Special Issue 1 (2020) *e*-ISSN: 2682-8383

Journal of Engineering Technology and Applied Physics

Susceptibility to Soil Erosion and Risk Assessment at Hilly Farms Using Geospatial Techniques

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https://doi.org/10.33093/jetap.2020.x1.2

Abstract **- Soil erosion is a serious environmental challenge which persistently diminishes available land resources globally. The impact of soil erosion is more severe at hilly regions where various techniques are deployed to evaluate its risk levels. However, the traditional approach of estimating the magnitude of erosion is tedious, costly, and considerably time consuming. This study was intended to assess the risk associated with soil erosion at hilly areas of Cameron Highlands through geospatial means. The Digital Elevation Model (DEM) with 5m resolution from Interferometric Synthetic Aperture Radar (IfSAR) was utilized to generate the slope in the highlands. Soil erosion rates was estimated using Universal Soil Loss Equation (USLE), while information about land use and cover were sourced from relevant government agencies. Inversed Distance Weighted (IDW) method of spatial interpolation was applied to predict the values of unknown pixels. The analysis shows that, there is 217.5 km² of the highlands which is greater than 45-degree accounted for about 30.5% of the total land area. Moreover, erosion risk assessment indicated that 66.3%, 11.4%, 11.7% and 10.8% are respectively classified as very low, law, moderate and high susceptible to soil erosion. In general, the risk of soil erosion is relatively low and could be attributed to dense vegetation coverage within the study watershed despite the steep slopes where it was found to be at very high risk to soil erosion susceptibility. However, there is need to deploy best management practices to reduce the effect of soil disturbances at hilly areas and prevent excessive soil loss in future.**

Keywords— Rainfall Erosivity, soil Erodibility, IfSAR, GIS, USLE

I. INTRODUCTION

Soil erosion is one of the major environmental issues in the world and is becoming a serious limiting factor for crop production almost everywhere [1]. Soil erosion phenomenon constitutes three main processes; the detachment of individual particle from the soil mass, transportation of those detached particles by erosive agents such as wind or water and deposition of those detached particles as sediments at downstream [2, 3]. Thus, soil erosion affects ecology negatively with consequences of reducing available lands for other natural resources. These reductions include crop productivity reduction, water pollution, and lower effective capacity of water reservoirs. Its effect usually leads to flooding, landslides, and destruction of habitats [4, 5]. Consequently, erosion can be described as a natural geological phenomenon which occur as a resulting of removal of soil particles by water or wind, transporting them elsewhere [6–8].

Human activities on the other hand, such as agricultural operations, deforestation, mining and conversion of forest to agriculture exacerbate the process of soil erosion, particularly on steep slopes with minimum or no control measures put in place [5]. Erosion can also be accelerated by climate change, tectonic activities, and other natural disasters [9–11]. Soil erosion has become an environmental challenge in recent years particularly in areas where there has been intensive use of lands for agricultural activities and developments for urbanization, like Cameron Highlands [12]. Furthermore, soil erosion deteriorates water quality of the streams, aquatic life, water conveyance systems, reservoirs, etc. The chemical influx from pesticides, fungicide, and fertilizers applications due to agricultural activities on hilly farms could be carried and deposited downstream [13]. This could eventually alter the chemical concentration such as sodium, potassium, nitrogen, phosphorus, and heavy metals in the irrigation water which affect the crop physiological process [14].

Previous studies established that, processes of soil erosion are influenced by biophysical factors of environment comprising of soil characteristics, climate, topography, soil

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cover and interactions between two or more factors [5, 15–17]. Reference [8] shows that, terrain characteristics is particularly crucial factor affecting the mechanism and processes of soil erosion. This include slope, length, aspect and shape and topography play a vital role in runoff generation and transportation. There is direct relationship between slope and runoff energy as such, the high the slope more the runoff collected and thus reduces infiltration [2]. The amount of runoff generated from high slope will tend to flow though available drains which if not sufficient, would lead to soil erosion.

