DEM and land slope based method of RUSLE LS factor calculation for soil erosion assessment

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Abstract. Soil erosion is one of the essential factors causing land degradation in tropical regions. The application of a model for soil erosion calculation enables a rapid assessment with a reliable result. The Revised Universal Soil Loss Equation (RUSLE) is the most used soil erosion model which can be applied under various climate conditions. This study was conducted to evaluate the performance of the Digital Elevation Model (DEM) and land slope-based method to estimate the RUSLE LS factor value for soil erosion calculation in the upstream of Progo Watershed Indonesia. Parameters of the RUSLE model including LS factor estimation in a DEM based were calculated by using a Geographic Information System (GIS) tool and presented in 30 meters grid size. RUSLE model validation was performed by using reference value from two different studies in Java Island, Indonesia. The result revealed that average soil erosion in the study area was 71.12 tons/ha/year based on the LS factor calculated by using DEM. Whereas, average soil erosion based on LS factor calculated by using land slope-based method was 438.68 tons/ha/year. According to the RUSLE model validation value, the RUSLE LS factor calculation by using DEM was more accurate than the LS factor calculated by using the land slope factor. This study provides a useful reference for soil erosion study particularly to develop methods for RUSLE model parameter assessment under different climate conditions.

1. Introduction

The rise of population growth in developing countries including Indonesia raises the utilization of land resources for food production. Event, land cultivation for farming reaches hilly areas as the upstream of watersheds which are characterized by steep sloping areas [1]. This condition increases land degradation problems indicated from the increase of soil erosion, landslide, sedimentation, flood, and other disasters. Lack of conservation principles in land cultivation accelerates land degradation in a watershed scale [2]. One of the areas with this condition in Indonesia is the upstream area of Progo Watershed which covers about 417.7 km² area (Figure 1). Deforestation in this area reduces at a significant level of vegetation cover. The local inhabitant cultivates the land for tobacco plantation [3]. Land extension for the plantation is centered in the area with a land slope of more than 30% [4]. Hereafter, land degradation particularly in the form of soil erosion has largely occurred.

Investigation of soil erosion levels in this area is required for conservation practices planning. Soil erosion modeling is one of the most possible ways for soil erosion assessment on a watershed scale. The use of models with proper validation provides accurate results and finding as the basis for conservation planning. One of the most popular models for soil erosion calculation is RUSLE. This model has been proven good for soil erosion calculation under various climate conditions [5,6]. RUSLE model is easy to be integrated with a GIS and the value of the RUSLE parameter is easy to be gained.
One of the most important parameters of the RUSLE model is the LS factor, expressing the effect of the slope-length aspect on soil erosion [7]. Methods for RUSLE LS factor assessment have been developed in various approaches considering the local condition of the research area. One of the methods for RUSLE LS factor assessment is developed based on DEM. Though this method has been used in some studies, the application of this method for soil erosion studies in Indonesia is still limited. In this study, the RUSLE LS factor assessment by using DEM was used and compared by LS factor assessment based on land slope value established by the Department of Forestry Indonesia (DFI) in 1998 and 2007 [8,9]. The comparison of these methods enables the best way in determining the RUSLE LS factor for future soil erosion studies.

2. Research Methodology

2.1. Soil Erosion Calculation by Using RUSLE Model

Soil erosion in the study area (upstream of Progo Watershed) was calculated by using the RUSLE model. This model consists of five main parameters as expressed in the equation below [10]:

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

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

Parameters of the RUSLE model were calculated by using GIS (Arc GIS 10.3) and presented in raster map forms in 30 meters grid sizes for the period from 2015-2019. GIS divides the raster maps into a square grid form in size 30 m x 30 m. GIS calculates soil erosion in cell grids basis, hence the average annual soil erosion can be estimated. In this study, soil erosion was classified into five categories based on soil erosion classification of DFI in 1998 [2,11] 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\(^{-1}\)).

2.2. Erosivity factor of rainfall-runoff (\( R \)). \( R \) factor expresses the effect of raindrop energy on soil particle's destruction and transport. In this study, the \( R \) factor was calculated by using the Lenvain equation as expressed below [12]:

\[ R_m = 2.2 \times (R_b)^{1.36} \]  \hspace{1cm} (2)
where \( R_m \) is the monthly R factor, \( R_b \) is the monthly rainfall (cm). Annual R factor is the sum of the monthly R factor. Rainfall data were obtained from four rainfall stations (see Figure 1) in the study area.

2.3. **Soil erodibility factor (K)**. K factor reflects the susceptibility of soil particles to be destroyed by raindrop energy. The soil map in the study was generated from the Water Resources Office of Serayu Opak, Indonesia. The value of the K factor was determined by using a reference value for some soil types in Java Island [13].

