Scenario of Vegetation Density for an Erosion Prediction Model

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Abstract: The aim of this study is to create a scenario for investigating the factors that affect the vegetation density and to design the formulation of vegetation density as one of the factors on the revised universal soil loss equation. The methodology consists of 1) measuring vegetation density in 10 watersheds/sub-watersheds by using satellite imagery and field observation; 2) studying the factors that influence vegetation density based on literature review; 3) determining the dominant factors that influence vegetation density based on statistical analysis; 4) formulating vegetation density based on the statistical analysis results; and 5) validating the formulation of vegetation density using the universal soil loss equation as the control. The result is expected to allow for prediction of the effect of reforestation on decreasing soil erosion.

Keywords: vegetation density, factor, erosion, watershed

1. Introduction

To date, the methods to predict soil erosion that are generally used are the USLE and RUSLE methods. Some researchers doubt the accuracy of the two methods. This is due to the data input that are difficult to be obtained accurately [1]. The data of soil erosion is used as the main input of sediment analysis in the river. The amount of erosion that occurs is affected by several factors, which are rainfall, topography, soil type, and regional management [2]. There are a variety of conditions for the factors, which make soil erosion difficult to be predicted. Therefore, the accuracy of soil erosion prediction is still very low.

Based on the reasons above, some problems can be identified in the prediction of soil erosion. 1) In the analysis of soil erosion by using the USLE and RUSLE methods, determining the parameters of topography, soil erodibility, and regional management is still difficult to a certain level of accuracy, and thus they are evaluated by certain approaches [3]. The topography factor is evaluated by land slope, the erodibility factor is evaluated by soil type, and the regional management factor is evaluated by land use. 2) In the prediction of soil erosion using the RUSLE method, the surface flow is evaluated by the land unit, such as a watershed. However, the consequence is that the land unit used as the base of this analysis has to be sufficiently large. 3) Reforestation is a government program that will decrease the sediment that enters rivers [4] [5] [6]. Reforestation will increase the percentage of land cover or vegetation density, which will reduce erosion. However, the size of the effect of
reforestation on decreasing sedimentation in a river or reservoir has not been well-predicted [7]. 4) Reforestation generally can be carried out by using herbaceous or other types of plants. In relation to soil erosion, the effect of reforestation on soil erosion is that if the reforestation activity can increase vegetation density, because of closer distances between vegetation, the surface runoff will decrease. 5) To find out the relationship between the level of vegetation density and soil erosion, data is needed on the amount of soil erosion that occurs due to various levels of vegetation density, with the condition that the other parameters are fixed.

The aim of this research is to predict the factors that affect vegetation density. Further, this study uses the factor of vegetation density for a model of erosion prediction.

2. Materials and Methods

This research analyses the relationship model between the level of vegetation density and the level of soil erosion. If the model can be built with good validity, it will be able to predict soil erosion based on the available vegetation density. For example, if the vegetation density level is 30%, the soil erosion that occurs would be X ton/ha/area, or if the vegetation density level is 60%, the soil erosion that occurs would be Y ton/ha/area, and so on.

The research location is the Brantas River area. To build the model of soil erosion by considering the vegetation density, 10 watersheds were selected in the Brantas River area with vegetation densities of < 20 %, 20-40 %, 41-60 %, 61-80 %, and > 80%. The model verification uses the Lesti watershed, which is geographically located in the southern part of Malang Regency. The main river in the Lesti watershed is the Lesti River and the area of Lesti watershed is 63.754 ha.

This research is divided into four parts, which consist of the analysis of the level of vegetation density in the research watershed, analysis of soil erosion based on the level of vegetation density, construction of a relationship model between vegetation density and the level of soil erosion, and to carry out model validation and verification. Principally, the following are the steps of the research method:

1. Analysis of the vegetation density in the Brantas River area: Analysis of vegetation density level can be carried out using two methods, which are interpretation from a land use map and prediction by using remote sensing of satellite imagery. The interpretation of a land use map is carried out if there is an available land use map for the research location; if not, remote sensing of satellite imagery is performed. The results are used to classify watersheds based on these levels of vegetation density: < 20 %, 20-40 %, 41-60 %, 61-80 %, and > 80 %).