Favorable weather condition in Cameron highlands coupled with fertile soil provide conducive atmosphere for crop cultivation. Though, the highlands have limited available lowlands spaces, the expansion of farming has been initiated on hills with considerable high slopes [5, 6]. Thus, farmers mostly are those that were producing at commercial quantities started shifting their operations to hillside areas as a potential alternative. This activity then exacerbated soil erosion processes in hilly areas particularly in Cameron Highlands which has been faced with serious challenges of soil erosion and landslide incidences.

There are several methods of estimating extent of erosion and its associated risk of losing a valuable land resource. The conventional way involves direct field measurements and evaluation of erosion parameters [18]. These activities are often laborious and costly because it requires considerable time and energy inputs. However, geospatial techniques nowadays, revolutionized the processes by making it simpler and cost effective [19]. GIS and Remote Sensing have been used to acquire ground information directly and process it without physical contact with objects [20]. The benefits of these tools become obvious particularly in areas that are not easily accessible like hilly or remote forestlands. Study conducted by Reference [21] discloses the ranges of degree of accuracy within which the hilly areas can be effectively studied through geospatial approach. However, the disaster risks assessment using these tools is limited because unavailability of data in some hilly regions [22].

The main purpose of this study was to assess the risks associated with soil erosion susceptibility at hilly areas of Cameron Highlands using USLE and geospatial approach. It involved sourcing information from government agencies and geostatistical procedure to generate areas vulnerable to potential erosion risk.

II. Materials and Method

A. Study Area

Cameron Highlands is located at the Pahang of Peninsular Malaysia and situated on Latitude of 4° 28'N, and Longitude of 101° 23'E. The average temperatures are 24°C and 14°C during the day and night, respectively. The elevation ranges between 1070 m and 2020 m above mean sea level with average annual precipitation of 2660 mm [23]. The rainfall occurs regularly in Cameron Highlands with relative peak amounts during the two major monsoons of April and November. The months of October and November are considered the wettest months with monthly rainfall amount of about 350 mm. Conversely, the least rainfall amount normally happens in the month of January and February and are the driest periods with rainfall amount of about 100 mm. [21]. Spatial distribution of rainfall shows that, more rainfall occurs in southwestern region comprises of Kea Farm, MARDI, Habu and Tanah Rata sub-catchments. The Cameron Highlands watershed is regarded as a vital hill station for the country which occupies an area of 712.18 square kilometers (Fig. 1). The area is surrounded by Kelantan and Perak from north and west respectively and has a potential for growing a wide variety of vegetables, flowers, and other ornamental plants. The excellent climatic condition in the highlands provides opportunity for agricultural activities as the major business and attracts many tourists. However, the gradual deterioration of the weather conditions coupled with other environmental issues raised an alarm for investigation of soil erosion issue [12].

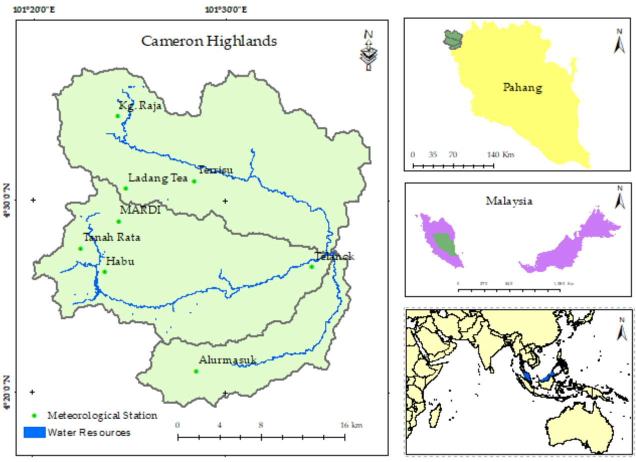

Fig. 1. Study area.

