Soil erosion and its correlation with vegetation cover: An assessment using multispectral imagery and pixel-based geographic information system in Gesing Sub-Watershed, Central Java, Indonesia

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Abstract. Soil erosion in caused by five factors: rainfall erosivity, soil erodibility, slope and slope length, crop management, and land conservation practices. In theory, vegetation as one of the affecting factors has invers correlation with soil erosion. This research is aimed to: (1) model RUSLE using pixel-based GIS, and (2) prove whether or not vegetation really has the said correlation with the soil erosion that occurs in Gesing Watershed. The method used in this research is divided into two: the use of RUSLE to estimate the soil erosion rate; and the use of fractional vegetation cover (FVC) formula to estimate the vegetation density in the area. Both methods used Landsat-8 OLI imagery, which is used to extract the RUSLE parameters as well as to derive the vegetation density through NDVI, and pixel-based GIS. The mapping of soil erosion rate distribution done in this research demonstrated that pixel-based modeling is able to represent a much more detailed and logical distribution of a phenomenon. The distribution of soil erosion rate in Gesing Watershed showed that the erosion rate in this area is relatively minor. About 1425.99 hectares and 1587.57 hectares of the total area have erosion rate of 0 – 15 tons/ha/yr (very mild) and 15 – 60 tons/ha/yr (mild) respectively.

1. Introduction
Soil erosion is one of many environmental problems that has to be managed. This natural phenomenon is the main cause of many cases of land degradation, regardless of the environmental condition whether it is arid or wet. Furthermore, the high intensity of rainfall may cause soil erosion to rapidly transport soil from its original place through overland flow [1]. Soil erosion which occur in a watershed boundary is basically caused by four factors: climate, the characteristics of soil, topography of the area, and landcover vegetation [2]. Vegetation effect on soil erosion can be identified from two conditions, canopy condition and basal area condition [3]. Tree canopy condition is related to the ability of trees to intercept rainfall and reduce the destructive energy to create raindrop erosion or splash erosion. Basal area vegetation, such as the presence of dry leaves, grass and other plant residue, can reduce overland flow which is the cause of sheet erosion. Moreover, basal plant roots provide open pores on the ground’s surface, where water can seep through and increase rainfall...
infiltration. The roots interweave with each other and create a more solid mass of soil which is more resistant to erosion [4]. Therefore, vegetation cover gives a very big influence in the soil erosion rate that occur in a certain watershed or area. This research is aimed to show the correlation between soil erosion, which is obtained by using RUSLE formula, and vegetation cover density, which is extracted from fractional vegetation cover (FVC).

2. Area of study
This research was held in Gesing Sub-Watershed, that is located in the eastern District of Purworejo, Central Java. This sub-watershed covers the area of 47.09 km$^2$ and most of its area is located in western part of Menoreh Hills, which is shown in figure 1.

![Figure 1. The location of Gesing Sub-Watershed](image)

3. Data and methods

3.1. Data
The remotely sensed data used in this study in Landsat-8 OLI imagery (path 120 row 60) which was obtained in February 22nd 2015. Not all bands are used in this study, only band 2, band 3, band 4, and band 5 were used to extract landuse information as well as land unit information, with the help of a geologic map in a 1:50000 scale.

_Peta Rupabumi Indonesia_ (Indonesian Base Map) was also utilized to get the contour data which was used to delineate the watershed boundary (in the form of triangulated irregular network), also as an input in the calculation of slope and slope length indices (SL in RUSLE, in the form of _flow accumulation_).
The secondary data of monthly rainfall from the year of 2004 until 2013 was obtained from the Central Java Meteorology and Climatology Agency.

3.2. Methods

3.2.1. RUSLE Model

In RUSLE model, there are five parameters affecting the rate of soil erosion: rainfall erosivity (R), soil erodibility (K), slope and slope length (LS), crop/cover management (C), and land conservation practices (P). All of those are combined to form this equation:

\[ A = R \times K \times L \times S \times C \times P \]  

(1)

3.2.2. Rainfall Erosivity Index (R)

Soil erosion, is basically the loss of soil caused by the detachment from the ground’s surface by raindrops. The heavier the rain, the bigger the raindrops, which will cause more soil particles to be detached from the surface. Using the rainfall data in 10 years span, rainfall erosivity is calculated using the equation formulated by Mahmud and Utomo [5].

\[ R_b = 10.80 + 4.15(H_b) \]  

(2)

Where \( R_b \) is the monthly erosivity index, and \( H_b \) represent the average rainfall per month in centimeter unit. The use of this equation is primarily caused by the unavailability of daily rainfall data provided by the Meteorology and Climatology Agency.

