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Assessment of soil loss using RUSLE method in Mrica Reservoir catchment, Central Java, Indonesia

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Abstract: The Indonesian government has identified the Serayu Watershed as a priority area for restoration within the National Mid-Term Development Plan. One of the significant challenges in this region is the high level of soil erosion, which threatens the overall ecosystem. This study aims to estimate the amount of soil loss in the Mrica Catchment using the Revised Universal Soil Loss Equation (RUSLE) Method. Various data sources were utilized, including soil type, rainfall, land cover, Digital Elevation Model, and conservation data. Geographic Information System (GIS) techniques were employed to calculate the critical factors required by the RUSLE Method, including soil erodibility (K), rainfall erosivity (Ri), slope length and steepness factor (LS), and cover management and conservation factor (CP). This research provides critical information for land management in Mrica Catchment. These factors were used to estimate soil loss in the Mrica Catchment, revealing a range between 62,553 tons per year (t/y) and 21,323,311 t/y, with an average value of 443.90 ton per hectare per year (t/ha/y). These results indicate high erosion potential based on the Classification of Erosion Hazard (HER). This study provides critical information for land management and offers suggestions for devising effective strategies to mitigate sedimentation impact in the Serayu Watershed. The highest soil loss values according to the RUSLE Method, both under the Environmental and Management Variable, are observed in the same location, namely, in the north of Mrica Catchment. The findings emphasize the urgent need for erosion control measures and sustainable land management practices in this priority restoration area.

Keywords: Mrica reservoir, RUSLE, soil loss

1. Introduction

Erosion and sedimentation are two significant problems that are influenced by hydrodynamic activity and sediment transport, which brings many hydrological changes to the watershed (Novico and Priohandono, 2012). Several factors affect the increase in erosion rates and accelerate its rate, including the increased population, anthropogenic needs, climate change, and the intensity of economic activity (Abu Hammad, 2011; Pambudi *et al.*, 2021). Soil erosion may be to blame for up to 80% of the degradation issue on agricultural land (Abu Hammad, 2011; Angima *et al.*, 2003). An increase in soil erosion has a linear relation with the increase in sedimentation, resulting in reservoir siltation (Abdul Rahaman

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et al., 2015). Reservoir sedimentation impacts the life of the reservoir, which can decrease by more than 65% and affect hydroelectric power purposes (Abdul Rahaman *et al*., 2015; Cantik *et al*., 2021; Chen and Tsai, 2017).

The negative impacts of erosion and sedimentation have been a concern of the Indonesian government. In 2009, the Indonesian government identified 108 critical watersheds in Indonesia to restore the condition of these watersheds (BAPPENAS, 2015). In line with the National Medium-Term Development Plan (RPJMN), of the 108 critical watersheds that have been observed, the Government of Indonesia will first prioritize 15 priority watersheds for restoration, one of which is the Serayu watershed (BAPPENAS, 2015). Soil and water conservation measures and efforts are needed to deal with this problem after analyzing the erosion hazard level of the Serayu watershed.

The Serayu River is one of the primary rivers that contribute significantly to the sedimentation of the Mrica Reservoir, a multipurpose reservoir. The Serayu River's route is heavily used for communities, agriculture, and other human activities, making it highly prone to its occurrence. Because of human activity, it is incredibly prone to significant contamination. One of the problems in the Serayu watershed that causes sedimentation in the Mrica Reservoir is damage in the upstream area, where there has been land degradation and an increase in erosion (Ainun Jariyah and Budi Pramono, 2013).

Problems in the Serayu Watershed are also triggered by land use. The existence of farming methods that ignore land conservation can also cause significant problems by increasing the rate of soil erosion (Eisenberg and Muvundja, 2020; Lesmana, 2020). In addition to land use and conservation issues, the catchment area of Mrica Reservoir Water is also a highland area with relatively high rainfall of roughly 4,000–4,500 mm/year, which might worsen erosion rates (Lembaga Kerjasama Fakultas Teknik UGM, 2015). This erosion problem caused a significant sedimentation increase in Mrica Reservoir. At the end of 2004, the remaining volume of the Mrica Reservoir was 78.05 million m^3 or around 55.26% of the initial condition (Cantik *et al*., 2021).