B. Assessment of Soil Erosion

The Cameron Highlands have been used for agricultural activities on regions characterized with rampant steep slopes. These operations make the highlands vulnerable to an accelerated soil erosion and sedimentation of downstream rivers. Consequently, it increases the risk of environmental disasters such as erosion, landslides, sedimentation, etc. Meanwhile, the agricultural area that have 45-degree slopes and above are selected for the purpose of this assessment using appropriate extension of ArcGIS10.5. The study area has been reported that, more than 60 percent of the highlands are above 15-degree slope [24]. Therefore, continue with agricultural operations in such situation are considered unsafe because it could lead to more erosion incidences.

Soil erosion can be estimated using Universal Soil Loss Equation (USLE) as proposed by reference [25] and used in many studies. This model was developed by the Department of Agriculture, United States of America, to support decision in soil conservation planning and management in Eq. (1). The model was further modified by many researchers to improve the prediction accuracy and to have wider range of applications. Reference [26] presented a method for estimating soil losses from fields of clay pan soils. Soil loss ratios at different slopes were given for contour farming, strip cropping, and terracing as well as limits for slope length for contour farming.

$$A = R \times K \times LS \times C \times P \tag{1}$$

, where

A = annual soil loss (tones/ha/year)

R = rainfall factor (MJ/mm/ha/yr)

K = soil erodibility factor (ton hour/ MJ/mm)

LS = slope length and steepness factors (dimensionless)

C = vegetation and management factor (dimensionless)

P = support practice factor (dimensionless)

C. Rainfall Factor (R-factor)

As a numerical index, the R-factor describes the aggressiveness of rainfall to erode a soil [27]. This factor is directly influenced by changes in precipitation pattern and is usually computed on monthly or yearly bases. There are many methods available for estimating R-factor which utilized different rainfall record series. Some methods used both annual and monthly rainfall data while some used total annual data only for computing the R-factor [28, 29]. This study uses equation proposed by reference [29] for calculation of the R factor based on empirical study in Indonesia as shown in Eq. (2). This equation is applicable to Malaysia because of similarity in climatic conditions with Indonesia and data for annual precipitation is easier to obtain than pluviographic data at 15 min intervals or less in a developing country.

$$R = \frac{2.5P^2}{100(0.073P+0.73)} \quad (2)$$

Where, P is the annual precipitation (mm)

D. Soil Erodibility (K-factor)

Tendencies of soil erosion depend largely on soil resistance to both detachment and transportability of detached particles [30, 31]. Some types of soil are not inherently resistant and are susceptible to erosion more than the others. K-factor of each soil is a function of its grain size, drainage or permeability, structure, organic matter content and cohesiveness of the aggregates. In addition, the K factor is a function of percentage of silt and coarse sand, soil structure, permeability, and soil type. In this study, the soil map was obtained in high resolution image format from Department of Agriculture, Malaysia (DOA). There are two classes of soil types sighted in the Cameron Highland region [18]. The K-factor value for those classes of the soil are extracted from the reference [23] and presented in Table I. Soil map was considered as a basic layer to derive the K factor layer. The vector soil map was converted into raster format using spatial analyst tool in ArcGIS. The values of soil layer were classified for each respective values of K factor using the reclassify tool of Spatial Analyst extension and subsequently raster layer of K factor was generated.

Table I. Soil erodibility factor in the study watershed.

Physical properties	**Soil series**	**Code**	**K-Factor**
Reddish yellow Podzolic soils with Lithosols on acid to intermediate igneous rocks	Soils of the Hills and Mountain (Steep land)	STP	0.1100
Podzols and Lithosols on acid igneous rocks at elevations of above 5000 feet	Serdang Kedah Durian Association	SDG-KDH-DG	0.1160

