Application of USLE and MUSLE Models for the Assessment of Soil Loss and Sediment Yield in Kuala Kari, Kelantan

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Abstract. Soil loss is one of the most essential issues in the world. It is considered as the main source of sediment that introduces into the ambient environment and cause extensive impact to the. The objective of the current study is to estimate the soil loss and sediment yield by applying the Universal Soil Loss Equation (USLE) and Modified Universal Soil Loss Equation (MUSLE). Data from a real site which is located in Kuala Kari, Kelantan, Northern Malaysia was obtained and utilized in which the site is subdivided into five catchments. Results show that the sediment yield produced from all the catchments was very high which has a significant impact to the adjacent water bodies. It is recommended that erosion, sediment and drainage control measures need to highlighted in an Erosion and Sediment Control Plan (ESCP) to be installed in the site so as to minimize soil loss and sediments generated from the site.

Keywords: Control measures, Estimation, Malaysia, sediment yield, Soil loss.

1. Introduction

Erosion is the process of soil dislocating from their original place and conveyed by water and gravity [1]. Soil erosion occurs naturally but due to the various human activities, the process can be highly quickened [2]. Sediments that resulted from erosion processes will have major impact on the surrounding water bodies and the mitigation alternatives are costly [3]. Impact of sediments may affect the navigation, sewerage systems, capacity of reservoirs; increase the chances of floods and the development of algae blooms [4], [5]; [6] and [7] highlighted the impact of runoff which may destroy the riparian systems and losing the top soil which will leave the less fertile subsoil.

The Universal Soil Loss Equation (USLE) enables the planners for the prediction of the average soil loss on an annual based. Although the USLE was developed for predicting the soil loss from agricultural fields in which many researchers implemented the USLE for construction sites and prove that it is an essential means for estimating the real amount of erosion [8] and [9]. Many other studies have been performed for assessing the soil erodibility using the USLE model [10]; [11]; [12]; [13] and [14]).
Modified Universal Soil Loss Equation (MUSLE) which is the greatest applied approach for the sediment yield assessment [15]. Sediments can be categorized as the main pollutant that introduces into the surface water [16]. Sediments can be considered as a carrier for other types of pollutants since it is generated from the soil wash and the soil may include nutrients, minerals and so forth. It affects the water quality which can be used in recreation facilities, municipal supply and aquatic life. The heavy rainfall and highly weathered soils which are also highly erodible have caused a severe sedimentation to the adjacent water property in Malaysian construction sites as a result of land clearing and earth work activities [17].

The aim of this research is to predict the annual soil loss and sediment yield utilizing the USLE and MUSLE models in Kelantan, northern Malaysia. The USLE and MUSLE models parameters were based on Malaysian conditions and climate.

2. Study Area

The proposed project of 365 ha of secondary forest into a rubber tree plantation (Timber Latex Clone) is located in Kelantan State, Northern Parts of Malaysia. It is located 151 km North-East Gua Musang town, and 94 km South-East from Kota Bharu. The proposed development is in the Kuala Krai district, which will be planned as an Eco-tourism town under the Rancangan Struktur Negeri (RSN) Kelantan 2020. Thus, due to this, most of the development in Kuala Krai will be emphasized on industrial cluster of herbs and wood products. There is a local community of Kampung Kebun Pisang, “Rancangan Pembangunan Tanah” (RPT) Kampung Pasir Jering, Kampung Dusun Ban, Kampung Batu Pagar and Kampung Dusun Gunung which is located about 12 km from the Sungai Durian junction. From the village area, it will take about 19 km to reach the boundary of the proposed project site. The proposed project site location is illustrated in Figure 1.

![Figure 1. Location of the project area within Kelantan State](image-url)
3.0 Methodology

Erosion risk analysis is a planning tool to identify the possible impacts on the environment when a project is undertaken at a particular site. There are many techniques used to analyze erosion risk and these techniques are normally based on commonly used methodologies and models. However, the use of models for soil erosion and sediment yield prediction should be experienced with care taking into consideration their limitations and the reliability of the data available for the prediction. In this research, the soil loss and sediment yield were estimated for five catchments (see Figure 2) by applying the USLE and MUSLE respectively. Soil loss due to erosion can be estimated using Equation 1 (DID, 2010):

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

(1)

Where,

- \( A \) = Computed soil loss in units of tonnes/ha/year;
- \( R \) = Rainfall factor (EI- units) for the duration of concern;
- \( K \) = Soil erodibility factor depending on soil types. The erosion rate per unit of erosion index for a specific soil, on a plot of 9 percent slope and 22.1 m (72.6 ft) long; 
- \( L \) = Slope length factor, the ratio of soil loss from the field slope length to that from 22.1 m length on the same soil type and gradient; 
- \( S \) = Slope gradient factor; the ratio of soil loss from the field gradient to that from a 9 percent slope, on the same soil type and soil length; 
- \( C \) = Cropping management factor, the ratio of soil loss from a field with specific cropping and management to that from the fallow condition on which the factor \( K \) is evaluated; 
- \( P \) = Erosion control practice factor; the ratio of soil loss with contouring, strip-cropping or terracing to that with straight row farming, up-and-down slope.

As shown in Equation 1 above, there are four parameters were considered: \( R \) factor, \( K \) factor, \( L \) factor, and \( CP \) factor. The Rainfall Factor value can be expected from the rainfall erosivity maps which have been created by Department of Irrigation and Drainage (DID) Malaysia for the state of Kelantan or using equation 2 (DID, 2010) as follows,

\[ R = \frac{1}{n} \sum_{j=1}^{n} \left( \sum_{k=1}^{m} (E)(l_{30})_{kj} \right) \]  

(2)

Where,

- \( E \) = total storm kinetic energy; 
- \( l_{30} \) = maximum 30 minute rainfall intensity measured in mm/hr; 
- \( j \) = index for the number of years used to compute the average; 
- \( k \) = index of the number of storms in each year 
- \( n \) = number of years to obtain average, and 
- \( m \) = number of storms in each year.

