# Soil Erosion Mapping using GIS Based Modeling in Catchment Area of Panglima Besar Soedirman Reservoir, Central Java Province, Indonesia

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**ABSTRACT**

The excessive use of land for farming in the catchment area of Panglima Besar (PB) Sudirman reservoir causes serious environmental problems, particularly in the form of soil erosion. A study about soil erosion is required as a basis for conservation planning. This study aims to determine the spatial distribution of soil erosion in the catchment area of the PB Sudirman Reservoir by using the RUSLE (Revised Universal Soil Loss Equation) model in ArcGIS 10.9. Five indicators were used for the soil erosion models such as rainfall erosivity (R), soil erodibility (K), slope length and slope steepness factor (LS), crop factor (C), and conservation practice factor (P). Those indicators were presented in a raster map format in 30-meter resolution. The results showed that the average value of soil erosion in the catchment area of PB Sudirman Reservoir was 104.82 tons/ha/year or equal to 4.13 mm/year (moderate category). Soil erosion with heavy and very heavy categories was found in the north and east parts of the study site. The results of this study provide a reference for determining the priorities of soil erosion control at the study site.

***Keywords:*** *Catchment Area, GIS, RUSLE Model, Soil Erosion*

## 1. INTRODUCTION

The land conversion that occurs in a watershed can also potentially cause a decrease in the hydrological conditions and functions of the watershed. This is like what happened in the catchment area of the PB Sudirman Reservoir, where there were a change in land use, specially protected forests that were converted to agricultural land with less application of conservation principles. Based on a report from PT. Indonesia Power UPB Mrica in 2007, river sedimentation that occurred has reached the intake drawdown culvert threshold, even 49.9% of the reservoir volume was filled with sediment deposit hence the life storage of reservoir was estimated to be only 30 years from the design age of 60 years [1].

Soil erosion was indicated as the main environmental problem in the catchment area of PB Sudirman Reservoir. Physically, the phenomenon of soil erosion can be seen directly on the land and rivers in the form of sedimentation. Indonesia is one of the tropical countries which is a fairly high level of agricultural crop plantation and soil erosion rates. Soil erosion in Indonesia has been reported to occur at the rate of 2-3 tons/ha/year in natural; conditions, in 40-400 tons/ha/year for agricultural land, and in 120-460 tons/ha/year for barren land [2].

Soil erosion will decrease land productivity which result in infertile soil because of the loss of the fertile layer on the soil surface. The loose soil particles will cause sedimentation and eutrophication downstream area of the river. The occurrence of this will cause flooding and greater siltation of the watershed, especially in water resources conservation structures such as reservoirs and irrigation canals. Since soil erosion has been indicated as the main problem in the catchment area of PB Sudirman Reservoir, a soil erosion study is important to understand the level and distribution of soil erosion, so that an appropriate strategies can be applied to control soil erosion in this area. Soil erosion studies by using models,


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particularly in Indonesia have been performed widely, however, a lack of observation data has become the main problem for model validation.

In this study, the spatial distribution of soil erosion in the water catchment area of the PB Sudirman Reservoir was estimated and mapped by using RUSLE (Revised Universal Soil Loss Equation) model in ArcGIS 10.9. The RUSLE model was validated using data from sedimentation measurements in the PB Sudirman Reservoir for the last 24 years. Some indicators such as rain erosivity, soil erodibility, length and slope of the land, and land use and conservation efforts were used and presented in the form of a raster map using a resolution of 30 meters.

## 2. MATERIAL AND METHODS

### *2.1. Study Area*

This study was conducted in the catchment area of PB Sudirman Reservoir in Central Java Province, Indonesia. The study site covers several districts in Central Java Province, namely Wonosobo, Banjarnegara, Temanggung, Batang, Pekalongan and Kendal regencies (**Figure 1**). The study site is geographically located at coordinates $07^0$ 05' - $07^0$ 4' South Latitude and $108^0$ 56'- $110^0$ 05' East Longitude. The area has an altitude of 213-3238 meters above mean sea level.