E. Topography (LS-factor)

LS-factor which is commonly regarded as a topographic factor has a profound influence on sediment transmittance and runoff characteristics throughout the runoff pathway. Many farms are sited on high slopes usually greater than 45 degree (Fig. 2). The L and S factors together signify the effect of steepness and slope length on soil erosion. The USLE model shows a combined effect of rill and inter-rill erosion. Rill erosion is mainly initiated by surface runoff and increases in downslope. Also, the inter-rill erosion is triggered principally by rain splash and is static along the slope [32]. Therefore, the L factor is greater where rill erosion tends to be greater than inter-rill erosion. In this work, Moore and Burch equation was applied to compute the LS factor in Eq. (3). The LS factor was computed using parameters such as flow accumulation, cell size and slope. It is observed that, the steeper and longer slope more the risk of higher erosion in many existing studies [33–35]. In this study, high resolution (5 m) digital elevation model has been applied to determine the extent area coverage of the hills to make classification based on slope gradients. Thus, to attain the desirable degree of resolution, IfSAR dataset was utilized. Flow accumulation was determined in ArcGIS10.5 environment.

$$LS = \left(\text{Flow accumulation} \times \frac{\text{Cell size}}{22.13}\right)^{0.4} \left(\frac{\sin(\text{slope})}{0.0896}\right)^{1.3} \quad (3)$$

Fig. 2. A typical Hilly Farm with slope greater than 45°.

F. Vegetation Cover (C-factor)

Soil erosion can be managed by adjusting the vegetation coverage and rates of soil disturbance in the field. Besides, erosion can be effectively reduced by increasing the amount of vegetation through reforestation. In this study, eight classes of vegetation covers were identified as Forest, water body, scrub, flower, mixed horticulture, urban settlement, bare land and tea farm. The C values for each vegetation class were excerpted from Tenaga National Berhad Research [34] and the reports of investigations established by previous studies [35, 36].

G. Support Practice (P-factor)

Conservation practices factor (P) explains the effect of erosion control practices on the soil such as sheltered cropping, unsheltered cropping, terraces, silt fences, subsurface drainage [21]. In some regions, alteration of support practices cannot be diagnosed via a land-use map because it usually lead to poor results [24]. Therefore, field investigation remains the best means to ascertain the level of supporting practice being applied and to gather the information required. In the present study, information about conservation practices was obtained from field survey. However, data on rain sheltered area was digitized from the 2 m resolution orthophoto for the entire project area [23]. Thus, the practice helps to reduce the cost of data acquisition on soil erosion affected area. Moreover, the studies obtained values of conservation practices (P) from the Department of Agriculture as shown in Table II [18]. This study presents details the study procedure which begins by obtaining land cover information, DEM from IfSAR, soil map and rainfall data which finally produced soil erosion susceptibility model.

Table II. Classification of land use factor.

Structure/ Practices	P factor
Bare land	1.0
Contour Planning	0.8
Grass Strip	0.5
Rain Shelter	0.1
Traditional Terraces	0.6

Moreover, the major activities involved for the erosion model are presented in the flow chart (Fig. 3). It comprises of four main input variables: Land cover, DEM, Soil Map and Rainfall data. To validate the model, field verification was conducted to ensure all farmlands are located within the slope of interest for the successful risk assessment. This procedure provides satisfactory outcome after visitation as most of the processed slopes using ArcGIS were found in conformity with what is obtainable in the field.

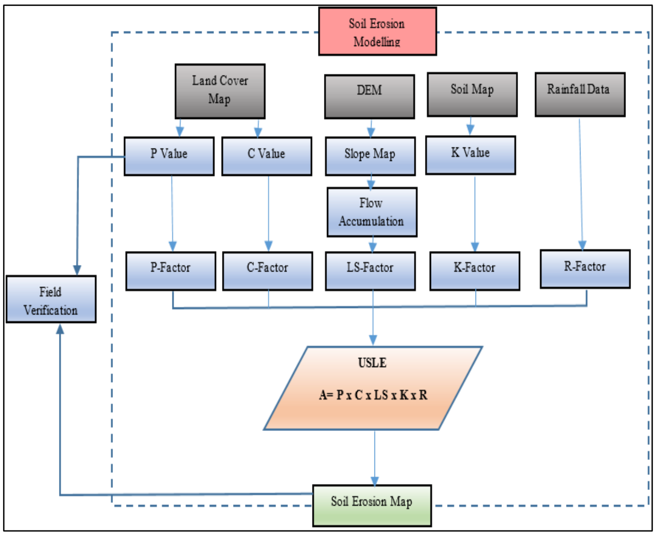

Fig. 3. Experimental flow diagram.