2. Analysis of soil erosion using the USLE method: Calculation of soil erosion in every watershed due to certain vegetation densities utilized the USLE method. The factors of R, L, S, K, and CP are known from the physical condition of the watersheds.

3. Modification of the USLE method by adding the factor of vegetation density percentage: This analysis was carried out for all watersheds. The results were then compared with the results of step 2 as above. If the results are not the same, the coefficient factor (f) is multiplied with the CP in the USLE equation. In this way, the USLE equation will become $E = R \times LS \times K \times f \times CP$ (the value of f may be different for the variety of vegetation density: < 20 % (f1), 21-40 % (f2), 41-60 % (f3), 61-80 % (f4), and > 80 % (f5)).

4. Verification of the modified soil erosion model: The model results were verified by comparing the results of soil erosion in another watershed (Lesti watershed) and the model results by using the modified USLE method.

5. To make sure that the modified model can be used on various soils, the modified model was applied outside of the research location. The selected location is a watershed in the Brantas River area. The level of vegetation density was analysed using satellite imagery.
Revised Universal Soil Loss Equation

For critical land, soil erosion is usually analysed by using the universal soil loss equation (USLE). Williams (1975) [8] concluded that sediment deposits in a basin are not calculated in the universal soil loss equation. This method more emphasizes on relatively plain agricultural use with a rainfall intensity that is not very high. Based on this reason, Williams modified the USLE by considering the factor of sediment deposits in the basin. The modification is by changing the rainfall erosivity (R) to the flow factor, with analysis of erosion as well as sediment movement in a watershed based on a single rainfall event. The modified USLE is called the revised universal soil loss equation (RUSLE) and takes the following form:

\[ E = R_w \times K \times L \times S \times C \times P \]  

(1)

Where:
- \( R_w \) = factor of surface erosivity according to Williams
- \( K \) = factor of land erodibility
- \( R \) = factor of rainfall erosivity
- \( LS \) = factor of land length and slope (topography factor)
- \( C \) = factor of crop (land preparation)
- \( P \) = factor of soil conservation technique

Surface Runoff Erosivity Factor

The factor of surface runoff erosivity is calculated with the formula of Williams (1975). As expressed in a study [8], the formula of Williams can be written as the following:

\[ Rw = 9,05 \left( \frac{Vo}{Qp} \right)^{0.56} \]  

(2)

Where:
- \( Vo \) = volume of surface runoff (m³)
- \( Qp \) = peak discharge (m³/s)

\[ Vo = R \cdot e^{-\frac{Rt}{Rc}} \]  

(3)

\[ Rc = 1.000 \cdot Ms \cdot \rho b \cdot RD \cdot \left( \frac{Et}{Eo} \right)^{0.50} \]  

(4)

\[ Ro = R / Rn \]  

(5)

Where:
- \( R \) = monthly/ yearly rainfall (mm)
- \( Rc \) = deviation capacity of soil moisture
- \( Ms \) = soil moisture content on the field capacity (%)
- \( \rho b \) = weight-volume of upper soil layer (mg/m³)
- \( RD \) = depth of effective roots (m), defined as an impermeable layer
  - For trees and woody plants: \( RD = 0.10 \)
  - For seasonal crops and grasses: \( RD = 0.05 \)
- \( Et/Eo \) = ratio between actual (Et) and potential (Eto) evapotranspiration
- \( Rn \) = number of rainfall days (hours)

\[ SY = a \left( \frac{Vo}{Qp} \right)^{b} \cdot K \cdot L \cdot S \cdot C \cdot P \]  

(6)

Where:
- \( SY \) = sediment yield in every rainfall event (ton),
- \( Vo \) = volume (m³),
- \( Qp \) = peak discharge
- \( a \) and \( b \) = coefficients, each being 11.8 and 0.56

By analysing soil erosion in different ways as with the USLE and RUSLE, different levels of land criticality may result.
3. Results and Discussion
Based on the equations above, soil erosion depends on the factors of rainfall intensity, slope length, land slope, soil type, land preparation, and crop management. The factors of rainfall and soil type cannot be minimized because they are natural factors. The factors of slope length and land slope also cannot be minimized. To minimize the factor of land management, land terracing is usually implemented, and to minimize the crop management [9], contour pattern is planting usually implemented.

