment area. The method which was used is hydrological modelling using HEC HMS (Hydrologic Modelling System). This research is essential, considering that the Jatibarang reservoir, which functions as a flood controller, is expected to be safe according to the target level of risk allowed. Changes in land use in the upstream of reservoir water catchment area according to the spatial plan of Central Java Province need to be evaluated for their impact on hydrological behaviour. This evaluation is to determine whether the designed spillway capacity is still suitable for flowing flood discharge due to changes in watershed hydrological parameters.

2. Methodology

This research is watershed hydrological modelling that discusses the amount of flood discharge and its effect on reservoirs. The components in the watershed studied were hydrological behaviour due to changes in land cover. The data used include watershed maps, soil types, land cover, hydrometeorological data, and reservoir physical data. Reservoir physical data include the elevation and volume relationship curves, spillway data and crest dam elevation data.

The HEC HMS model requires input data in the form of sub-basin data, meteorological data and transformation methods of rain-runoff. Rain data used as input in the form of rain design results of frequency analysis, using the frequency distribution equation. Evaluation of reservoir safety level in terms of the capacity of the spillway to drain the flood discharge plan.

2.1. Watershed modelling

The main components of the HEC-HMS model are Basin model, meteorologic model, control specifications, time series data, and paired data. Running a hydrological model requires a series of rainfall data to represent a watershed or commonly referred to as areal rainfall. Observation discharge data as calibration data to obtain land hydrological parameters. This is necessary considering the value of hydrological parameters, there is no absolute value, and all based on estimates according to land use and watershed characteristics. The accuracy of the results of the hydrological model needs calibration using observational data. Model calibration needs to be done to see the suitability of the observation data and the simulation results. To check the reliability of this model, this study uses statistical indicators using the root mean square errors, RMSE. The equation of each parameter is:

\[
RSE = \left( \frac{\sum (Q_i - Q_o)^2}{\sum (Q_i - \bar{Q}_o)^2} \right)^{1/2}
\]

Where \( Q_i \) and \( Q_o \) are the estimated and observed discharges (m\(^3\) s\(^{-1}\)), respectively; \( \bar{Q}_e \) and \( \bar{Q}_o \) are means of the expected and observed discharges (m\(^3\) s\(^{-1}\)), respectively; \( n \) is the number of data pairs. The correlation coefficient test showed the relationship between simulation results and observed data. The Correlation coefficient was calculated using the following equation [2]:

\[
r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2}(y_i - \bar{y})^2}
\]

Where \( x_i \) is observed data, \( y_i \) is the simulation result, \( x_{mean} \) is mean observed data and \( y_{mean} \) mean simulation result. Rainfall-runoff simulation in each sub-watershed requires several component models, namely:

1. Rainfall model is an input to the watershed system
2. Loss models - to calculate runoff volume (effective rain)
3. Direct runoff models - to transform from effective rain into surface runoff
4. Baseflow models - to calculate the amount of base flow

In this study, the method used in the precipitation component is user’s hyetograph, losses are used the CN method, hydrograph transformation is used SCS Unit hydrograph model, baseflow is used observation data, and routing is used Lag time method.

2.2. Data requirements
Considering that the main components of the model are the basin model, meteorological model, control specification model, time-series data, and paired data, the data that must be prepared in running the HEC HMS model is a watershed and sub-watershed maps, rain data can be in the form of single events or continue as well as paired data in the form of data pairs such as elevation data and storage volume.

The data used in this study consist of the 2016 land use map and the 2011-2031 spatial planning map. Rainfall data is in the form of maximum daily rainfall from Gunungputri, Kalisari and Sumurjurang stations for the period 1996-2016. Daily observed flow data in the AWLR Kalipancur period 2001-2015. While maps of soil types were obtained from the forestry service.

2.3. Description of Kreo watershed
Jatibarang reservoir is located on the Kreo River, 15 km Southwest of Semarang City. Administratively located in the districts of Gunungpati and Mijen. It was built in 2009 and started operating in 2015. The primary function of the reservoir is as a flood control and provider of raw water with a capacity of 2.4 m3/sec, a hydroelectric power plant with a capacity of 1.5 MW and as a nature tourism area.

Technical data of the reservoir are:
   a. Catchment area: 53.0 km2
   b. Inundation area: 189 Ha
   c. Areal of inundation: 1.1 km2
   d. Flood water level: El. +155.3 m
   e. High water level: El. +151.8 m
   f. Normal water level: El. +148.9 m
   g. Low water level El. +136.0 m
   h. Gross storage capacity: 20,400,000 m3
   i. Net storage capacity: 13,600,000 m3
   j. Dead storage capacity: 6,800,000 m3