2.4. **Slope length-steepness (LS) factor**. LS factor indicates the length and steepness effect of slope on soil erosion. LS factor was obtained from DEM and reference value from DFI [8,9] as shown in Table 1.

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| Slope Class | Land Slope | Value of LS |
|-------------|------------|-------------|
| I           | 0 - 8 %    | 0.4         |
| II          | 8 - 15 %   | 1.4         |
| III         | 15 - 25 %  | 3.1         |
| IV          | 25 - 40 %  | 6.8         |
| V           | > 40 %     | 9.5         |
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LS factor determined from DEM was calculated in Arc Hydro Tools of GIS by using equation 3 [14,15]. DEM (SRTM 1 Arc-second) was obtained from the United States Geological Survey (USGS).

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

(3)

where flow acc. is the accumulated slope effect on soil erosion, map resolution is the grid size of the map, and \( \sin \text{slope} \) is the slope degree of land in sin.

2.5. **Vegetation management (C) and control practice (P) factor for soil erosion**. C and P factors express the effect of vegetation management and conservation practices on soil erosion control. C and P factors were calculated as a CP factor in this study. CP factor value was determined from the reference value of the CP factor for some types of land use in Java Island [12]. Land use map was obtained from Indonesian Earth Surface Map in 2019.

3. **Results and Discussions**

3.1. **R and K Factor of RUSLE**

Annual rainfall from four rainfall stations (Jumo, Temanggung, Kaloran, and Parakan) was recorded from 2,100 mm to 2,500 mm in the study area. R factor was calculated for each station and analyzed by using Inverse Distance Weighting (IDW) method to gain the R factor value of the study area (Figure 2a). Rainfall and R factor value were high in the north part and lower in the south part of the study area. Diversity of R factor value indicated a diversity of rainfall patterns in Indonesia as reported in some previous studies [1]. For the K factor, the map of soil type showed that the study area was covered by a soil type of latosolic red yellow. According to the reference value of the K factor for some soil types in Java Island [13], the K factor for this soil type was 0.36 t h MJ\(^{-1}\) mm\(^{-1}\) (Figure 2b). Areas with more sand and coarse granular content will have a higher K factor value [1].
3.2. **LS Factor of RUSLE**

DEM-based LS factor indicated a more various value compared with LS factor value obtained from the reference value of DFI (Table 1) as shown in Figures 3a and 3b. LS factor value increases with the increase of land slope value [14]. The use of GIS for DEM based LS factor calculation enables a detailed assessment in grid scales.

3.3. **CP Factor of RUSLE**

The land use map revealed five types of land use such as shrub, settlement, forest, mixed farmland, and rice field. The map of land-use types and CP factor in the study area is shown in Figures 4a and 4b.
Mixed farmland covered the largest area of the study area (54.4%), followed by rice field (28%), settlement (12.8%), shrub (4.4%), forest (0.4%), and water body (0.3%). Land use type map showed that the middle area of the study area was dominated by rice field, while the north, south, east, and west part were dominated by mixed farmland.

3.4. Assessment of DEM and Land Slope for LC Factor Calculation.
LS factor calculated from DEM and the reference value of DFI were used for soil erosion assessment. The result showed that average annual soil erosion was 71.12 t ha$^{-1}$ yr$^{-1}$ (Figure 5a) for the LS factor calculated using DEM. Whereas, for LS factor determined from the reference value of DFI, the average soil erosion was 438.68 t ha$^{-1}$ yr$^{-1}$ (Figure 5b). These results were then validated by using the result of two different soil erosion studies in two different watersheds in central java [1] and east java [15] province Indonesia which are resulting in the average annual erosion of about 70 t ha$^{-1}$ yr$^{-1}$. This validation procedure was applied as suggested in some previous studies [16,17], where field measurement data of soil sedimentation was not available in the study area.

![Figure 5. Soil Erosion from DEM (a) and DFI Referenced Value (b) Based LS Factor](image)

According to model validation, DEM based LS factor showed a more accurate result than DFI referenced value based. Figure 5a and 5b showed a similar pattern of soil erosion distribution where erosion with heavy (180-480 t ha$^{-1}$ yr$^{-1}$) and very heavy (>480 t ha$^{-1}$ yr$^{-1}$) were scattered in the west and east part of the study area. However, the coverage area for those soil erosion classes in Figure 5b was larger than Figure 5a. A study by Saputro and Sastra Negara (2014) by using DFI referenced value-based LS factor [8] in Central Java Province Indonesia resulted in an annual average erosion value of less than 100 t ha$^{-1}$ yr$^{-1}$. While a study by Suriadikusumah et al. (2019) in West Java Province Indonesia [9] reported an average annual erosion of more than 1,000 t ha$^{-1}$ yr$^{-1}$. These studies are not clearly described in model validation. The difference in determining the LS factor was significantly affecting the result of soil erosion calculation. Validation is mandatory for model applications. Hence, uncertainty in the model application can be minimized.