The RUSLE method calculates soil loss in places with significant surface flow but is not intended for areas without surface flow, while the MUSLE Method working principle is different from USLE. The erosion calculation produced by USLE Method is based on rainfall. MUSLE Method does not consider rainfall a source of erosion energy but uses runoff intensity to simulate the processes of erosion and sediment formation(Koirala *et al*., 2019). A comparison of erosion rate predictions utilizing the USLE, MUSLE, and RUSLE Methodologies reveals that the RUSLE Method produces more consistent results compared to all methods (Hanafi and Pamungkas, 2021). Using the RUSLE Method approach to assess erosion rates demonstrates that the RUSLE Method can provide effective erosion control strategies in severely damaged parts of the Serayu watershed (Lesmana, S.B., 2020). Therefore, the objective of this study is to predict the amount of soil loss that occurs in the Mrica Catchment using the RUSLE Method. The estimated soil loss can be used as a reference in considering effective and efficient efforts to be carried out to control reservoir sedimentation in Mrica Reservoir.

2. Materials and Methods

2.1. Study area

The research area of this study is Mrica Reservoir Catchment, which is located in the Southern Section of Central Java Province and covers an area of 98,703 Ha, with 54.36% of the land in Wonosobo Regency and 45.64% in Banjarnegara Regency. Three main rivers that play a significant role in contributing sediment to Mrica Reservoir are the Serayu River, Merawu River, and Lumayang River. The Mrica Reservoir is geographically located at coordinates 07°05′-07°4′N Latitude and 108°56'-110°05' E Longitude. The Mrica Reservoir is represented in Figure 1.