Layers of land will peel off when exposed to rainfall. If the soil surface is directly exposed to rainfall, there will be a greater amount of peeled-off soil. However, if the soil is protected by crop or vegetation, there will be a lesser amount of peeled-off soil. Soil that is more densely covered by vegetation will have a lesser amount of direct exposure to rainfall. Therefore, as the vegetation cover becomes more dense, the amount of peeled-off soil becomes smaller. In other words, higher percentage of vegetation cover leads to a smaller amount of soil erosion. The factor of soil erosion decreases for every vegetation percentage class that becomes the focus in this research. If the factor of decreased soil erosion due to the vegetation density is represented by $f$, the equations above can be modified as the following:

$$E = R \times L \times S \times f \times K \times C \times P$$

Vegetation Density
The increased human demand for land use can decrease the level of vegetation density. The use of digital data makes it possible to obtain the distribution data of vegetation density for all types of land use. The identification of vegetation density can be carried out by interpreting satellite imagery digitally using the NDVI (Normalized Difference Vegetation Index) transformation. For this research, the obtained value of vegetation index in the Brantas watershed was utilized for finding the erosion level based on the level of vegetation density.

Rainfall
Rainfall erosivity is the ability of rainfall to cause erosion. To analyse the erosivity index, rainfall data is needed, which was obtained from a rainfall recorder. The analysis of rainfall erosivity index in this case utilized the equation of Bols (1978) [10] as shown below:

$$R = 6.12 \text{ (RAIN)}^{1.21} \text{ (DAYS)}^{0.47} \text{ (MAXP)}^{0.53}$$

(7)

Where:
- $R$ = yearly mean rainfall erosivity
- RAIN = yearly mean rainfall (cm)
- DAYS = amount of mean rainfall per year (days)
- MAXP = mean maximum rainfall in 24 hours per month for the period of 1 year (cm)

Slope Length and Land Slope
The factors of slope length ($L$) and land slope ($S$) are generally calculated together and mentioned as the topography factor ($LS$). The formula of $LS$ is shown below [10]:

$$LS = L^{0.5} \left( 0.00138 S^2 + 0.00965 S + 0.0138 \right)$$

(8)

Where:
- $L$ = slope length (m)
- $S$ = land slope ($\%$)

Factor of Land Erodibility
The factor of land erodibility ($K$) shows the resistance of soil particles to the process of peeling off and soil particles transport due to the kinetic energy of rainfall. The resistance depends on topography, soil texture, soil aggregate stability, infiltration capacity, organic content, soil chemicals, and the
magnitude of human disturbance [10]. The erodibility index was determined by using the Hammer method (1978) [11] as shown below:

\[
K = \frac{(2.713 \times 10^{-14})(12 - a) + 3.25 (b - 2) + 2.5 (c - 3))}{100}
\]

Where:

- \( M \) = from a table
- \( a \) = percentage of organic material
- \( b \) = the value of soil structure
- \( c \) = the value of soil permeability

The value of erodibility was obtained based on soil types, according to research results of several soil types on the island of Java. The values of erodibility can be seen in Table 1.

