Vegetation cover modelling for soil erosion control in agricultural watershed

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Abstract. Vegetation has an important role in surface runoff and soil erosion control. Deforestation, especially in the upstream watersheds, has increased land degradation problems, mainly in the form of soil erosion. This study aims to investigate the effectiveness of vegetation cover for soil erosion control in an agricultural watershed. Soil erosion calculation was performed using Revised Universal Soil Loss Equation (RUSLE) model. While spatial analysis tools of Arc GIS 10.3 were used for soil erosion-vegetation correlation modelling. Five parameters such as rainfall erosivity (R), soil erodibility (K), length-slope factor (LS), crop management factor (C) and conservation practices factor (P) used to assess soil erosion in the existing condition. Those parameters were presented in grids cell of land units with 30 meters resolution. Five scenarios of vegetation cover such as 10%, 15%, 20%, 25% and 30% were used for the modelling. The result showed the increase of vegetation cover from the existing condition from 4.8% to 30% can significantly reduce about 76% of soil erosion. Preservation of about 30% vegetation cover in the upstream area of the watershed, enables farming practices with a low risk of soil erosion. The findings of this study provide a fundamental base for conservative farming concept development.

1. Introduction
Agricultural practices under tropical climate are promising for economic improvement. High rainfall intensity with deep and fertile soil layer enables crop production with a high yield. Land cultivation for agriculture in the tropics must be followed by the right conservation practices. Without that, agriculture practices will increase land degradation particularly in the form of soil erosion as happened in the agricultural watershed upstream of the Progo river system, Indonesia. This watershed was dominated by agricultural land particularly for tobacco plantation [1]. Soil erosion upstream of the watershed has caused sedimentation downstream [2]. Due to its function as a water harvesting area for the sustainability of the groundwater system, intensive conservation practice is mandatory for this watershed. Conservative farming or farming practices with a low risk of land degradation by applying conservation principles may offer a probable way to overcome this problem.

Conservation practices for a critical watershed with heavy soil erosion and sedimentation can be applied by using conservation structures or vegetative methods. Conservation structure is effective for soil erosion and sedimentation control however it is costly. Whereas, the vegetative method by increasing vegetation cover into a proper proportion offers an alternative way at a lower cost. Vegetation has been reported effective for soil erosion control [3, 4]. However, the standard for minimum vegetation cover is still hard to be specified for each region under various environmental conditions. Soil erosion-
vegetation correlation studies under various conditions are still needed to determine the standard for each region. In this study, the modelling of vegetation cover for soil erosion control was performed in a tropical watershed which was dominated by agricultural land. By knowing the required vegetation cover for resulting low soil erosion, the minimum standard of vegetation can be recognized to support the conservative farming application.

2. Methodology

2.1. Study site
This study was performed in an agricultural watershed located in the Temanggung Regency, Central Java of Indonesia. This site is the north part of the Progo river system covers about 417.7 km² area where agricultural land was covering more than 80% of the watershed area (Figure 1). Topographically, this site is situated from elevation of 500 m.a.s.l. to 1,450 m.a.s.l. High deforestation for agriculture compounded by low conservation practice and high rainfall intensity is causing soil erosion in this area and sedimentation downstream [2].

Figure 1. Map of the study site

2.2. Soil erosion assessment
The RUSLE model integrated with Arc GIS 10.3 software was used for soil erosion assessment in this study. This model consists of five parameters as shown in equation 1 [5]. These parameters were presented in the grids form (raster format). Hence, the average value of soil erosion from those grids (land units) can be obtained from spatial analysis of the Arc GIS 10.3.

\[ AE = R \times K \times LS \times C \times P \]  

where AE is the average soil loss [t ha\(^{-1}\) yr\(^{-1}\)], R is the parameter of rainfall erosivity (MJ mm ha\(^{-1}\) h\(^{-1}\) yr\(^{-1}\)), K is the parameter of soil erodibility (t h MJ\(^{-1}\) mm\(^{-1}\)), LS is the parameter of slope length-steepness (dimensionless), C is the parameter of land use management (dimensionless), and P is the parameter for conservation activity (dimensionless). The value of those parameters was collected from some sources from the period of 2015 to 2019.
2.2.1. Rainfall erosivity (R). Parameter of rainfall erosivity expresses soil particle's potency for destruction by rainfall energy and flowing by runoff. The rainfall erosivity parameter was estimated by considering rainfall value as expressed in equation 2 [6].

\[ R = \sum_{i=1}^{12} 2.2 (R_i)^{1.36} \]  

where R is rainfall erosivity, R\(_i\) monthly rainfall (cm). The data of rainfall were obtained from four rainfall stations as shown in Figure 1. The map of rainfall erosivity (R) for the study site is presented in Figure 2a.

2.2.2. Soil erodibility (K). Parameter of soil erodibility expresses the resistance of soil particles decomposition by rainwater energy. Therefore, the value of K was commonly determined by considering the soil type. Soil erodibility in this study was estimated based on the reference value of soil erodibility for some types of soil in Java Island of Indonesia [7]. The soil map showed that the study site is covered by latosolic red-yellow soil [8]. The value of soil erodibility (K) for this soil was 0.36 t h MJ\(^{-1}\) mm\(^{-1}\).

2.2.3. Slope length–steepness (LS). LS expresses the effect of the slope length-steepness parameter on soil erosion. Parameter of slope length-steepness (Figure 3a) was estimated by using equation 3 in ArcGIS 10.3 [9, 10]. Flow accumulation and slope of the land in equation 3 were calculated from Digital Elevation Model (DEM) data of the study site obtained from the United States Geological Survey (https://www.usgs.gov/).

\[ LS = \left( \frac{\text{flow accumulation} \times \text{grid size}}{22.13} \right)^m \times \left( \frac{\sin \text{slope}}{0.0896} \right)^n \]  

where flow accumulation is the effect of accumulated slope on soil erosion, the grid size is the resolution of data. The value of m and n for equation 3 were 0.5 and 1.4 for an area dominated by agricultural land [10].