III. Results and Discussion

A. Classification of Hilly Lands Based the Slopes

The result of slope analysis for the highlands shows that 217.5 km^2 (30.5 %) of the area is classified as high erosion potential area whose slopes is 45 degree and above (Fig. 4). It is clear that most of these regions are either developed or undergoing the process of developments. The major crops planted on hilly farms comprised of tea, fruits, and vegetables. Moreover, major towns in the area include Tanah Rata, Kg. Habu, Complex Pertanian, MARDI, Terrisu and Alurmasuk sub-basins. It was found that these regions are undergoing intensive agricultural operations and conversion of forest into residential areas. This findings support the claim made by reference [21] which is in agreement with the reports provided by reference [18] that, there is rapid conversion of forest to agricultural farms in Cameron Highlands. Although, large agricultural farms (about 57.6 %) are prepared under shelter system which ensure diversion of rain drops away from direct contact with both crops and soil. However, the huge surface runoff generated become a significant issue of concern that require proper handling to avoid channel erosion and eventual landslides [24]. This is understood since the high the slope, the more runoff velocity because gravitational force is increase with increase of potential difference. Thus, high erosion risk is expected to occur at more sloppy lands provided all other factors remain the consistent. Nevertheless, erosion is bound to take place in both cases and that, protective measures are required to minimize the degree of the incidences.

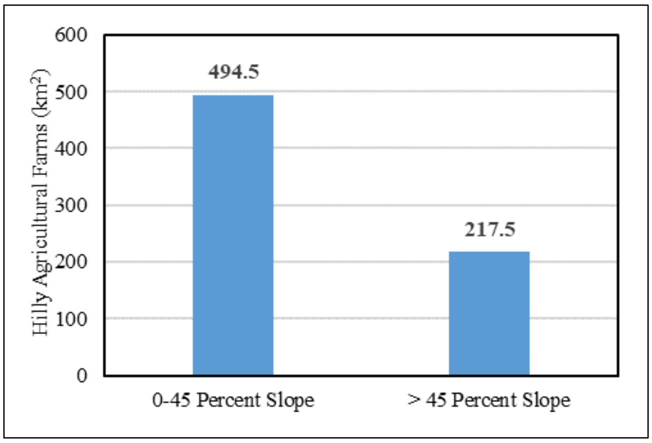

Fig. 4. Classification of highlands based on slope.

B. Rainfall Erosivity and Soil Erodibility

Figure 5 presents the rainfall erosivity assessment where highest value of 1,540.5 MJ $mmha^{-1}yr^{-1}$ is observed at area around Kea Farm with corresponding minimum value of 2,326.7 MJ $mmha^{-1}yr^{-1}$. The high erosivity usually occurs at southwestern part which includes Tanah Rata, Habu and Ringlet as important towns with many agricultural farms. Moreover, high erosive power indicates tendencies of the rainfall to cause erosion and thus, efforts are required to reduce its impacts. This demonstrates that, southwestern regions are more vulnerable to erosion and therefore more attention should be directed toward the region particularly where farming operations are being conducted. Hulu Telom and Kg. Raja sub-catchments for example, have lowest erosivity values which shows that, there is less rainfall power to cause erosion compared to other parts.

In Cameron highlands, there are to distinctive types of soil as provided by reference [18] (Fig. 6). Both soil types of STP and SDG-KDH-DG have their erodibility values as 0.11 and 0.116, respectively. The regions between Kea Farm and Tanah Rata inclusively fall within SDG-KDH-DG soil type while all other parts are predominantly occupied with STP soil type.