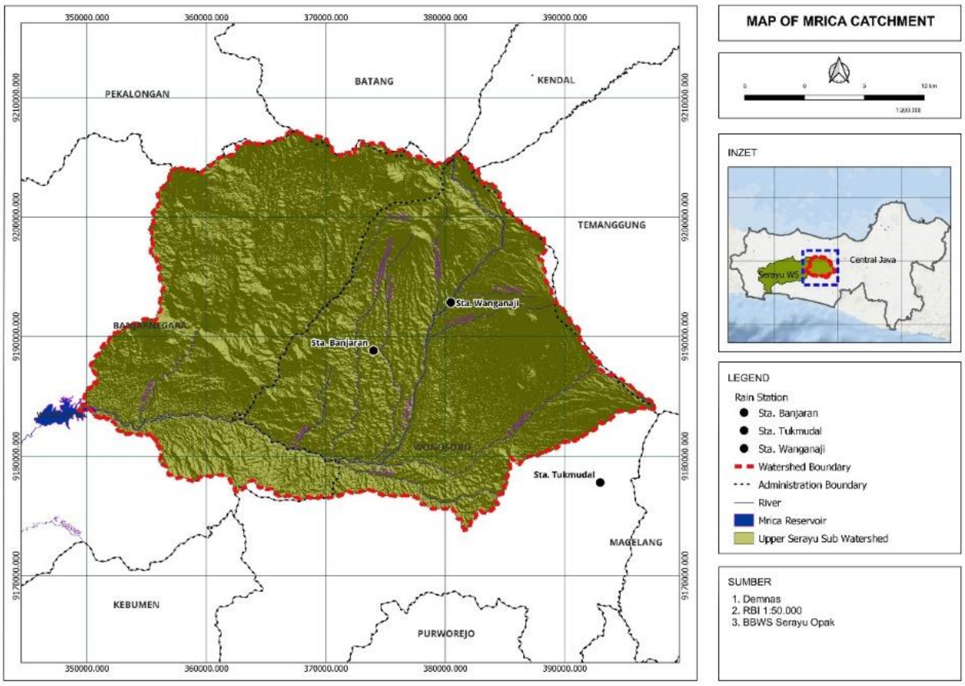

Figure 1. Mrica reservoir catchment area, the Upstream Serayu Watershed

2.2. Data collection

This study relied on secondary data and did not include any soil samples from the site. The secondary data used in this study are monthly and annual precipitation data from 2012 to 2016 at three rainfall stations, namely Banjaran, Tukmudal, and Wanganaji Rainfall Stations, with coordinates as shown in Table 1. We used Digital Elevation Model (DEM) data with 8 meters spatial resolution (Badan Informasi Geospasial, n.d.) obtained from DEMNAS. The DEM data was used to derive slope and slope length data, and it will also be used to delineate the watershed boundary. Soil type and land cover data were derived from vector data by Balai Besar Wilayah Sungai Serayu Opak dan Kementerian Lingkungan Hidup dan Kehutanan. The land management and conservation data (CP) were determined based on Chay Asdak, 1995 (Saputra *et al*., 2020). All these data will be processed using QGIS as Geographic Information System (GIS) software to calculate the soil loss using the RUSLE Method. Vector data is processed using GIS to be converted into raster data, and the scale is adjusted according to DEM spatial resolution.

Table 1. Coordinate of Rainfall Stations

Station	Coordinate	
	Latitude	Longitude
Banjaran	-7.3911	109.963
Tukmudal	-7.3282	109.930
Wanganaji	-7.2917	109.925

2.3 Soil Loss Analysis

In this study, the RUSLE Method estimates soil loss in the Serayu Watershed. The RUSLE, or Revised Universal Soil Loss Equation, is an erosion prediction method used to estimate the annual soil loss carried by water runoff from a particular land slope, considering a specific cropping and management strategy within a defined area. Its extensive utilization has underscored the effectiveness and credibility of the RUSLE method for achieving erosion-related objectives (Christanto *et al*., 2018). Equation 1, representing the RUSLE Method, is employed to compute soil loss (Renard, 1997).

$$A = R \times K \times LS \times C \times P \quad \text{....(1)}$$

where A represents the annual average soil loss, expressed in metric tons per hectare per year (t/ha/y), LS denotes the factor that accounts for slope length and steepness, R stands for the rainfall erosivity factor, measured in megajoules per millimeter per hectare per hour per year (MJ mm/ha/h/y), P represents the land conservation factor, K signifies the soil erodibility factor, quantified in metric tons per hectare per hour per hectare per megajoule per millimeter (t/ha/h/ha/MJ/mm) and C represents the land cover management factor (Abdul Rahaman *et al.*, 2015).

To determine the value of R (erosivity) from the RUSLE Method, a formula devised by Wischmeier and Smith (1978) and then updated by Arnoldus (1980) (Panagos *et al.*, 2015) can be utilized (Eisenberg and Muvundja, 2020). Equation 2 shows the erosivity formula.

$$R = \sum_{i=1}^{12} 1.735 \times 10\left(1.5 \log_{10}\left(\frac{P_i^2}{P}\right) - 0.08188\right) \quad ....(2)$$

where the rainfall erosivity factor (MJ mm/ha/h/y) is represented by R, the annual rainfall (mm) is represented by P, and Pi represents the monthly rainfall (mm). Meanwhile, the soil erodibility factor (K) represents the ability of soil particles to weather and move due to precipitation's kinetic energy. Several physical and chemical features of the soil determine the ease with which soil erodes. These erodibility factors are indices that are used to forecast long-term average soil loss due to sheet and rill erosion under agricultural systems and conservation strategies. The main soil type at a location determines soil erodibility values.

Eq. 3 may be used to implement the LS factor (Bizuwerk *et al.*, 2003). In which FA indicates flow accumulation obtained from the GIS hydrology analysis tool, CS is cell size, m is 0.5 for slope angle >5%, 0.4 for slope 3%-5%, 0.3 for slope 1%-3%, and 0.2 for slope <1%, and s is the slope in percentage.

$$LS = \mathrm{Pow}\left(\frac{FA \times CS}{22.13}\right)^m \times (0.065 + 0.045s + 0.0065s^2) \quad ....(3)$$

GIS software is used to support the calculations and map renderings in this study. The results were processed in GIS using Inverse Distance Weighted (IDW) analyst tools to interpolate values. Geostatistical estimation and extensive calculations will be used, considering the statistical and spatial heterogeneity of the data. For rainfall erosivity factors, by examining point samples to create a continuous surface of erosivity, it studied rainfall erosivity variables throughout spatial space. This surface of erosivity is characterized in terms of both spatial continuity and a model of how it can vary.