4. Conclusions
DEM based LS factor calculation showed a more accurate result than DFI referenced value-based LS factor calculation for soil erosion calculation in this study. The use of DFI referenced values for LS factor estimation needs improvement. The class of land slope as shown in Table 1 must be extended in a larger number. Hence, the LS factor value reflecting the length-steepness of land can be specifically defined. Future studies to investigate the correlation between land slope-LS factor value are required under various physical conditions of watersheds on a regional and global scale. Model validation is also compulsory to control the uncertainties of model application.
References

[1] Setyawan C, Lee C Y, and Prawitasari M 2019 Investigating spatial contribution of land use types and land slope classes on soil erosion distribution under tropical environment Nat. Hazards 98 697-718.

[2] Harjianto M, Sinukaban N, Tarigan S D, and Haridjaja O 2015 Erosion prediction and soil conservation planning in Lawo watershed Indonesia J. Environ Earth Sci. 5(6) 40-50.

[3] Djajadi, Thamrin M, Rachman A, and Isdijoso S H. 1992. Conservation of Tobbaco Land temanggung. J. Tobbaco and Fiber Res. 7 (1-2) 19-16.

[4] Suyana J, Sinukaban N, Sanim B, and Purwanto M Y J 2013. Kajian Kemampuan Lahan pada Usahatani Lahan Kering Berbasis Tembakau di Sub-DAS Progo Hulu Sains Tanah-Journal of Soil Science and Agroclimatology 7(1) 1-8.

[5] Gananasri B P and Ramesh H 2015 Assessment of soil erosion by RUSLE model using remote sensing and GIS-a case study of Nethravathi Basin Geosci. Fron.t 7 953-961.

[6] Shrestha D P, Suriyaprasit M, and Prachansri S 2014 Assessing soil erosion in inaccessible mountainous areas in the tropics: the use of land cover and topographic parameters in a case study in Thailand Catena 121 40-52.

[7] Mitasova H, Mitas L, Brown W M, and Johnston D 1999 Terrain modeling and soil erosion simulations for Fort Hood and Fort Polk test areas (Champaign: University of Illinois at Urbana Champaign).

[8] Saputro G E and Sastranegara M H 2014 A Study On The Erosion Danger And Important Value Index In The Forest Community Of The Village Candiwulan Kutasari Sub District Purbalingga Biosfera 108-123.

[9] Suriadikusumah A, Rokhaesih and Mulyono A 2019. Assessment of erosion hazards due to land use change in Cianten subwatershed, Indonesia Earth and Environmental Science 393 1-8.

[10] Renard K G, Foster G R, Weesies G A, McCool D K, and Yoder D C 1997 Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE) (Washington: U.S. Department of Agriculture).

[11] Herawati T 2010 Spatial analysis of erosion danger level at Cisadane watershed area Bogor district J. Nat. Conserv. For. Res. 7(4) 413-424.

[12] Asdak C 2007 Hidrology and watershed management (Yogyakarta: Gadjah Mada University Press) (in Indonesian).

[13] Vis M 1987 A procedure for the analysis of soil erosion and related problems in water and land resources management studies (The Hague: International Reference Centre for Community Water Supply and Sanitation).

[14] Sigalos G, Loukaidi V, Dasaklis S, Drakopoulou P, Salvati L, Ruiz PS, and Mavrakis A 2016 Soil erosion and degradation in a rapidly expanding industrial area of Eastern Mediterranean basin (Thriasio plain, Greece) Nat. Hazards 82:2187.

[15] Andriyanto C, Sudarto, and Suprayogo D 2015 Estimation of soil erosion for a sustainable land use planning: RUSLE model validation by remote sensing data utilization in the Kalikonto watershed J. Degrad. Min. Lands Manag. 3(1) 459-468

[16] Shrestha D P, Suriyaprasit M, and Prachansri S 2014 Assessing soil erosion in inaccessible mountainous areas in the tropics: the use of land cover and topographic parameters in a case study in Thailand CATENA 121 40-52.

[17] Ali S A and Hagos H 2016 Estimation of soil erosion using USLE and GIS in Awassa Catchment, Rift valley, Central Ethiopia Geoderma Reg. 7 159-166.

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