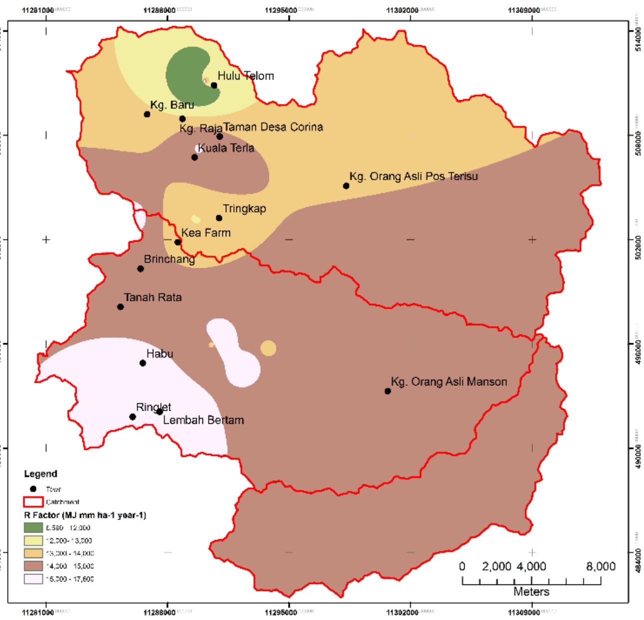

Fig. 5. Rainfall Erosivity (R-factor).

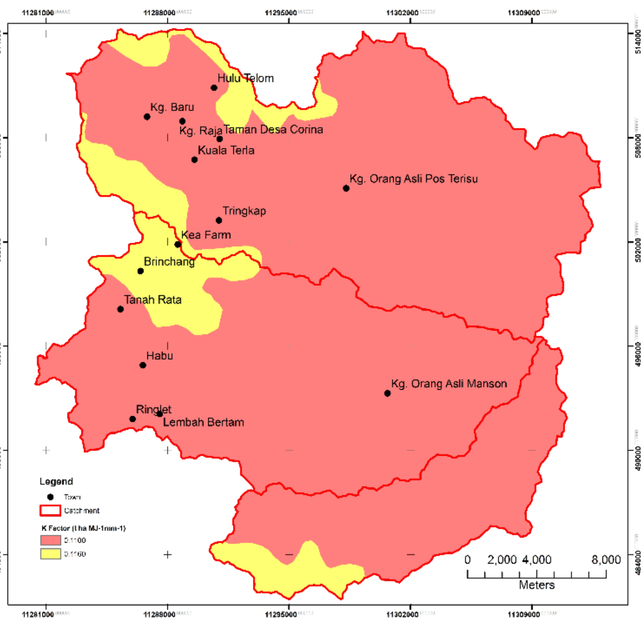

Fig. 6. Soil Erodibility (K-factor).

C. LS, C and P Factors for Soil Erosion Estimation

The slope factor was calculated from Digital Elevation Model in ArcGIS10.5 from which the LS factor was computed and presented in Fig. 7. This operation involves the use of a specified query (Agricultural operation and slope gradient of ≥ 45°). As stated above, 30.5 % of the total area matched this requirement and thus, proceeds with next stage of erosion risk assessment. The LS factor is a dimensionless parameter and found in the range of 0 to1. Similarly, major cover types are found as a forest, agriculture, residential area, water body, and roads. For the agriculture alone, main crop covers identified are tea, vegetables, fruits, and varieties of valuable flowers. This finding support with the previous reports by several researchers who worked in the same study watershed [5, 14, 23]. Moreover, this study adopts the same supporting practices (P factor) as that of prepared by the Department of Agriculture [18]. Both C and P factors are dimensionless and ranged from 0 to 1 as well (Fig. 8). Whenever their values approach zero, it indicates a bare land surface with no vegetation cover and no soil conservation measure in place. However, if the values approach one, it shows a situation with full surface vegetation cover and effective soil conservation strategies are put in place. In this study, we found that large area (about 70 %) is covered with forest while other form of land uses took the remaining percentage. Nevertheless, agricultural activities is growing and expected to continue to expand because of it economic returns [23]. This operation becomes the second largest land use after forestland which puts the soil at risk of erosion and other form of environmental degradations such as floods, landslides and sedimentation of rivers [5].