There are two (2) components in the formulation of the RUSLE Method in this study, namely Environmental Variables, which consider that all variables in the calculation are constant, and Management Variables, which assume that factors C and P are two factors which can be seen in Table 2.

Table 2. Land management and conservation (CP) (Asdak, 1995 in (Saputra *et al.*, 2020))

No	Land Use	CP Value
1	Scrubland	0.30
2	Secondary Dryland Forest	0.01
3	Forestry plantation	0.05
4	Habitation	0.95
5	Plantation	0.50
6	Dryland farming	0.28
7	Dryland farming (mixed)	0.19
8	Field	0.01
9	Open space	0.95

3. Results and discussion

3.1 Rainfall Erosivity

Calculation of rainfall erosivity in Mrica Catchment using Equation 1 by calculating monthly and annual rainfall data from three stations as shown in Table 1. The rainfall data used is from 2012 to 2016. According to the result of this study, the rainfall erosivity factor in the Mrica Catchment ranges from 317.25 to 360.94 (MJ mm/ha/h/y).

3.2 Soil Erodibility

Soil or geological characteristics can affect the soil erodibility factor, i.e., porosity, parent material, texture, structure, etc. (Schwab *et al.*, 1993). The Mrica Catchment contains various soil types, including grumosol, regosol, alluvial, and latosol. The soil erodibility factor for each soil type is the smallest at 0.115 and the largest at 0.259, as shown in Table 3.

Table 3 Soil Erodibility

Soil Type	Area (Ha)	Soil Erodibility (K)
Alluvial	924.76	0.259
Grumusol	5,770.66	0.176
Latosol	88,878.43	0.115
Regosol	3,337.73	0.590

The largest soil type in the Serayu Subwatershed is latosol, with an area of 88.878.43 Ha and a K value of 0.115, followed by grumosol, with an area of 5770.6 Ha and a K value of 0.176, and regosol, with an area of 3337.3 Ha and the same K value as latosol, which is 0.115. In contrast, the smallest soil type is alluvial, with an area of 924.76 Ha and a K value of 0.259. In this study, the soil erodibility factor that has been determined becomes input data for GIS to obtain a soil erodibility map that can be seen in Figure 4.

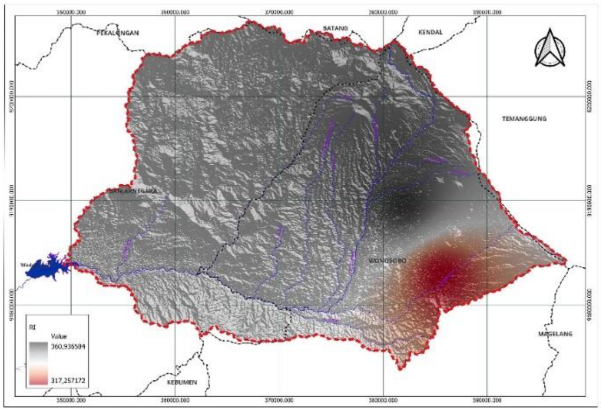

Figure 2. Annual Rainfall Erosivity

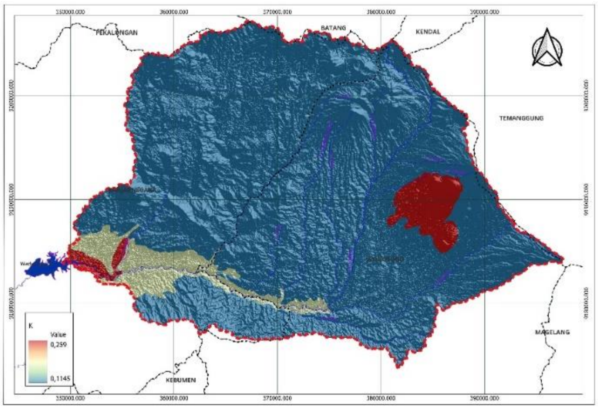

Figure 4. Soil Erodibility

3.3 Slope Length and Steepness Factor

The variable slope length and steepness factor (LS) is used to calculate how much soil is lost in the watershed, implying that the LS factor controls the volume of soil lost. According to Eq. 1, if the LS value is greater, the soil loss in the watershed will also be greater, and vice versa. Elevation data from the Mrica Catchment is required to calculate the LS factor.

