Soil erosion mapping using GIS based model in agricultural area of Progo watershed, Central Java, Indonesia.

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Abstract. Soil erosion remains a strenuous problem for agricultural practices, particularly in tropical regions as happened in Indonesia. This study aimed to investigate the distribution of soil erosion in agricultural areas of a tropical watershed. The Revised Universal Soil Loss Equation (RUSLE) model in a Geographic Information System (GIS) was used for soil erosion assessment. RUSLE model parameters were collected from various sources. Soil erosion was classified into five classes such as very low (0-15 t ha⁻¹ yr⁻¹), low (15-60 t ha⁻¹ yr⁻¹), moderate (60-180 t ha⁻¹ yr⁻¹), heavy (180-480 t ha⁻¹ yr⁻¹), and very heavy (>480 t ha⁻¹ yr⁻¹). The result showed that the average soil erosion in the study site was 71.1 t ha⁻¹ yr⁻¹. More than 50% of the study site was occupied by very low class soil erosion, while heavy and very heavy class soil erosion occupied more than 20% of the study site. The finding of this study provides a useful reference for soil erosion control and studies.

1. Introduction
As an important part of the land, the soil has important roles in crop production. Land cultivations for farming are massively found in tropical regions, where rainfall is available in a large number. Frequently, these activities are causing land degradation in the form of soil erosion and reducing land productivity. Soil erosion has been reported causing many deprivations, especially in tropical countries [1,2]. Therefore, soil erosion study is necessary as the basis for soil erosion control planning [3,4]. Reliable information on soil erosion distribution provides a fundamental consideration to determine priorities and types of soil conservation strategies.

Soil erosion studies have been performed in various approaches, depending on geological conditions and data availability of each country. In Indonesia, soil erosion is commonly investigated by using a model that provides a faster result. However, most of the model applications for soil erosion assessment are not completed by model validation. Therefore, the accuracy of the study result cannot be achieved properly. The lack of field measurement data for model validation has become a challenge for model application. In this study, the soil erosion model was validated by using reference values from other studies in Java Island, where the geographical condition of the study sites tends to be the same as suggested in some previous studies [5,6].

2. Methodology

2.1. Study site
This study was conducted in agricultural areas, north of Progo Watershed. Administratively, the study site is located in Central Java Province, Indonesia and covers about 417.7 km² area (Figure 1). Annual
rainfall reaches more than 2,000 mm. Elevation points were scattered from 500 - 1,450 m.a.s.l. The study site was dominated by farmland, covering more than 80% of the study site.

2.2. RUSLE model
The RUSLE model has been used for soil erosion assessment under various tropical conditions. Nowadays, RUSLE is mostly combined with GIS and remote sensing technology for soil erosion assessment [7,8]. The equation of RUSLE is expressed below [9]:

\[ SE = R \times K \times LS \times C \times P \]  \hspace{1cm} (1)

where SE is the average annual soil erosion [t ha\(^{-1}\) yr\(^{-1}\)], R is the rainfall-runoff erosivity factor (MJ mm ha\(^{-1}\) h\(^{-1}\) yr\(^{-1}\)), K is the soil erodibility factor (t h MJ\(^{-1}\) mm\(^{-1}\)), LS is the slope length-steepness factor (dimensionless), C is the cropping management factor (dimensionless), and P is the erosion control practice factor (dimensionless).

The value of RUSLE parameters was collected from various sources and assigned for five past years (2015-2019). Those parameters were presented in a raster map in 30 meters of map resolution and overlaid in map algebra of spatial analyst tool of GIS (software of Arc GIS 10.3). Soil erosion was then classified into five classes i.e. very low (0-15 t ha\(^{-1}\) yr\(^{-1}\)), low (15-60 t ha\(^{-1}\) yr\(^{-1}\)), moderate (60-180 t ha\(^{-1}\) yr\(^{-1}\)), heavy (180-480 t ha\(^{-1}\) yr\(^{-1}\)), and very heavy (>480 t ha\(^{-1}\) yr\(^{-1}\)) according to the soil erosion classification of the Department of Forestry Indonesia in 1998 [10,11].

2.2.1. Rainfall-runoff erosivity factor (R).
Rainfall-runoff erosivity is the potential of soil to be destroyed and flowed by rainwater energy. In this study, R factor was calculated by using equation 2 as expressed below [12]:

\[ Rm = 2.2 \times (Rb)^{1.36} \]  \hspace{1cm} (2)

where Rm is monthly rainfall erosivity, Rb monthly rainfall (cm). Annual Rainfall-runoff erosivity is the sum of monthly rainfall erosivity. Rainfall data were collected from four rainfall stations in the study site. R factor values from those rainfall stations were then analyzed by using Inverse Distance Weighting (IDW) to obtain the mean value of this factor (Figure 2a).
2.2.2. **Soil erodibility factor (K).**
Soil erodibility is the susceptibility of soil particles for destruction by rainwater energy. The study site is covered by latosolic red-yellow soil (Figure 2b). In this study, K value was determined by using a reference value for some soil types in Java Island [13], where for the study site, the value of K was 0.36 t h MJ⁻¹ mm⁻¹. The soil map was obtained from the water resources office of serayu opak, Indonesia.

