Suitability Conservation Types Analysis of Panglima Besar Soedirman Reservoir

Widodo Brontowiyono^{1,*}, Rizal Kartika Wardhana¹, and Dhandhun Wacano²

¹Department of Environmental Engineering, Universitas Islam Indonesia, Yogyakarta, Indonesia

²Center for Climate Change and Disaster Studi (PuSPIK), Department of Environmental Engineering, Universitas Islam Indonesia, Yogyakarta, Indonesia

Abstract. Mrica Reservoir located in Banjarnegara Regency is a multipurpose reservoir. Based on the report of PT Indonesia Power Unit Pembangkitan (UP) Mrica in 2016, the sediment of Mrica Reservoir has entered the critical phase as it reached 114.25 million m³ and the value of land-cover index of Mrica reservoir was 80% of the total watershed area with the average sedimentation rate reaching 4.09 million m³ per year. It is estimated that the reservoir will be full of sediment by 2021. The main cause of the high rate of sedimentation in Mrica reservoir is the changes in land use and agricultural-plantation activities in the upper river areas and along the river flow of Serayu River, Merawu River, and Lumajang River. This study aimed to determine the appropriate type of conservation for Mrica Reservoir. The method used was the Analytical Hierarchy Process (AHP), in which the determination of conservation efforts was based on secondary data and observation. According to the current condition of Mrica Reservoir, the planned conservation efforts include two types, namely non-structural conservation and structural conservation. If the conservation begins in 2019, the total sediment in 2021 will decrease to 74% and it is predicted that the sediment will be exhausted by 2056.

Keywords: a reservoir; sediment; land use change; conservation

1 Introduction

Panglima Besar Jenderal Soedirman Reservoir or also known as Mrica Reservoir in Banjarnegara Regency is a multipurpose dam. In addition to the function as a hydroelectric power plant (PLTA), this reservoir is also a source of water for rice field irrigation, fishery system for fishponds, and tourism objects. The reservoir has an installed electricity capacity of 180.93 MW with 957-km² water catchment area (DTA) and an initial capacity of 148.29 million m³. With a sedimentation rate of 2.4 million m³/year, the reservoir is expected to operate for around 60 years with the operational life ending in 2049 (Wulandari, 2007).

Sedimentation has an impact on the decline in capacity and operational life of a reservoir, thus requiring an effective reservoir management system. When there is heavy rainfall, eroded sediment transported by the river collects in the reservoir, thereby reducing

* Corresponding author: widodo.brnto@uii.ac.id

reservoir volume, forming a delta around the reservoir, changing river flow, losing energy, as well as damaging reservoir inlet and outlet which affects the reservoir working system (Zende, 2018).

Accumulation of sediment in a reservoir affects its functions, such as provision of water for electricity generation, raw water, irrigation, and flood control. In addition, the amount of sediment in a reservoir puts a greater burden on the reservoir construction, affecting therefore the operational life of the reservoir (Wahyudi, 2004).

PT Indonesia Power Unit Pembangkitan (UP) Mrica in its 2016 report stated that Mrica reservoir sediment has come to a critical phase since it has reached 110.69 million m³ or about 75% of the reservoir volume. The average sedimentation rate from the initial year of operation in 1988 to 2015 amounted to 4.09 million m³/year. This rate is about twice as high as what was planned and therefore reduces the reservoir life to half (30 years instead of 60 years). Conservation activities have been carried out by PT Indonesia Power UP Mrica, such as sediment flushing using Drawdown Culvert (DDC), ejecting flushing through the spillway and reforestation in the upper reaches of Mrica watershed. However, the results remained ineffective in suppressing the rate of sedimentation. The interventions were even considered detrimental to the company because flushing requires a large amount of water, with a ratio of the amount of sediment discharged to the water needed being 1:10. This condition has forced PT Indonesia Power UP Mrica, the Regional Government of Banjarnegara Regency, the community, and various related elements to work together to overcome the problem of sedimentation in Mrica Reservoir (Darsono, 2016).

Based on this problem, a particular study is required to determine the reduction of sedimentation rate and reservoir conservation to make later mitigation efforts more effective. It is expected that the results of this study can become a reference in the efforts to conserve and maintain Mrica reservoir.