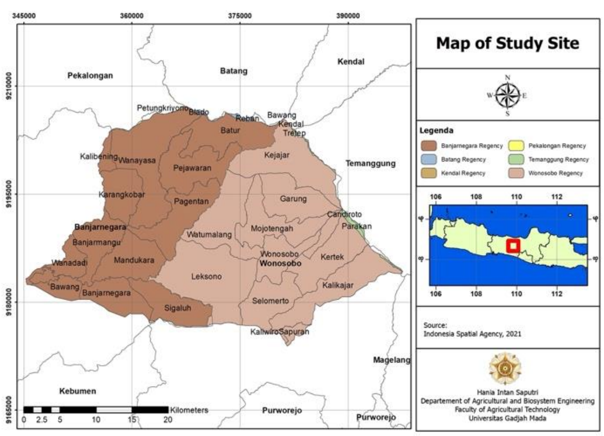


**Figure 1** Upstream watershed of PB Sudirman reservoir

### *2.2. Data Analysis*

Soil erosion rate in the study site was determined by considering some indicators such as rain erosivity, soil erodibility, land length, and slope, land use, and conservation practices activities. The RUSLE model [3] is an improvement from the previous model [4] as written in Equation 1.

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where :

A = Average annual erosion
R = The rainfall erosivity factor
K = The soil erodibility factor
LS = The factor of the length and slope of the land
C = The factor of vegetation management
P = The factor of soil conservation

In this study, soil erosion was classified into some level of soil erosion hazard as described in **Table 1** [5].

**Table 1** Erosion Hazard Classification

| No | Erosion class (Ton/ha/year) | Class | Criteria |
|---|---|---|---|
| 1 | 0 – 15 | Very Low | Very Good |
| 2 | 15 – 60 | Low | Good |
| 3 | 60 – 180 | Moderate | Moderate |
| 4 | 180 – 480 | High | Heavy |
| 5 | >480 | Very High | Very Heavy |

#### *2.2.1. Rainfall Erosivity Factor (R)*

The rainfall erosivity factor (R) value was estimated by using the equation developed by Lenvain as written in Equation 2.

$$Rm = 2.21\ (Rb)^{1.36} \quad (2)$$

Where :

Rm = The rainfall erosivity

Rb = Monthly rainfall

#### *2.2.2. Soil Erodibility Factor (K)*

The value of the soil erodibility factor (K) can be obtained from the soil type data. In this study, the K value was determined based on reference values of K for some soil types in Indonesia as written in **Table 2**.

**Table 2** Reference K Value for Various Lands in Indonesia

| ID | Soil Type | K Value |
|---|---|---|
| 1 | Latosol red | 0.12 |
| 2 | Latosol red yellow | 0.26 |
| 3 | Latosol | 0.31 |
| 4 | Latosol brown | 0.23 |
| 5 | Regosol | 0.11 |
| 6 | Lithosol | 0.29 |
| 7 | Grumusol | 0.20 |
| 8 | Alluvial | 0.47 |

#### *2.2.3. Slope Length Factor (LS)*

The length and slope factor values in the present study were determined based on the LS values in various land slope classes as shown in Table 3 [6].

**Table 3.** Reference LS Value Based on Land Slope Class

| Slope Class | Land Slope | LS Value |
|---|---|---|
| I | 0 - 8 % | 0.4 |
| II | 8 - 15 % | 1.4 |
| III | 15 - 25 % | 3.1 |
| IV | 25 - 40 % | 6.8 |
| V | > 40 % | 9.5 |

### *2.2.4. Land Use Factors and Conservation Practices (CP)*

The value of land use factors and conservation in the present study practices was determined based on the CP value for various types of land use in Indonesia as shown in Table 4 [7,8].