From calculations on GIS, it was found that the value of the LS factor varied between 0-54. The LS map is processed using GIS as shown in Figure 5 below.

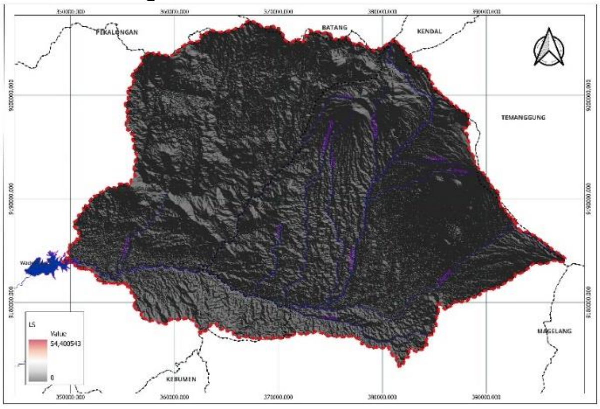

Figure 5. Steepness Factor and Slope Length

3.4 Conservation Factor and Cover Management

The factor values of conservation practice (P) and cover management (C) also determine the amount of soil loss in a watershed. After topography, land cover is the second most crucial factor determining soil loss since it can intercept rainfall and increase infiltration (Koirala *et al.*, 2019).

A higher C value indicates that the watershed is susceptible to significant soil erosion (Abdul Rahaman *et al.*, 2015). The P factor is reduced by employing conservation strategies that minimize runoff volume and velocity (Panagos *et al.*, 2015). The P factor is between 0 and 1, with a P value around 0 showing high-quality conservation practices (Morgan *et al.*, 1998). Soil and Water Conservation (SWC) practices must be developed and verified to establish the most acceptable SWC strategies suited for land cover (Tian *et al.*, 2021).

The data for land conservation and land cover in Mrica Catchment was obtained from the Ministry of Environment and Forestry. Table 4 shows the land cover in the Mrica Catchment. According to Table 4, the land cover with the most significant percentage is dryland farming, which is 39.3% of all total area in Mrica Catchment. The cover management and conservation factor (CP) varies between 0.01 to

0.95. It is then processed with GIS to produce the CP map shown in Figure 6.

Table 4. Land Cover

Classification	Area (Ha)
Shrubs	532.76
Secondary dryland forest	3,188.94
Forestry plantation	10,925.50
Habitation	3,766.31
Plantation	375.81
Dryland farming	38,823.22
Dryland farming (mixed)	34,251.73
Field	6,428.70
Open space	410.16
Total	**98,703.13**

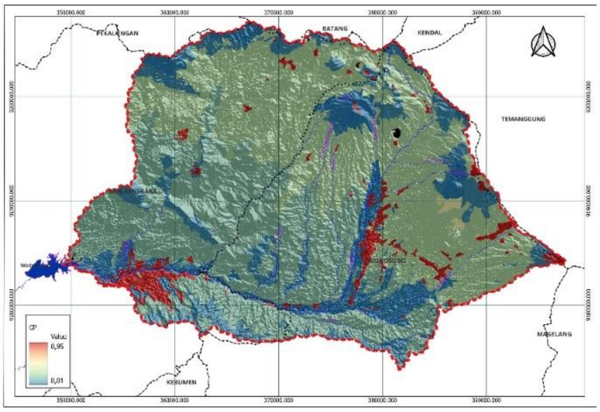

Figure 6. Cover Management and Conservation Factor

3.5 RUSLE's Soil Loss

The outcomes of soil loss will be classified as environmental variables and management variables. Environmental Variable is a map that shows soil loss taking into account the CP factor, while Management Variable is a map that takes into account the CP factor, which is a factor that can change at any time and cannot be used as a benchmark in calculating soil loss, so the CP value is ignored. Considering the CP (Environmental Variable) value, the soil loss map is presented in Figure 7.