3.2.3. Soil Erodibility Index (K)

Erodibility is defined as the soil vulnerability to erosion [2]. It is mostly dependant on the texture of the soil, the stability of soil aggregation, infiltration capacity, and also the the contents of organic and chemical materials [6]. The equation for K index used in this study is formulated as follows [6]:

\[ K = 1.292 \left[ 2.1 \times 10^{-6} \times (\% silt \times (100 - \% clay))^{1.14} \times (12 - \% OM) + 0.0325 (S_s - 2) + \frac{0.025}{f_{pm} - 3} \right] \]  

(3)

Where \( S_s \) is the soil structure with values of: 1 for very fine granular, 2 for fine granular, 3 for medium or coarse granular, and 4 for blocky, platy, or massive; \( f_{pm} \) stands for soil permeability class with the values of: 1 for very slow infiltration, 2 for slow infiltration, 3 for moderately slow infiltration, 4 for moderate infiltration, 5 for moderately rapid infiltration, and 6 for rapid infiltration.

3.2.4. Slope and Slope Length Index (LS)

Area with higher slope and longer slope length tend to have higher soil erosion rate. In flat surface, raindrop splash will only cause the soil particles to detach in various directions, whereas in a sloped surface, those particles will detach only in the direction of the slope [7]. How much soil detached from ground surface, in this case, depends on the degree of the slope; the greater the slope, the larger the amount of soil lost because of detachment. The LS index is extracted using flow accumulation which can be formulated using the Moore and Burch equation [8]:

\[ LS = \left( \frac{\text{flow accumulation} \times \text{cellsize}}{22.13} \right)^{1.1} \times \left( \frac{\sin \text{slope}}{0.0896} \right)^{1.1} \]  

(4)

3.2.5. Crop Management Index (C)

Crop and management index can be obtained by using multispectral classified landuse information and a C-index table from literatures, but this method can be a little difficult to work with sometimes, especially if the C-index table cannot represent the landuse present in the study area. In this case, this
study utilizes the C-factor from normalized vegetation index (NDVI) as suggested by De Jong [9]. The NDVI indices of vegetated area (forest) and open area (bare soil) present in Gesing Watershed are then analyzed through a regression analysis as dependent variable, while the independent variable is the sample index of 1 for forest (or dense vegetation) and 0 for bare soil.

3.2.6. Conservation Practice Index (P)
Multiple informations, such as administration boundary, landuse, and slope, were used to obtain the P-factor. Slope can sometimes give variations to the conservation practice of one type of landuse, certain landuse in steep slope are sometimes left as is it with no conservation applied. On the other hand, administration boundary affect the conservation practice through how agricultural instructions from agricultural/ forestry institutions are delivered. The value of each P-factor is obtained through field observation and matching the practices found in field with literary P-factor table by Abdurakhman [10].

3.2.7. Fractional Vegetation Cover (FVC)
Fractional vegetation cover refers to percentage of vegetation cover in one pixel [11]. FVC can be considered as a derivative of Normalized Difference Vegetation Index since it is formulated using NDVI values.

\[
FVC = \left( \frac{1}{\text{NDVI}_v - \text{NDVI}_s} \right) \times \text{NDVI} + b \times 100
\]

NDVI\(_v\) refers to the NDVI value for forest or dense vegetation (NDVI = 1 or NDVI\(_{\max}\)), while NDVI\(_s\) refers to NDVI value of bare soil (NDVI = 0 or NDVI\(_{\min}\)). Field observation was done in the study area to retrieve 25 point samples in total of places with dense vegetation cover and places with bare soil. The vegetation density of the 25 sample points extracted from both FVC and field observation are then analyzed using regression to obtain the actual vegetation density.

4. Results and discussion

4.1. Soil erosion in Gesing Sub-Watershed
The soil erosion in Gesing Sub-Watershed, form the appearance of it in figure2, can be considered not very serious. The areas with varying rates are mostly located in the mid-watershed section. Table 1 shows that erosion rate of 15-60 t/ha/yr is dominating the sub-watershed with the area of 1587.57 ha, while the more severe rate of 60-180 and 180-480 t/ha/yr are only distributed only in some areas.

| Watershed Section | Soil Erosion Rate (ton/ha/year) | Area (ha) |
|-------------------|---------------------------------|-----------|
|                   | 0 – 15                          | 15 - 60   | 60 - 180 | 180 – 480 | >480 | Area (ha) |
| Lower             | 594.82                          | 109.70    | 13.30    | 717.82    | 267.55 | 7.83 | 3010.12 |
| Mid               | 455.98                          | 1080.23   | 1198.53  | 267.55    | 7.83   | 4941.71 |
| Upper             | 375.19                          | 397.64    | 154.39   | 14.49     | 941.71 |