**Table 4.** CP Value in Different Types of Land Use

| No | Plant Conservation and Management | CP Value |
|---|---|---|
| 1 | Forest | |
| | a. Not distrubed | 0.01 |
| | b. No undergrowth, with litter | 0.05 |
| | c. No plants, no litter | 0.50 |
| 2 | Bush | |
| | a. Not distrubed | 0.01 |
| | b. Some grass | 0.10 |
| 3 | Garden | |
| | a. Mixed garden | 0.02 |
| | b. Yard garden | 0.20 |
| 4 | Plantation | |
| | a. Perfect ground cover | 0.01 |
| | b. Partial ground cover | 0.07 |
| 5 | Grass | |
| | a. Perfect ground cover | 0.01 |
| | b. Partial ground cover, overgrown with weeds | 0.02 |
| | c. Imperata: burning once a year | 0.06 |
| | d. Lemongrass | 0.65 |
| 6 | Agricultural crops | |
| | a. Tubers | 0.51 |
| | b. Grains | 0.51 |
| | c. Nuts | 0.36 |
| | d. Mixture | 0.43 |
| | e. Irrigated rice | 0.02 |
| 7 | Farming | |
| | a. 1 year planting, 1 year uncultivated | 0.28 |
| | b. 1 year planting, 2 years uncultivated | 0.19 |
| 8 | Agriculture with conservation | |
| | a. Mulch | 0.14 |
| | b. Terrace bench | 0.04 |
| | c. Contour cropping | 0.14 |

## 3. RESULT AND DISCUSSION

### *3.1. Rainfall Erosivity Factor (R)*

The rainfall erosivity was calculated by using rainfall data for the last six years (2016-2021) from six rainfall stations located in the catchment area of the PB Sudirman Reservoir, namely Sigaluh, Batur, Pagentan, Karangkobar, Garung, and Kertek Rain Stations. The rain erosivity value that has been obtained was then mapped using the IDW (Inverse Distance Weighted) tool in Arc GIS 10.9. The result rain erosivity map can be seen in **Figure 2**.

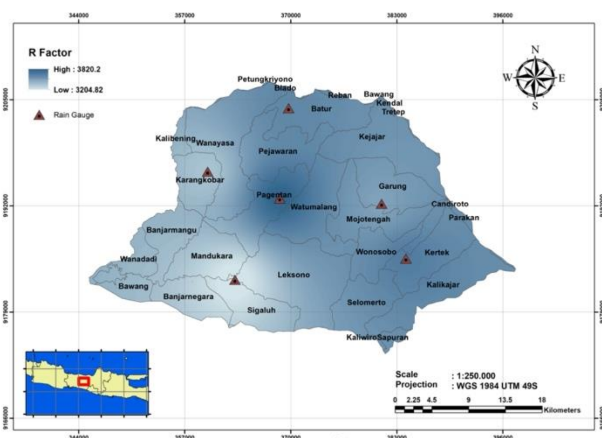


**Figure 2** R Factor Map of the Study Site.

### *3.2. Soil Erodibility Factor (K)*

Soil erodibility is a level of sensitivity of soil to erosion. Soil erodibility value is influenced by structure, texture, organic matter, and soil permeability. In this study, data on soil types at the study site were obtained from the Main Office of Serayu Opak River, the ministry of public works Indonesia. The study site has four types of soil, namely Latosol, Regosol, Grumusol, and Alluvial.

The erodibility value of each soil type was different, the highest K value was found for alluvial soil at 0.47 and the lowest was for Regosol soil at 0.11. Thus, alluvial soil types have the easiest possibility to be eroded, and regosols were difficult to erode in the area. The spatial distribution of soil erodibility in the study site is shown in Figure 3.

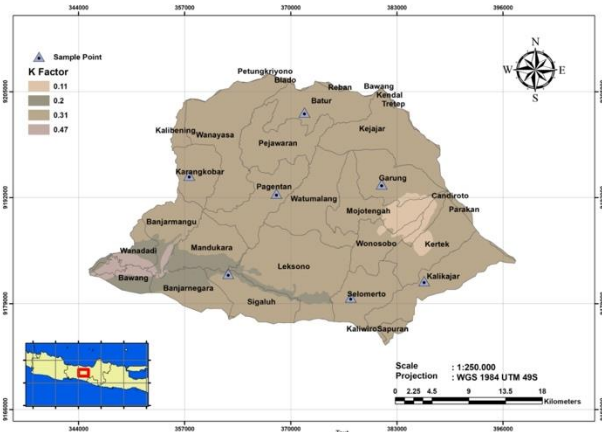


**Figure 3** K Factor Map of Study Site.

## *3.3. Slope Length Factor (LS)*

The length and slope of the land are the two topographic elements that have the most influence on runoff and soil erosion. Land slope data for the study site was obtained from Indonesia Geospatial Agency (Badan Informasi Geospasial). Land slope data was used to determine the LS factor in the study site. LS map in the catchment area of the PB Sudirman Reservoir is shown in Figure 4.