![Figure 2. RUSLE R (a) and K (b) factor of the study site](image)

2.2.3. **Slope length–steepness (LS) factor.**
LS factor reflects the effect of length and steepness of slope on soil erosion. In this study, LS factor (Figure 3a) was generated from the Digital Elevation Model (DEM) by using equation 3 in Arc Hydro Tools of GIS [14,15]. DEM SRTM 1 Arc-second in 30 meters resolution gained from the United States Geological Survey (USGS) was used for LC factor calculation.

\[
LS = (\text{flow acc.} \times \text{map resolution}/22.13)^{0.5} \times (\sin \text{slope}/0.0896)^{1.4}
\]  
(3)

where flow acc. is the accumulated slope effect on the cells, map resolution is the dimension of map cell size and sin slope is the slope degree of land in sin. Flow accumulation was calculated using the Arc hydro tool which is available in GIS.

2.2.4. **Cropping management (C) and erosion control practice (P) factor.**
C and P factors reflect the effect of cropping management and erosion control practice on soil erosion. In this study, C and P were calculated as CP factors, where the value of this factor was determined from the reference value of the CP factor of Java Island for some types of land use [12]. Based on the land use map was obtained from Indonesian Earth Surface Map, there were five types of land use in the study site such as shrub (CP= 0.1), settlement (CP= 0.2), forest (CP= 0.05), mixed farmland (CP= 0.51) and rice field (CP= 0.02) as shown in Figure 3b.

![Figure 3. RUSLE LS (a) and CP (b) factor of the study site](image)
3. Results and Discussions

Soil erosion mapping by using GIS enables a quick assessment with more accurate results. RUSLE parameters were presented in raster map form for soil erosion assessment in spatial analyst tools (map algebra) of Arc GIS 10.3. GIS divides a raster map into a grid cell (square form) with a map resolution as the cell size. Quantitative assessment of soil erosion by using the RUSLE model in Arc GIS 10.3 showed that average annual soil erosion in the study site was 71.1 t ha\(^{-1}\) yr\(^{-1}\). This result was a small difference with soil erosion assessment in Kalikonto watershed, East Java Province (model validation by using erosion plot) which was resulting in 72.0 t ha\(^{-1}\) yr\(^{-1}\) average annual erosion [16]. While, another soil erosion assessment study in the Wadaslintang watershed, Central Java Province (model validation by using field measurement data of soil sediment) was resulting in 67.61 t ha\(^{-1}\) yr\(^{-1}\) average annual erosion [17]. Kalikonto and Wadaslintang watershed have a similar physical condition (the area is dominated by farmland) as found in the study site. Soil erosion distribution in the study site in five different classes is shown in Figure 4.

![Figure 4. Soil erosion distribution in the study site](image)

Table 1. Soil erosion distribution in five different classes

| Range (t ha\(^{-1}\) yr\(^{-1}\)) | Category   | Area (km\(^2\)) | %   |
|----------------|------------|-----------------|-----|
| 0-15           | Very low   | 223.82          | 53.6|
| 15-60          | Low        | 63.15           | 15.1|
| 60-180         | Moderate   | 85.49           | 20.5|
| 180-480        | Heavy      | 37.08           | 8.9 |
| >480           | Very heavy | 8.14            | 1.9 |

In general, average annual soil erosion in the study site is in the moderate category (71.1 t ha\(^{-1}\) yr\(^{-1}\)). This finding indicated the increase of soil erosion to heavy and very heavy categories can occur rapidly. Hence, soil erosion control in the area with heavy and very heavy erosion is required. Soil erosion
control can be applied easier by focusing on the area with a high land slope. Long-term conservation scenarios by increasing forest vegetation cover in hilly areas can be applied for soil erosion control in the existing condition.

4. Conclusions
The present study revealed that the average annual soil erosion in the study site was $71.1 \text{ t ha}^{-1} \text{ yr}^{-1}$ (moderate category). Soil erosion with heavy and very heavy was scattered in the northeast and southwest of the study site where the land slope tended to high. The effect of the land slope factor on soil erosion was more dominant than the other factors such as rainfall distribution, soil type, and land use type. The map of soil erosion distribution can specifically show the location of critical areas. Hence, the priority area for conservation practices programs can be recognized.

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Acknowledgements
We would like to thank the Directorate of Research Universitas Gadjah Mada for providing fund of this study through RTA Research Grant 2020.