Soil Erosion Analysis using RUSLE Model at the Minitod Area, Penampang, Sabah, Malaysia

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Abstract. Soil erosion is one of the leading causes of soil degradation and is often associated with agricultural intensification, deforestation and human activities that did not take care of environmental sustainability. Assessing the soil erosion is essential, and therefore, detail assessment on the prediction of soil erosion and its impacts has been carried out spatially using the application of the Revised Universal Soil Loss Equation (RUSLE) at the Minitod area, Penampang, Sabah, Malaysia. The parameters of the RUSLE model were determined using the Geographical Information System (GIS). There are six factors parameter maps were considered in RUSLE: rainfall erosivity factor (R), soil erodibility (K), slope length and steepness (LS), cover management(C) and conservation practice (P). These factors were calculated to determine their effects on annual soil erosion in the study area. About 36.65\% of the study area was classified as very low, 16\% as low, 15.71\% as moderate, 21.59\% as high and 10.09\% as very high. Soil erosion hazard has been identified using the model and found to be significant in areas with a slope above 25°. All findings showed that integration of GIS could be used for spatial analysis on a regional scale. Production of the value maps can be applied to development planning areas, especially for housing and agriculture developments.

1. Introduction
Soil erosion is one of the leading causes of soil degradation and is often associated with agricultural intensification, deforestation and human activities that did not take care of environmental sustainability. The interaction between land use, topography, rainfall intensity and soil types be made up of the soil erosion procedure in the biophysical environment [1].

Soil erosion is one of the potential risks of the study area, that might affect the study area and its surrounding environment. The most notable risks that associated with soil erosion are sedimentation to the lowland area and at the extreme level is the occurrence of the mudflow. Increased of deposition would affect the hydrological system of the stream due to the changes of the stream characteristic such as the depth of the drainage and the velocity of the water flow. An extreme situation would lead to the occurrence of the flash flood at the lower ground of the area.

The primary objective of this study is to determine the estimated average annual soil erosion (A) value spatially by using the Revised Universal Soil Loss Equation (RUSLE) model. Geographic Information Systems (GIS) technology had been used in the past decade to calculate and solve the issues related the soil erosion on a regional scale instead of at a field level [2]. The most frequent
methods used for soil erosion assessment is the Revised Universal Soil Loss Equation (RUSLE). Revised Universal Soil Loss Equation (RUSLE) is the altered form of Universal Soil Loss Equation (USLE), which has been used at different geospatial scales by dividing a region of appeal keen into sub-areas with similar parameters and connected with GIS framework [3].

Research topics related to soil erosion has its own history and scientific basis underlying all been researched for decades. However recently, continue to review progress and are increasingly focused on the topic in more detail about the modeling mechanisms. There are three types of soil erosion models in different research (Table 1): (1) Empirical model, which represents the natural environment or that are based on statistical observations of the empirical [4]. This model is often used for modeling complex process, particularly useful to identify the source of sediment. (2) Physical-based model represents the natural processes that describe each system by consolidating individual physical processes of more complex models. The equations in the model formula are illustrated by natural processes such as stream flow or sediment transport [5]. Perfection in this model can explain the spatial variability of its most important features found on the soil surface as topography, aspect, slope, vegetation, soil, climate and various other parameters including precipitation, temperature, precipitation and evaporation (evaporation) [6]. (3) Conceptual model is a mixture of empirical and model-based physical model (Table 1) and its application more applicable to answer general questions related to catchment processes [5, 7].