The soil erodibility factor value can be predicted based on the soil maps generated by DID Malaysia or by using equation 3 as follows:

\[ K = \left[ 10 \times 10^{-4}(12 - OM)M^{1.14} + 4.5(S - 3) + 8.0(P - 2) \right]/100, \]  

(3)

Where,

- \( M \) = (% silt + % very fine sand) x (100 - % clay); 
- \( OM \) = % organic matter; 
- \( S \) = soil structure code, and 
- \( P \) = permeability class.

[18]; developed Equation (3) for the estimation of soil erodibility factor for Malaysia soil series. Slope length and steepness factor (\( LS \)) considerably affect soil erosion rate. (DID, 2010) guided the direct
estimation of slope length and steepness factors. At specific site, the couple of management factors for controlling the soil loss are the cover management and practice support. To predict the sediment yield \( (Y) \), the (MUSLE) Equation was adopted and applied as shown in equation 4 below:

\[
Y = 89.6 \left( V \cdot Q_p \right)^{0.56} (K \cdot L \cdot S \cdot C \cdot P)
\]

(4)

Where,

"89.6 = constant; \( Y \) = Sediment yield per storm event (tonnes); \( V \) = Runoff volume (m\(^3\)); \( Q_p \) = Peak discharge (m\(^3\)/s)"

The runoff volume can be estimated based on equation 5 which is recommended by the DID (DID, 2010) as follows:

\[
WQV = C_v \cdot (P_d) \cdot A
\]

(5)

Where,

"WQV = Water quality volume (m\(^3\)); \( C_v \) = Runoff coefficient (Unitless); \( P_d \) = Rainfall depth for water quality design storm (m); and \( A \) = Contributing drainage area (m\(^2\))."

In applying the MUSLE for the estimation of the sediment yield, the Rational Method and Time Area Method were used to predict the peak runoff. It is clear that the Rational Method was applied when the catchment area is less than 80 ha, else; Time Area Method was applied (DID, 2010).

4.0 Results and Discussions

The required information for the prediction of the loss of soil and the yield of sediments from each catchment include the slope length, slope steepness, soil data, land cover, catchment area, length of runoff path and the relevant ARI. Results from this study include "the estimation / prediction of soil loss and sediment yield" generated from the site. Based on the information gathered from the site (i.e. five sub-catchments), the calculations were carried out and presented in Table 1 as shown below:

| Cat. No. | R    | K    | LS   | CP | Soil loss (Tonne/yr) | Runoff vol. (m\(^3\)) | \( Q_p \) (m\(^3\)/s) | Sediment yield (tonnes) |
|----------|------|------|------|----|----------------------|------------------------|------------------------|------------------------|
| 1        | 15500| 0.005| 0.1471| 1  | 512.55                | 19196.07               | 2.666                  | 28.574                 |
| 2        | 15500| 0.005| 0.1531| 1  | 911.60                | 32803.25               | 4.5560                 | 54.196                 |
| 3        | 15500| 0.005| 0.1573| 1  | 649.76                | 22756.91               | 3.1606                 | 36.970                 |
| 4        | 15500| 0.005| 0.1640| 1  | 731.33                | 24567.22               | 3.4121                 | 41.996                 |
| 5        | 15500| 0.005| 0.1794| 1  | 1416.9                | 43511.39               | 6.043                  | 87.140                 |

In Table 1 above, the R factor and K factor estimation were based on the relative maps of the Kuala Kari, Kelantan (DID, 2010). It is observed that the sediment yield is very high which introduced lots of
sediments into the adjacent water body. Such quantity of sediments is going to have massive impact to the environment (impact the aquatic life, reduce navigation areas, etc). The sediment yield generated from catchment (5) is the highest among other catchments (87.140 tonnes) due to the LS factor and the runoff within the catchment. Catchment (2) is the second highest in terms of sediment generated (54.196 tonnes) followed by catchments (4, 3 and 1) which generate (41.996, 36.970 and 28.574 tonnes) respectively. To overcome this problem, an erosion and sediment control plan need to be highlighted and implemented especially in catchments with high runoff volumes and sediment yields. Thus, erosion control, sediment control and drainage control measures are required to be installed to minimize such massive issue. Figure 2 illustrates the relationship between the soil loss and sediment yield for the five catchments.

As shown in Figure 2 above, as the soil loss increases, the sediment yield increases as well since the dislocated and eroded soil is deposited into the adjacent water bodies.

5. Conclusions

Malaysia is a humid tropical country in which heavy rainfall occurs during the year round. The heavy rainfall together with loose soil will result in soil erosion that shall eventually being introduced to the adjacent water as sediments. The study area was sub-divided into five catchments with different areas. The "soil loss and sediment yield" were predicted for each catchment using the USLE and MUSLE respectively. The loss of soil and yield of sediment in catchment 5 is very high as compared to other loss of the other catchments which are 1416.9 tonne / year and 87.140 tonnes since the surface area is larger than other catchments. The sediments generated due to the eroded soil from this has a great impact to the ambient environment thus sediment and drainage control measures need to be installed according to a well prepared Erosion and Sediment Control Plan (ESCP) in order to minimize the amount of sediments and minimize the cost of dredging.
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