4.2. Vegetation cover of Gesing Sub-Watershed
The information of vegetation cover and density are retrieved through field observation in 25 points all over Gesing Watershed. From the regression analysis with the FVC vegetation density, the correlation coefficient of 0.615 shows the great correlation between the field vegetation density and the FVC density, and by using the regression formula, the actual vegetation density is extracted and is shown in figure 3.
Table 2. The area of each vegetation density class in Gesing Sub-Watershed

| No. | Vegetation Density | Area (ha) |
|-----|--------------------|-----------|
| 1.  | 0 – 20%            | 227.96    |
| 2.  | 20 – 40%           | 116.12    |
| 3.  | 40 – 60%           | 473.95    |
| 4.  | 60 – 80%           | 2017.9    |
| 5.  | 80 – 100%          | 1872.88   |

The classification for the vegetation density is divided into 5 classes standardized by the Department of Forestry in 2004 [12]. From figure 3, it can be seen that the vegetation density of Gesing Sub-Watershed is somewhat dense, because most of its area is dominated by forests, as seen in Figure 4. It is visible that the mid section and the upper section of the watershed has fairly high vegetation density, but compared to the upper section, the mid section has more areas with very high vegetation density (80-100% coverage). The mid section of the watershed is dominated by forests; natural forests in the mid-lower section and production forest in the mid-upper section. Natural forest consists of mainly wild bamboos and shrubs grown in sloped areas with no conservation practice, while the production forest consists of allelopathic trees such as teak (*Tectona grandis*) and mahogany (*Swietenia mahogani*) which are able to retard the growth of the basal vegetation.
4.2.1. Correlation between vegetation cover density and soil erosion rate

Table 3 shows that soil erosion is still inevitable in areas with high vegetation density (60-100% coverage). The theory says that the higher the vegetation coverage/density, the lower the erosion rate; but this is not the case in this study. From the condition of the sub-watershed itself, the areas with high vegetation density are located mostly in the mid-watershed section. Moreover, the areas with high erosion rate are also located in the mid-watershed section. In this case, the high vegetation density in Gesing sub-watershed does little effect in minimizing soil erosion rate. The cause may come from the vegetation types existing within the mid-watershed section that are mostly allelopathic or grown in areas without conservation practices. Allelopathic vegetation negatively affects the growth of other plants, especially basal vegetation. It had been said before that basal cover helps reduce soil erosion by encouraging rainfall infiltration, but because of the lack of basal cover present, water tends to run on the ground surface in the form of overland flow. On the other hand, natural forest with high density of shrubs and wild bamboos in the areas without any kinds of conservation practice makes it easier for the soil to detach and move down the slope, hence the occurring soil erosion.
Table 3. Area of Gesing Watershed based on the vegetation density and soil erosion

| Soil Erosion Rate | 0 - 20% | 20 - 40% | 40 - 60% | 60 - 80% | 80 - 100% | Area (ha) |
|-------------------|---------|----------|----------|----------|-----------|-----------|
| 0 - 15 ton/ha/yr  | 146.97  | 67.80    | 202.51   | 370.54   | 638.17    | 1425.99   |
| 15 - 60 ton/ha/yr | 64.08   | 28.52    | 108.91   | 609.48   | 776.57    | 1587.57   |
| 60 - 180 ton/ha/yr| 13.14   | 10.83    | 101.62   | 819.83   | 420.80    | 1366.22   |
| 180 - 480 ton/ha/yr| 2.13   | 6.22     | 50.71    | 197.10   | 25.88     | 282.04    |
| >480 ton/ha/yr    | 0.81    | 0.64     | 2.84     | 3.30     | 0.24      | 7.83      |
| Area (ha)         | 227.14  | 114.01   | 466.59   | 2000.25  | 1861.67   | 4669.65   |

5. Conclusion

Gesing Sub-Watershed, although most of its area is covered by high density vegetation, still has many areas with severe soil erosion rate. The vegetation cover is supposed to have an inverse correlation with the rate of soil erosion, but that does not seem to be case in this study. Based on the result of this research, the internal and external conditions of the vegetation in the area give an important influence on the vegetation-erosion relationship. The allelopathic characteristic of the planted vegetation present in the study area turns out to be giving a significant effect on how the presence of basal cover affects the rainfall infiltration. Conservation practice also gives a crucial influence on soil erosion, especially in sloped areas.

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