2 Method

2.1 Data Collection

The data used in this study was secondary data obtained from relevant agencies. The data needed in this research includes:

1. sedimentation rate;
2. suspended load data;
3. characteristics of sediment;
4. topographic map;
5. land-use map.

2.2 Data Analysis

In this study, the analysis was carried out by investigating the condition of Mrica reservoir based on the data collected and observation. After that, a literature study was conducted on reservoir conservation efforts based on the characteristics and conditions of Mrica reservoir. The best conservation efforts were analyzed using the AHP (Analytical Hierarchy Process) method with the following steps:

- A. Develop a hierarchical structure of problems.
The main tool of the Analytical Hierarchy Process (AHP) model is the hierarchy of the problems that are resolved.

- B. Make a pairwise comparison matrix.
- C. Calculate the priority of each variable.
The steps are as follows:
 - 1) Make pairwise comparisons of each criterion.
 - 2) The results of each paired comparison are displayed in a pairwise comparison matrix (pairwise comparison).
 - 3) Share each element in a particular column with the value of the number of columns.
 - 4) The results are then normalized to obtain the eigenvector matrix by averaging the number of rows.
- D. Calculate the priority of each variable after knowing the weight of each variable

2.3 Determination of Conservation Efforts

Determination of the conservation efforts for Mrica reservoir was divided into two parts, namely technical and conservation in a non-technical manner based on the nature or extent of damage to each parameter. Technical conservation includes construction of control structures and determination of sediment dredging techniques in reservoirs, while non-technical/semi-technical conservation includes such conservation activities as vegetative and social handling.

3 Results

3.1 Analysis of the Condition of Mrica Reservoir

The erosion and sedimentation in the reservoir are due to the high changes in land function in Mrica reservoir watershed.

Table 1. Recapitulation of Land-Use Change in Mrica reservoir watershed 2001-2009

Land Use	2001	2009	Change
	Km2	Km2	%
Homogeneous Forest	229.13	67.12	(-) 70.71%
Heterogeneous Forest	194.08	74.74	(-) 61.49%
Open Land	154.07	98.14	(-) 36.30%
Other Plantations	0.14	93.3	(+) 66542.86%
Tea Plantation	0.83	8.17	(+) 884.34%
Gardens/fields	91.35	317.62	(+) 247.70%
Rice Fields	15.74	54.04	(+) 243.33%
Settlement	28.66	60.8	(+) 112.14%

Source: Hanafi, 2015

This land-use change caused an increase in the rate of erosion and sedimentation in Mrica reservoir, resulting in the presence of water hyacinth (*Eichhornia crassipes*), increased total sediment in the reservoir, and irrigation system disruption because the sediment volume increased while the volume of water in the reservoir decreased, thus

affecting the operational time of Mrica reservoir. As a result, it requires handling or conservation in the upstream area or the source of erosion and in Mrica reservoir.

Table 2. Assessment of Reservoir Conditions

Parameters	Level of Damage		
	Low	Mid	High
Upstream Erosion	-	-	✓
Middle Erosion	-	✓	-
Downstream Erosion	✓	-	-
Sedimentation Rate	-	-	✓
Amount of Sediment	-	-	✓
Change in Land Function in Upstream	-	-	✓
Total	1	1	4

Table 1 suggests that the watershed and reservoir conditions are in the high level of damage. Therefore, effective conservation efforts are necessary which must involve the society and be sustainable. Conservation management is carried out in two types, namely non-structural conservation and structural conservation.

3.2 Hierarchy Structure of Conservation Method Selection

This study has objectives, alternatives, and various criteria whose positions must be clarified in the hierarchical structure. The structure of the hierarchy is prepared by conducting literature studies on reservoir conservation and analysis of secondary data that has been collected previously. After a hierarchical structure is arranged, weighing the level of importance in compiling a pair-wise comparison matrix is carried out. Weighing is based on the analysis of secondary data and the results of observations in the location.

The following are various hierarchical elements and structures (Figure 1) that have been determined based on the analysis of secondary data and the results of observations in the location.