The spillway data:
   a. Design flood (Q 50 years): 240 m / sec
   b. Max.flood design (Outflow): 1,300 m3 /s
   c. Crest Spillway: El + 148,9 m
   d. Spillway width: 15.0 m
   e. Elevation of emergency spillway: El + 151.8 m
   f. The width of Emergency spillway: 307 m
   g. Spillway channel width: 24 m
   h. Stilling basin: El + 82.50 m
Kreo watershed is one of the sub-watersheds located on the far left side of the Garang watershed with an area of approximately 68 km². The Jatibarang Dam was built on the Kreo river with a catchment area of about 53 km². Based on the map of land cover in 2006, land use is dominated by plantation land (47.40%), wetland (26.95%), forests (11.04%) and settlements (9.27%). While based on the 2031 RTRW map analysis, it is planned that there will be an increase in residential land, an increase in forest land (with the presence of a critical land planting movement) and a reduction in plantation land and rice fields. Land cover data from the two maps reviewed are shown in Table 1:

| No. | Land uses  | Land use of 2016 | Land use 2031 |
|-----|------------|------------------|---------------|
|     |            | Area (ha)        | (%)           | Area (ha)     | (%)           |
| 1   | Forest     | 757.43           | 11.04%        | 860.05       | 12.54%        |
| 2   | Hydrological modelling |                 |               |               |               |
| 3   | Settlement | 635.99           | 9.27%         | 1,217.42     | 17.75%        |
| 4   | Plantation | 3249.61          | 47.40%        | 1,812.06     | 26.43%        |
| 5   | Rice field | 1848.1           | 26.95%        | 1,726.02     | 25.17%        |
| 6   | Bushes     | 63.50            | 0.93%         | 0.56         | 0.008%        |

2.4 Hydrological modelling
Kreo Watershed Modelling is shown in Figure 1. Running model is carried out with different land-use condition map scenarios, namely the 2016 map and 2013 spatial plan. The different data in the two situations are watershed hydrological parameters. Watershed hydrological parameters in succession in each scene are: initial CN is 66.4 and predicted CN is 69; Initial storage (S) is 128.48 mm and S prediction is 114.2 mm; Initial abstraction (IA) was 25.7 mm and predicted IA was 22.8 mm and initial imperviousness was 9.27% and predicted imperviousness was 17.75%. There is no change in reservoir characteristic data from the two scenarios.

![Figure 1. Hydrological modelling of Jatibarang Reservoir in Garang Watershed](image)

2.5 Model Simulations
The rain data used as input for the HEC HMS model is in the form of design rainfall with return periods 50 years and 1000 years. The design rainfall data is based on an analysis of the frequency of regional rainfall from three rain posts in the Kreo watershed, namely the Kalisari, Gunungpati and Sumurjurang posts. The rain-runoff transformation model used the SCS unit hydrograph method. The hydrological parameters of the watershed used CN parameters, initial abstraction, storage coefficient, and imperviousness. The rain distribution used the Mononobe method with an average rain duration of
6 hours. Model calibration used observation discharge data at the Kalipancur ALWR post in the Kreo watershed. The designed rainfall in various return periods is shown in table 2.

| Time (hr) | Distribution | R$_{50}$ | R$_{100}$ | R$_{1000}$ |
|----------|--------------|---------|----------|-----------|
| 1        | 55.03        | 115.36  | 126.32   | 162.56    |
| 2        | 14.30        | 29.98   | 32.83    | 42.25     |
| 3        | 10.03        | 21.03   | 23.03    | 29.64     |
| 4        | 7.99         | 16.74   | 18.34    | 23.60     |
| 5        | 6.75         | 14.14   | 15.48    | 19.93     |
| 6        | 5.90         | 12.36   | 13.53    | 17.42     |

| Designed rainfall (mm/hr) | 209.62 | 229.54 | 295.39 |

3. Results and Discussions

The simulation of the HEC HMS model in the Jatibarang reservoir is carried out by inputting the design rain data, the characteristics of the Kreo watershed expressed in the hydrological parameters, as explained previously. Reservoir data that is used as a limitation is the volume reservoir curve and reservoir elevation, the elevation of crest and width of spillway and crest dam elevation.

Evaluation of changes in land use in the Kreo watershed based on discharge can be reviewed based on the magnitude of the designed flood discharge. In the initial conditions of Jatibarang reservoir construction, the magnitude of the Q$_{50}$ design discharge was 240 m$^3$/s. Based on the latest rain data and land use map in 2016, Q$_{50}$ flood discharge increased to 253 m$^3$/s. Furthermore, using an RTRW land use map, the amount of discharge is predicted to increase to 286.8 m$^3$/s. This increase in discharge is used as a basis for evaluating the performance of the spillway, which illustrates the ability of the reservoir to drain excess runoff that cannot be retained.

The evaluation of the performance of the main spillway is reviewed based on the increase in water level to the peak elevation of the lighthouse and the availability of sufficient freeboard. Initially planned water level elevation at Q$_{50}$ at +151.5 m. The results of the water level analysis on the Q$_{50}$ flood discharge based on the spatial planning map, namely at +152.2 m elevation. An increase of 0.72 m. At this elevation, the emergency spillway is working, because the crest elevation is at +151.8. When compared with the crest dam elevation +157.00, the dam is quite safe. An evaluation also needs to be done for the flood discharge plan for Q$_{1000}$. In this flood discharge, water level elevation is about +153.7 m.
4. Conclusion

Based on the results of the evaluation of land use maps and hydrological analysis using data with time series up to 2016, it can be concluded several things. An increase in the value of hydrological parameters for CN and imperviousness, as well as a decrease in initial storage and initial abstraction increasing flood discharge. The impact of increased Q50 flood discharge, resulting in an emergency spillway designed to flow flood discharges greater than Q50, must function at debits smaller than Q50. An increase in the designed flood water level that was initially at +151.8 m elevation, with changes in hydrological parameters, Q50 water level increased to an elevation of +152.2 m. In general, reservoirs are quite safe from changes in discharge due to land use, but an emergency spillway that functions faster than previously planned shows the reliability of flood control is reduced.

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