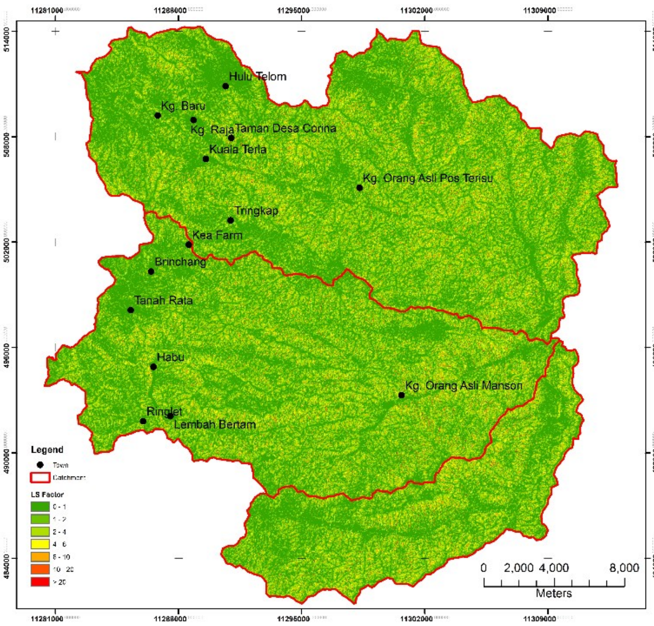

Fig. 7. Slope length and steepness (LS-factor).

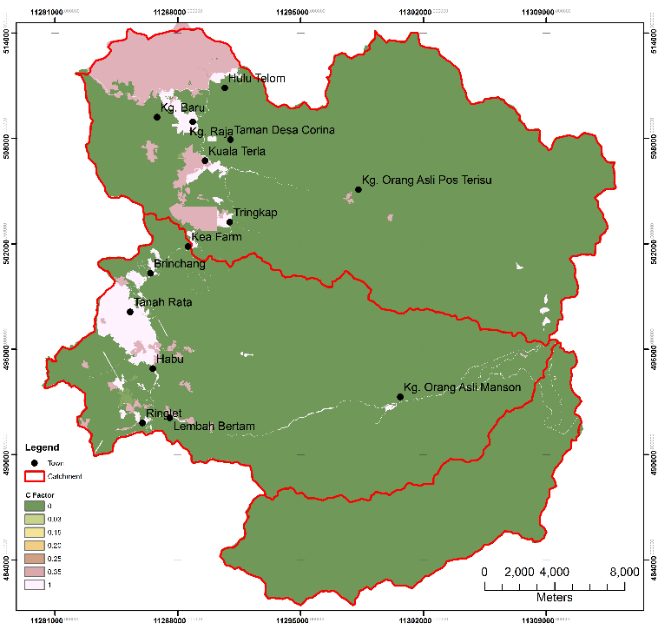

Fig. 8. Crop cover (C-factor).

D. Potential Erosion and Susceptibility Assessment

The annual soil loss map for each sub-catchment in Cameron Highlands were produced by clipping each R, K, LS, C and P values of the selected catchment area from the original factors. The raster calculator was employed to overlay the clipped factors to produce the annual soil loss map for each sub-catchments of the Cameron Highlands, that is upper catchment and lower farmlands (Fig. 9). In this study, the annual soil loss produced from the sub-catchments of Telom and Bertam regions are computed as 38 t $ha^{-1}year^{-1}$ and 73.9 t $ha^{-1}year^{-1}$ respectively. Comparing with soil erosion classification standards by DID, it shows that this rate of soil erosion in Cameron Highlands watershed was at high side and thus, control measures need to be put in place. Although, the area coverage of the two major sub-catchments (Telom and Bertam) are almost the same, however, the erosion rates were found significantly different. This could be attributed to the high erosivity of rainfall which was found in the Bertam while lower in Telom sub-catchments. Also, the different in land use is another crucial factor responsible the huge soil loss in Bertam sub-catchment since the largest agricultural operations as well as massive land developments are being conducted therein [21, 23, 36].