| Table 1. The variety of research models in soil erosion rates (modified from [7]) |
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| **Model types** | **Model Methods** | **References** |
| Empirical model | Musgrave Equation | Musgrave (1947) |
| Pacific Southwest Interagency Committee Method (PSIAC) | Pacific Southwest Interagency Committee (1968) |
| Dendy-Bolten Method Flaxman Method | Flaxman (1972) |
| Equation (MUSLE) Sediment | Renfro (1975) |
| Delivery Ratio Method | Dendy & Bolten (1976) |
| Universal Soil Loss Equation (USLE) | Wischmeier & Smith (1978) |
| Soil Loss Estimation Model for South Africa (SLEMSA) | Elwell (1978) |
| Physical-based model | Sediment Concentration Graph | Johnson (1943) |
| Erosion Kinematic Wave Models | Hjelmfelt et al. (1975) |
| Renard-Laursen Model | Renard & Laursen (1975) |
| Quasi-Steady State Areal Non-point Source Watershed Environment Response Simulation (ANSWERS) | Foster, Meyer and Onstad (1977) |
| Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS) | Knisel (1980) |
| Water Erosion Prediction Project (WEPP) | Laflen et al. (1991) |
| European Soil Erosion Model (EUROSEM) | Morgan (1998) |
| Conceptual model | Unit Sediment Graph | Rendon-Herrero (1978) |
| Instantaneous Unit Sediment Graph | Williams (1978) |
| Sediment Routing Model | Williams & Hann (1978) |
| Discrete Dynamic Models | Sharma & Dickinson (1979) |
| Agricultural Catchment Research Unit (ACRU) | Schulze (1995) |
| Hydrologic Simulation Programme, Fortran | Walton & Hunter (1996) |

2. Background of the Study Area
Minidot situated at the Penampang district and partly Kota Kinabalu area. The location of the study area is shown in Figure 1. It is bounded between latitude line N 05° 53’ 25” to N 05° 58’ 3” and
longitude line $E\ 116^\circ\ 02\ '\ 20\ "$ to $E\ 116^\circ\ 11\ '\ 52\ "$.

The topographic setting of this area is mainly controlled by its lowland in the western part and the mountainous region in the eastern part.

The rapid development in the study area where lands were cleared for construction activities. Landuse within the study area consist of secondary vegetation and shrubs (Figure 2). Thick vegetation cover is mostly covering the both sides of the ridge. A quarry activity can be found on the northern part of the study area. Adjacent to the study area (western part) are Country Height Apartment and Plaza, cemetery, Kg. Bantayan, Kg. Kitabu and Taman Putra Pogun. Other important landmark is, St. Marcellinus Church, Taman Sri Cassia, Chi Ying Shi Temple, Kg. Tindai, Kg. Sukang, etc. Earthworks are currently on-going at the top of the ridge (Figure 3).

![Figure 1. Location of the study area.](image)

![Figure 2. Shrub and secondary forest cover most of the western part of the ridge and the lowland area.](image)
3. Material and Methods

Soil erosion modelling was used to predict the likely amount of soil erosion. Some predictive models could be utilized as a predictor. The lack of data availability in the study area has limited the options for selection of data-intensive model. Perhaps, the most widely used and considered the most reliable method is based on the Universal Soil Loss Equation (USLE) [8, 9]. In RUSLE, the rainfall factor of the unique USLE was replaced by the rainfall erosivity factor [10]. The model is representing soil erosion risk by considering six factors, where each of the function is expressed numerically, forming an equation to predict soil loss. All these parameters were mapped in GIS raster format. It is represented by the following equation (1):

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

(1)

Where;
- \( A \) = estimated average annual soil loss (ton/ha-1/yr-1)
- \( R \) = rainfall erosivity factor (MJ mm ha-1 yr-1)
- \( K \) = soil erodibility factor (tons/ha-1/mm-1)
- \( L \) = slope length factor
- \( S \) = slope gradient factor
- \( C \) = vegetation cover-management factor
- \( P \) = support practices

3.1 Rain Erosivity Factor (R)

The rate of soil erosion is associated with the rainfall influence to break the soil surface and cause surface runoff to occurs [11, 12]. Has introduced the calculation to get the R values by referring to the annual average rainfall and intensity data for 30 minutes at a maximum for each gauge stations. The R factor measures the effects of the rain and yields the quantity and the rate of runoff factor [2]. The rainfall data obtained from Malaysia Meteorological Department (METMalaysia) were used to calculate The R based on the equation (2). The equation was chosen based on the previous study that suitable in tropical countries like Malaysia.

\[ R = [(9.28 * P) - 8838] * 1 \]  

(2)

Where;
- \( P \) = annual average rainfall
- 130 = rainfall intensity for 30 min.

![Image](image-url)

**Figure 3.** Earthworks on the top of the ridge in the study area.
The rain gauge stations have been registered into the GIS environment by entering the location coordinate. The average rainfall data for each rainfall station has been stored as an attribute in the GIS (Figure 4). Based on the input, a mean annual rainfall was considered and interpolated using Inverse Distance Weighting (IDW) to create a continuous raster rainfall data within the study area.