Fig. 1. AHP Structure Selection of Conservation Type for Mrica Reservoir

3.3 Non-Structural Conservation

Erosion can be caused by several factors such as climate, topography, soil characteristics, and vegetation conditions. Vegetation greatly affects the level of erosion that occurs and there is a need to deal with land in the upper watershed area by improving the quality of vegetation, especially in areas with heavy to very heavy erosion. The function of vegetation is that it can strengthen soil structure due to the spread of plant roots and influence the flow of rainwater runoff on the surface. Vegetation conservation planning is carried out based on land use maps and land slope maps (Figure 2) in the upper watershed.

Fig. 2. Mrica reservoir watershed land-use map of 2009

The following non-structural conservation activities can be carried out to prevent the rate of erosion while improving the economic quality of the community around the watershed:

3.3.1 Socialization

The socialization activities were carried out in stages involving the people in the upper watershed and those living around the hydropower reservoir of PB Soedirman. These socialization activities were conducted in three Mrica watersheds, including Serayu river, Merawu river, and Lumajang river.

Fig. 3. Socialization Activity in Mrica Watersheds

3.3.2 *Hyacinth Plant as Fish Food*

Water hyacinth (*Eichhornia crassipes*) plants contain 3.2% nitrogen and have a C/N ratio of 15. The content of water hyacinth plant is very effective to be used as herbivorous and omnivorous fish food. According to data from the Indonesian Central Bureau of Statistics, in 2015 there were 1.603.800 fish with a total weight of 36.430 kg successfully harvested and cultivated on a land with an area of 23.05 Ha. The use of hyacinth (*Eichhornia crassipes*) as a raw material for fish food is very helpful for the society as food is given as much as 3% per day of the total weight of fish (Widyastuti, 2012). If the total weight of fish production is 36.430 kg, then the need for fish food (pellet) is 1.093 kg per day with 15% hyacinth (*Eichhornia crassipes*) content in the pellet, resulting in the need for 164 kg of hyacinth per day. Therefore, the use of fish can reduce hyacinth plant by 164 kg per day.

Fig. 4. Fish Ponds around Mrica Reservoir

The production of pellet can be profitable for PT Indonesia Power UP Mrica. It can also provide economic benefits for the people in the area around the reservoir by replacing the pellet commonly purchased with water hyacinth pellet for fish food. Therefore, this activity can involve the surrounding communities while increasing the number of fish in the reservoir and the potential for handling hyacinth blooms.

3.3.3 Reforestation

Reforestation is carried out in stages in the upstream of reservoir watershed and around Mrica reservoir (Figure 5). This activity involves and empowers the surrounding community. The company helps to provide tree seedlings requested by the community and later the community itself will take care of and have the benefits from the tree.

Fig. 5. Reforestation Activities Report (Source: PT. Indonesia Power UP Mrica, 2017)

3.3.4 Conservation Field School

This training and community empowerment activity along Mrica watershed involve a land management/cultivation program by planting hard-trunked plants, such as coffee, to reduce the impact of erosion.

Fig. 6. Conservation Field School Activities

In the conservation field-school activities, coffee plants were chosen because 90% of the roots of coffee plants are concentrated in the soil layer between 0-30 cm of depth. This results in the formation of a good root tissue in the surface layer of the soil, producing well-

bonded soil by the roots. In lands with 50% to 60% slope, coffee plants can reduce the erosion rate by 81% (Fahmuddin, 2002).

In addition to planting coffee plants, it is necessary to plant soil cover crops that aim to withstand the splashing of rainwater and the flow of water above the soil surface. The selected cover crops are sweet potato plants because these plants do not have a large impact on coffee production. Sweet potato reduces the erosion rate by up to 41% (Sumarni, 2006).

3.4 Structural Conservation

Sediment conservation is structurally carried out to manage reservoir sediment effectively and efficiently. Sediment handling methods are dissected based on volume, technical, and handling location. The following is detail on structural sediment handling:

3.4.1 Flushing

Flushing through the Drawdown Culvert (DDC) according to established procedures has been used and it requires a lot of water, with a ratio of the amount of sediment discharged to the water needed reaching 1:10 (Darsono, 2016). Flushing is an effort to overcome sediment collection around Power Intake. It is carried out only if the sediment elevation is above the DDC threshold, if it is still below then no flushing is performed (If the sediment elevation $>+187\text{ m}$, then flushing is done immediately). Flushing is also possible if the inflow of water that enters the dam is $\geq 1000\text{ m}^3$.