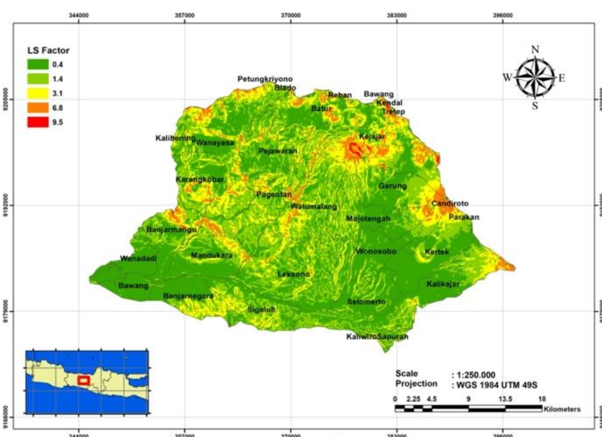


**Figure 4** LS Factor Map of Study Site.

The spatial distribution of the lowest LS index of 0.4 dominates the sub-districts of Wanadadi, Bawang, Banjarnegara, and Wonosobo. Meanwhile, the distribution of the highest LS index of 9.5 was found in the Districts of Kejajar and Candiroto. High slopes in these areas have a high potential for erosion compared to other sub-districts. Area with a greater slope of the land will have a greater rate of soil erosion [9,10].

## *3.4. Land Use Factors and Conservation Practices (CP)*

The CP value is the ratio between the average soil eroded from land planted with crops and the land without crops [11,12]. The catchment area of the PB Sudirman Reservoir was dominated by land use in the form of gardens with an area of 315.23 km$^2$ (30.98%) and moor with an area of 298.81 km$^2$ (29.37%).

The high CP value was owned by land use type of moor (0.19). This is due to the plant roots being planted which are not strong and are not good at resisting rain erosivity so it can damage the soil surface layer, especially when coupled with the steep slope of the land. Meanwhile, land use such as forests has a low CP value because the forest has strong roots as well as a high density and canopy so that it can withstand rain erosivity.

However, the existence of forests in the upstream watershed area of the PB Sudirman Reservoir only covers an area of 14.13 km$^2$ (1.39%), due to forest degradation in the form of conversion of forest functions to agricultural land, so this can potentially cause a decrease in the condition and hydrological function of the watershed. A map of CP factors in the upstream watershed area of the PB Sudirman Reservoir is shown in **Figure 5**.

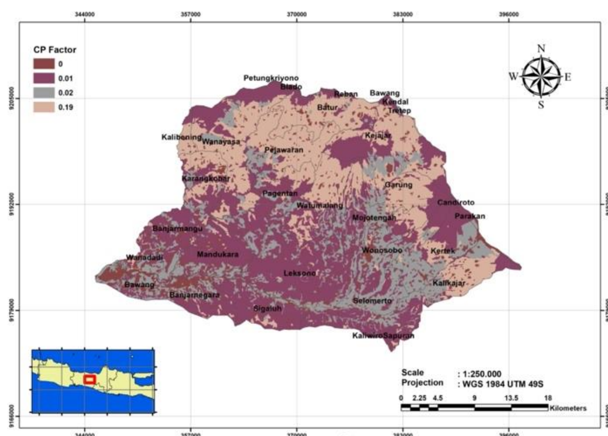


**Figure 5** CP Factor Map for Upstream PB Soedirman Reservoir

The lowest spatial distribution of the CP index of 0 is found in several areas in the upstream Serayu watershed. Meanwhile, the distribution of the highest CP index of 0.19 dominates the northern part of the watershed, so that this area has a high potential for erosion compared to other areas.