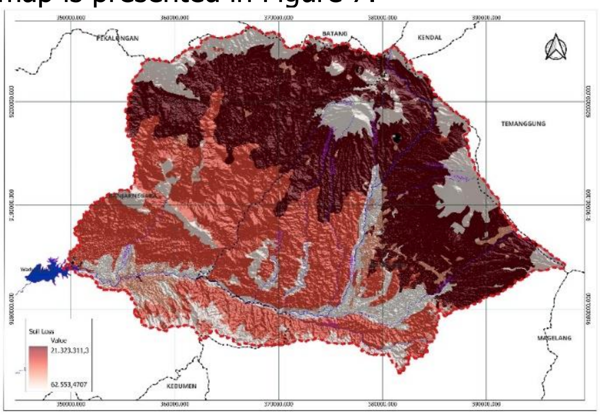

Figure 7. Soil Loss (Environmental Variable)

Based on Figure 7, it can be seen that soil loss values vary between 62,553 tons/y to 21,323,311 tons/y. The Mrica Catchment analyzed in this study had a total area of 98,703.13 Ha; hence, the total soil loss was 443.90 tons/ha/y. Following the Ministry of Environment and Forestry's Erosion Hazard Classification (EHR), soil loss in the Mrica Catchment is high.

On the Management Variable, the amount of soil loss without considering the CP value or the CP value is ignored. CP factor is related to land cover and conservation data, which are dynamic and cannot be assumed to be constant throughout the year. The soil loss map for the Management Variable can be seen in Figure 8.

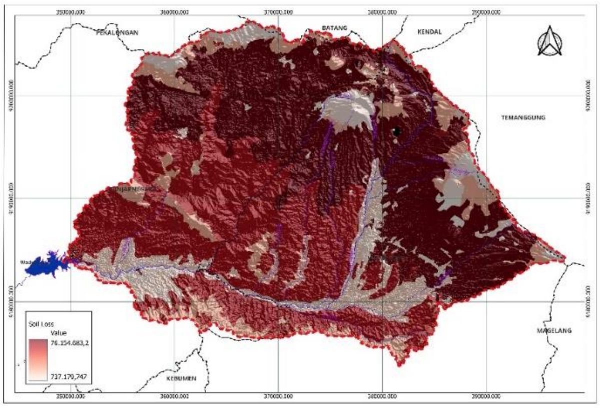

Figure 8. Soil Loss (Management Variable)

4. Conclusion

This study has demonstrated soil loss estimation in the Mrica Catchment using the Revised Universal Soil Loss Equation (RUSLE) Method. Based on the results of the soil loss analysis, the RUSLE Method emerges as an effective approach for predicting soil loss in watersheds when all relevant variables, including erodibility, rainfall erosivity, slope length, and steepness, as well as cover management and land conservation, have been accurately measured. The total soil loss, as determined by the RUSLE Method for an area of 98,703 hectares, amounts to 21,323.311 metric tons per year or 443.90 tons per hectare per year, particularly in regions dominated by dryland farming.

According to the RUSLE Method, the area with the highest soil loss values is reliably identified in both Environmental and

Management variables, notably dense in the northern area of Mrica Reservoir Catchment. It is important to note that repeated erosion of a certain severity can impact soil solubility and fertility. The soil loss estimates calculated in this study can serve as a valuable reference for devising effective and efficient strategies to control reservoir sedimentation in the Mrica Reservoir.

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Contributor Statement

BKPC, **RP**, and **EGAS** as principal contributors made primary contributions to this manuscript, taking on the responsibilities of conceiving the idea, data collection, developing the methodology, performing the analysis, and writing full manuscript.

DL as supporting contributor with responsibility to oversee the writing and the calculations. **KNA** also contributed in a supporting role, assisting the principal contributors in writing the manuscript.

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