Source: PT. Indonesia Power UP Mrica, 2016
Fig. 7. Intake DDC in 2015

3.4.2 Check Dam

Check dam construction is focused on locations with heavy and very heavy erosion rates. Here are the basic considerations determining the location of the check dam (Table 3):

Table 3. Consideration for Determining the Location of Check Dams

No	Locations	Erosion Level	Slope
C1	Upstream	Very Heavy	>25°-45°
C2	Upstream	Very Heavy	>15° -25°
C3	Upstream	Very Heavy	>25° -45°
C4	Upstream	Very Heavy	>15° -25°
C5	Middle	Heavy	>15° -25°
C6	Middle	Very Heavy	>25° -45°
C7	Downstream	Heavy	>8°-15°
C8	Middle	Heavy	>8°-15°
C9	Middle	Heavy	>8°-15°

Table 3 indicates that the check dam location is based on the level of erosion and the height of the slope.

Fig. 8. Map of Check Dam Location

In research conducted by Mishra (2006) and Karim (2014) using Soil and Water Assessment Tool (SWAT) software, the use of check dam to control sedimentation rate can reduce it by more than 64%. Construction of check dams, besides being able to reduce the rate of erosion, can also function as a place to deviate and accommodate rainwater. As a result, during the dry season, farmers around can utilize check dams as a source of water for watering plants.

3.4.3 Sediment Dredging

The current Land Cover Index of Mrica reservoir production has reached 80% of the total watershed area with an average sedimentation rate of 4.09 million m³ per year which is equivalent to 11.197 m³/day. Under these conditions, the reservoir will be full of sediment by 2021. Excess sediment can be dredged using Auger Cutter Suction Dredger (ACSD) (Figure 9).

Source: Dredgeyard.com

Fig. 9. Auger Cutter Suction Dredger

Based on the average sedimentation rate, it is planned to procure two ACSD dredges with a total sediment dredging capacity of 7.008.000 m³/year. With the ACSD dredgers expected to operate in 2019, the total sediment load will be reduced to 74% of the total reservoir volume in 2021 and completely removed by 2056.

3.5 Calculation of the Analytical Hierarchy Process (AHP)

In this study, the determination of the best conservation method was calculated using the AHP method. The division of importance level scales is in accordance with the AHP scale, namely 1 to 9 based on secondary data analysis and observation on the comparison of each alternative with the specified criteria, namely reduction volume, ease of implementation, implementation time, and economic analysis. The results of AHP matrix calculation are as follows:

0.026	0.190	0.114	0.194	X	0.563	Socialization	0.089
0.128	0.095	0.159	0.230			Hyacinth Plant as Fish Food	0.133
0.205	0.119	0.091	0.173			Reforestation	0.169
0.179	0.143	0.114	0.144			Conservation Field School	0.160
0.077	0.214	0.205	0.115			Flushing	0.127
0.154	0.071	0.136	0.086			Check dam	0.127
0.231	0.167	0.182	0.058			Sediment Dredging	0.195

According to the calculation results, it can be stated that the conservation method using ACSD dredger is the best choice as an alternative to handling the sediment of Mrica Reservoir with a total value of 0.195. Dredging using ACSD dredgers can reduce sediments in the reservoir by 7.008.000 m³/year and the dredging process can be done easily and quickly, but it requires substantial costs for procurement, operations, and maintenance. Therefore, other alternative conservation methods are still implemented to reduce the total sediment entering the reservoir, maintain Mrica watershed, and increase the economy of the community in the watershed and Mrica Reservoir.

4 Conclusions

- 4.1 The average sedimentation rate of Mrica reservoir is 4.09 million m³ per year. The main cause of the high sedimentation rate is changes in land function, in which the greatest land depreciation is the land function as a homogeneous forest, reaching 71%.
- 4.2 The current condition of Mrica reservoir has entered a critical phase where the total reservoir sediment has reached 114.25 million m³ (75% of the reservoir volume).
- 4.3 Two planned conservation efforts include non-structural conservation and structural conservation. If the conservation begins in 2019, then the total sediment will decrease to 74% in 2021 and it is predicted to be exhausted in 2056.

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