2.2.4. Land use management (C) and conservation activity (P). Parameter of land use management and conservation activity express the effect of these factors on soil erosion. In this study, these factors were calculated as a CP factor and determined based on the reference value of CP factor for some land use types in Java Island of Indonesia as proposed by Asdak in 2007 [6]. The land use map in the study site was gained from the geospatial information agency of Indonesia in 2019. There were five types of land use in the study site. The CP value for those land use types (Figure 3b) were 0.02 (rice field), 0.05 (forest with a few of litter), 0.1 (shrub), 0.2 (settlement), and 0.51 (dry agricultural land).
Figure 3. Map of slope length–steepness (a) and land use management-conservation activity (b)

2.3. Soil erosion classification and modelling
The modelling was performed by enhancing vegetation cover (forest) from the existing condition 4.8% (forest and shrub) to 10%, 15%, 20%, 25%, and 30%. A maximum vegetation cover of 30% was determined based on socio-economic consideration where land occupancy by the local inhabitant was high (more than 80%), hence a higher vegetation cover scenario was hard to be applied. For knowing the effect of vegetation cover on soil erosion in detail, soil erosion was classified into five categories 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\(^{-1}\)) according to the classification system of the Department of Forestry Indonesia [11,12].

3. Results and discussion

3.1. Soil erosion in existing and vegetation cover 10% condition
Arc GIS divided a map (raster data) into grids in a square form with the size as composed in the map resolution size. Spatial analysis tools of Arc GIS enable soil erosion assessment in the grid's base. The assessment showed average soil erosion of about 71.1 t ha\(^{-1}\) yr\(^{-1}\) in the study site (moderate category). There were about 464,073 grids resulted in the soil erosion map. Soil erosion was high in the area with a high land slope as shown in Figure 4a. The same procedure was also used for soil erosion assessment under vegetation cover 10% condition. The result showed that average soil erosion in this condition was 39.5 t ha\(^{-1}\) yr\(^{-1}\) (low category) as shown in Figure 4b. There was about a 44.4 % reduction in soil erosion from the existing condition. The green color indicated an area with low soil erosion, whereas the red color indicated an area with heavy soil erosion.

Figure 4. Soil erosion in existing (a) and vegetation cover 10% (b) condition
As a model validation, the result in the existing condition was compared with the result of soil erosion studies in two different watersheds of Java Island which were validated by using soil erosion plot and field assessment of sediment deposit [13,14]. The result showed that there was no significant difference between those studies means that the RUSLE model was acceptable in this study. It can be used for soil erosion model validation when field measurement data is not available as shown in some past studies [15,16].

3.2. Soil erosion in vegetation cover 15% and 20% condition
The increase of vegetation cover to 15% and 20% reduce soil erosion into 31.8 t ha\(^{-1}\) yr\(^{-1}\) (19.5%) and 25.5 t ha\(^{-1}\) yr\(^{-1}\) (19.8%) as shown in Figure 5. These soil erosion values were still in the low category.

3.3. Soil erosion in vegetation cover 25% and 30% condition
The increase of vegetation cover to 25% and 30% reduce soil erosion into 20.65 t ha\(^{-1}\) yr\(^{-1}\) (19%) and 17.05 t ha\(^{-1}\) yr\(^{-1}\) (17.4% and low category) as shown in Figure 6.

3.4. Vegetation cover-soil erosion correlation.
The result indicated the highest soil erosion reduction in the increase of vegetation cover from existing conditions (4.8%) to 10% condition. It reduces about 44.4% of soil erosion, while in the other vegetation cover conditions, it reduces about 19%. Generally, the increase in vegetation cover from 4.8% to 30% reduces about 76% of soil erosion (Table 1). The increase of 5% vegetation cover reduces soil erosion by about 10.81 t ha\(^{-1}\) yr\(^{-1}\) or about 24%.
Table 1. Vegetation cover-soil erosion correlation

| Vegetation cover | Soil Erosion (t ha\(^{-1}\) yr\(^{-1}\)) | Category | Reduction (%) |
|------------------|----------------------------------------|----------|---------------|
| Existing (4.8%)  | 71.2                                   | Moderate | -             |
| 10%              | 39.5                                   | Low      | 44.4%         |
| 15%              | 31.8                                   | Low      | 55.3%         |
| 20%              | 25.5                                   | Low      | 64.1%         |
| 25%              | 20.65                                  | Low      | 71.0%         |
| 30%              | 17.05                                  | Low      | 76.0%         |

The effect of vegetation on soil erosion may differ in each region, affected by the environmental condition. Studies by Zou et al. in 2008 [17] and Eshghizadeh et al. in 2016 [3] indicated more than 30% vegetation cover was required to reduce soil erosion into tolerable value. In the situation where the dependence of the local community on the land is low, reforestation in the upstream area by increasing vegetation cover more than 30% is possible. In reverse conditions (high dependence of the local community on the land), a combination of vegetative methods and conservation structures offer a more reliable way to control soil erosion.

4. Conclusions
Soil erosion in the existing condition was in the moderate category. The increase of vegetation cover from the existing condition of 4.8% to 30% reduces about 76% of total erosion and changes the category of soil erosion rate from moderate to low. The land slope was significantly affecting soil erosion in the study site. Hence, the increase of vegetation cover for soil erosion control must consider the land slope distribution, to reduce soil erosion into tolerable value. Agricultural practices with a low risk of soil erosion were possible in the study site by maintaining 30% of vegetation cover in the steeply sloping area.

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