3.2 Soil Erodibility Factor (K)
Soil erodibility factor (K) defines the sensitivity of the land or soil component to erosion, the mobility of the silt, and the amount of runoff assumed an individual rainfall contribution as calculated in a standard form. The K factor values were obtained from the Department of Agricultural Sabah based on their soil type classification. All data were recorded in attribute tables using spatial vector format and later converted into spatial raster format using the conversion tools (Figure 5).

3.3 Slope Length and Steepness Factor (LS)
The topographic factor including the slope length and the steepness (LS) represents a ratio of soil loss below specified condition to the standard slope steepness and slope length. This equation can be changed according to the suitability of an area. The LS factor produces high flow velocity and surface runoff. Flow accumulation was the theme of the accumulated flow grid described as the number of pixels grid, while the cell size is the length size of pixels in the grid theme [13]. This process can be
obtained using hydrology tools in ArcGIS Arctool Box. The digital elevation model (DEM) has been used to generate the topographic map with contour gaps of 10 meters to produce the L and S. The DEM is converted into spatial raster format for further analysis. To generate the L, the data produced from the DEM required several steps like creating the fill DEM, flow direction and flow accumulation. While for the S, the steepness also generated from the DEM data. After the process of creating both completed, both raster data were calculated in the raster calculator based on the equation (3) to produce LS factor (Figure 6).

$$LS = Pow([\text{Flow accumulation}] * 10/22:13,0.4) * Pow(\sin([\text{slope}]) * 0.01745/0.0896,1.4) * 1.3$$

(3)

Figure 6. Slope Length and Steepness Factor (LS) map.

3.4 Vegetation Cover-Management Factor (C)
The vegetation cover-management (C) is defined as the ratio of soil loss from the soil surface with specific plant continuously until exposed [8]. The value of this factor depends on the soil covers, management practices and the growth and the protection at any time of the rain can cause erosion to take place. In this case, the C value is determined based on the type of land use in the study area (Figure 7). This data has been converted from vector to raster data after the digitizing process.

Figure 7. Vegetation Cover-Management Factor (C) map.
3.5 Supporting Conservation Practices Factors (P)

The P values are in the range of 0 to 1 and depend on land management activities in the study area. In this study, the P value for each of the types of soil obtained from [14] base on the classification of types of land use (Figure 8).

![Figure 8. Supporting Conservation Practices Factors (P) map.](image)

3.6 Average Annual Soil Loss Value Analysis (A)

The multiplication process between layers of thematic maps in RUSLE model will be done to obtain the final output spatial analysis. All six parameters map RUSLE factors (R, K, LS, C and P) will be multiplied using the raster calculator to get the total value of A.

4. Conclusion

The estimated soil erosion risk over the study area is shown in the following Table 2.

| Slope Range | Hectares | %    | Tons/ha/yr |
|-------------|----------|------|------------|
| <15°        | 30.00    | 58.9 | 496        |
| 15° – 25°   | 19.62    | 38.5 | 1042       |
| 25° – 35°   | 1.27     | 2.5  | 687        |
| 35° – 90°   | 0.03     | 0.1  | 365        |
| **Total**   | **50.92**| **100.0** |          |

Based on the slope analysis of the whole study area, 58.9% or about 30 ha of the land area has slope less than 15° and followed by slope range of 15-25° (38.6%). Slope area with above 25° was only about 2.6% or about 1.30 ha. High erosion risks were observed to be associated with steep slope, which is mostly found to the southern part of the study area (Figure 9). The erosion risks at the Minitod area were largely in the range of low to moderate risks.

Current assessment on the impact of the earthwork that is currently ongoing at the top and slope of the ridge (eastern part of the study area), is expected to create low to medium risks of sedimentation of eroded soil to the existing apartment, with the assumption that the earthwork is limited to the current area. However, any possibility of expansion of the embankment at the slope of the ridge (eastern part of the study area), runoff with eroded soil might potentially affect the existing residential area,
especially during heavy rain. The removal of vegetation at the slope, would reduce the filtering ability and therefore increase the erosion risk potential.

Figure 9. Potential erosion risks and erosion prone areas at the study area.

5. Conclusion
Soil erosion and its associated risks such as sedimentation and mud-flood of the property and its surrounding was mainly in the range between low to moderate. The higher risk was limited mostly in the steep slope above 25°, mostly at the south and southeast of the study area.

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