| Soil Type                     | Soil Type                        | Source                      |
|-------------------------------|----------------------------------|-----------------------------|
| Regosol, Jatiluhur            | 0.23 – 0.31                      | Ambar and Syarifuddin, 1979 |
| Latosol, Jatiluhur            | 0.16 – 0.29                      |                             |
| Red latosol, Jatiluhur        | 0.12                             |                             |
| Brown latosol, Jatiluhur      | 0.26 – 0.23                      |                             |
| Grumosol, Jatiluhur           | 0.31                             |                             |
| Grey Humic, Jatiluhur         | 0.20                             |                             |
| Hydromorphic, Kelabu          | 0.20                             |                             |
| Mediterranean, Yogyakarta     | 0.26                             | Kurnia and Suwarjo, 1977    |
| Lithosol, Yogyakarta          | 0.19                             | Bols, 1979                  |
| Grumosol, Yogyakarta          | 0.24 – 0.31                      | Centre of Environmental     |
| Mediterranean, Caruban        | 0.21 – 0.32                      | Studies UB, 1984            |
| Grumosol, Caruban             | 0.26                             |                             |
| Andosol, Pujon                | 0.04 – 0.10                      |                             |
| Cambisol, Pujon               | 0.12 – 0.16                      |                             |
| Mediterranean, Ngantang       | 0.20 – 0.30                      |                             |
| Lithosol, Malang Selatan      | 0.26 – 0.30                      |                             |
| Regosol, Malang Selatan       | 0.16 – 0.28                      |                             |
| Cambisol, Malang Selatan      | 0.17 – 0.30                      |                             |
| Mediterranean, Dampit         | 0.21 – 0.30                      |                             |
| Latosol, Malang Selatan       | 0.14 – 0.20                      |                             |
| Source: Utomo, 1994           |                                  |                             |

Analysis of soil erosion was carried out by using a GIS (Geographical Information System) by overlaying the layers of rainfall erosivity (R), topography (LS), soil erodibility (K), and land management (CP). The overlay became the land unit. Each land unit has specific values of R, LS, K, and CP. The soil erosion was calculated by multiplying the factors of R, LS, K, and CP for each land unit. The value of R, LS, K, and CP are the data attributes from all factors integrated into the GIS.

**Crop Factor**

The last factors of the USLE equation is C and P. The C factor indicates the overall effect of vegetation, soil surface condition, and land management on soil loss (erosion). However, the P factor, as the ratio of erosion of soil with certain material that is applied certain soil conservation treatments to the average erosion of soil with certain material without conservation actions, assuming that the other factors that cause erosion are assumed not to change. The practice of cropping, which is conducive to decreasing running water velocity and leads running water to directly flow to a lower place, can decrease the value of P. The assessment of P factor in the field is easier if done together with the C factor, because both factors are in fact quite related. Determining C and P is very
complicated because many factors have to be considered (Harjowigeno, 2001). In this study, the CP factor is determined by using the approach presented in Table 2.

Table 2. The value of CP factor for several crops in Indonesia

| No. | Type of crops               | CP Value |
|-----|-----------------------------|----------|
| 1   | Areas without crops         | 1.000    |
| 2   | Forest                      | 0.001    |
| 3   | Brush                       | 0.01     |
| 4   | Garden                      |          |
|     | - Mixture                   | 0.02     |
|     | - Garden                    | 0.07     |
|     | - Yard                      | 0.20     |
| 5   | Agricultural crops          |          |
|     | - Root vegetables           | 0.63     |
|     | - Grains                    | 0.51     |
|     | - Nuts                      | 0.36     |
|     | - Tobacco                   | 0.58     |
|     | - Mixture                   | 0.43     |
|     | - Paddy                     | 0.02     |
| 6   | Bench terrace + crops       | 0.01 – 0.07 |
| 7   | Contour terrace + crops     | 0.03 – 0.28 |
| 8   | Wide-bottomed terrace + crops | 0.03 – 0.37 |

Source: Utomo, 1994

4. Conclusion
Based on the literature study above, it can be concluded that the vegetation density is predicted as the factors of rainfall, slope length and land slope, land erodibility, and crop types. In addition, the vegetation density is predicted to affect the erosion model greatly.

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