## *3.5. Soil Erosion and Erosion Hazard Classification*

RUSLE erosion is calculated based on a raster with a resolution of 30 meters by adjusting the input variables into the same dimensions. The results of the overlapping (overlay) of each RUSLE variable, namely rain erosivity

(R), soil erodibility (K), land length and slope (LS), and land use and conservation practices (CP) will give a value for the measure of erosion in the Upper Watershed PB Sudirman reservoir. Based on the analysis, the average erosion value is 104.82 tons/ha/year or equivalent to 4.13 mm/year and is included in the moderate erosion class.

The most dominant erosion hazard was in the very low category with an area of 432.26 $km^2$ (42.49%), followed by the low category with an area of 247.17 $km^2$ (24.29%), medium category of 159.44 $km^2$ (15.67%), followed by the high category with an area of 114.03 $km^2$ (11.21%) and the very high category with an area of 64.49 $km^2$ (6.34%). The spatial distribution of the level of erosion hazard is presented in Figure 6.

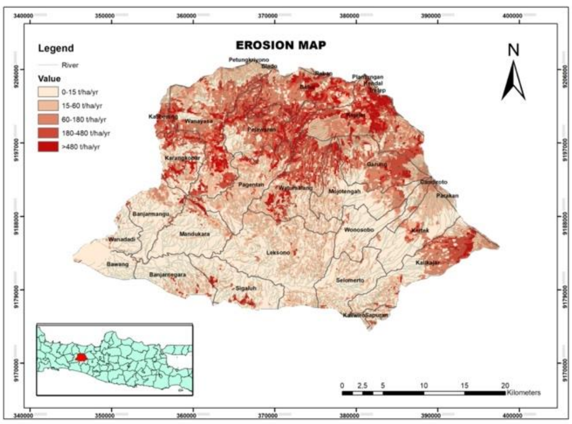


**Figure 6** Distribution Map of Soil Erosion Hazard Levels for Catchment Area of PB Sudirman Reservoir.

The high erosion in the northern and eastern regions is caused by the slope of the land and the use of agricultural land in the form of moor and the majority is planted with seasonal crops and horticultural crops, especially vegetables. The roots of the plants planted on this land use are not strong and are not good at resisting rain erosivity so that it can damage the surface layer of the soil, especially when coupled with steep slope conditions and high rainfall.

Meanwhile, the southern region with erosion classifications of very low and low. This is because most of these areas have land uses with low CP values such as rice fields, settlements, and gardens. In addition, the area is also dominated by a flat land slope of 0-8%. The flatness of the slopes coupled with the dominance of low CP values in the area resulted in erosion which tends to be smaller when compared to the northern and eastern regions. The LS value has a positive correlation with the magnitude of the erosion value [13]. Soil erosion in the area with high and very high category can be controlled by soil and water conservation. A combination of some conservation method has been reported effective to reduce soil erosion under tropical climate condition [14].

### *3.6. RUSLE Model Validation*

The calculation of erosion rate using the RUSLE model showed an average value of 104.82 tons/ha/year or equal to 4.13 mm/year (moderate class category). Model validation indicated RUSLE model was acceptable to be used in this study. The high and very high erosion hazard is in the area northern and eastern of PB Soedirman reservoir.

## 4. CONCLUSION

The average value of erosion that occurs in the upstream watershed of the PB Sudirman Reservoir using the RUSLE model is 104.82 tons/ha/year or equal to 4.13 mm/year with the category of moderate erosion class. Thus, it is necessary to have a strategy for land conservation efforts, especially in areas that have high and very high erosion rates. Vegetatively, this can be done through agroforestry, the use of cover crops, and the use of grass strips. Meanwhile, mechanically it can be done by making bund terraces and bench terraces.

## AUTHORS' CONTRIBUTIONS

**Dimas Prabowo Harliando**: data collection, data analyses, publication draft writing. **Hania Intan Saputri**: data collection, data analysis, publication draft writing. **Chandra Setyawan**: research and data analysis supervision, publication draft writing **Abdurahman Khidzir**: data collection, data analyses. **Sahid Susanto**: research supervision, research concept advisory. **Muhamad Khoiru Zaki**: research supervision, publication draft review.

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