In addition, the soil type in Bertam is completely SDG-KDH-DG which is slightly more erodible than STP, which is present at some parts of Telom catchment. It is found that, Tanah Rata, Habu and Ringlet sub-basins are among the areas fall within high erosion zones, which could be due to the intensive agricultural operation and devilments going on in the regions. This result is consistent with report provided by reference [18] that lower catchment of Cameron Highlands could have suffer more erosion cases. Nonetheless, Hulu Telom, Kg. Baru and Kg. Raja sub-watersheds are among the area under Telom sub-catchment with less susceptible to potential erosion. This could be explained by the fact that, relatively more resistant soil is found in the region.

Furthermore, this study utilized the computed soil erosion factors (USLE) to extract the annual soil losses in each sub-regions of interest as earlier described. Thereafter, spatial distributions of soil erosion risk within the agricultural hilly areas of Cameron Highlands was developed. The soil erosion layer has been classified into four severity zones as very low, low, moderate and high classes of soil loss for clear interpretations.

E. Susceptibility of Erosion and Risk Zoning

In this study, we introduced soil erosion risk zoning to ease identification and managing hilly farm erosion problems. The grid sizes of approximately 1 km^2 were constructed alongside with potential erosion risk map (Fig. 10). Furthermore, the susceptibility is then expressed in term of full grid, half grid or quarter grid sizes. The advantage of this approach is that, both farmers and management can easily trace a vulnerable farm when the coordinates matched with the actual farm. It is clear that, farmlands at Ringlets, Kea Farm, and Tanah Rata regions exhibit more intense soil erosion and thus, are more susceptible. This was found consistent with the study conducted by reference [5], where the same regions are reported having high potential soil erosion and sediment yields. The erosion zones represented by erosion classes can be interpreted considering the portion of grid occupied with potential risk. Conversely, most of hilly areas with no agricultural activities are classified as very low erosion prone areas.

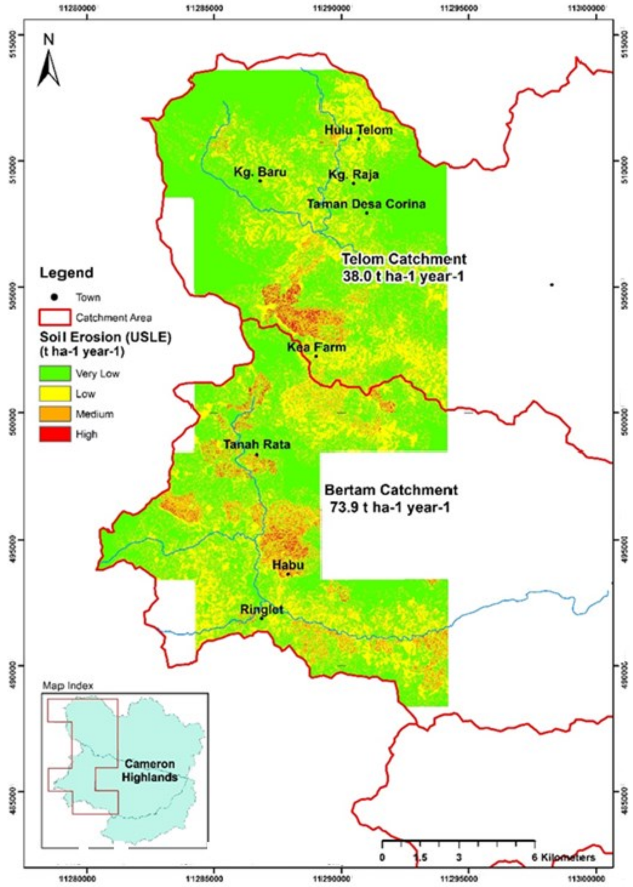

Fig. 9. Soil erosion risk map.

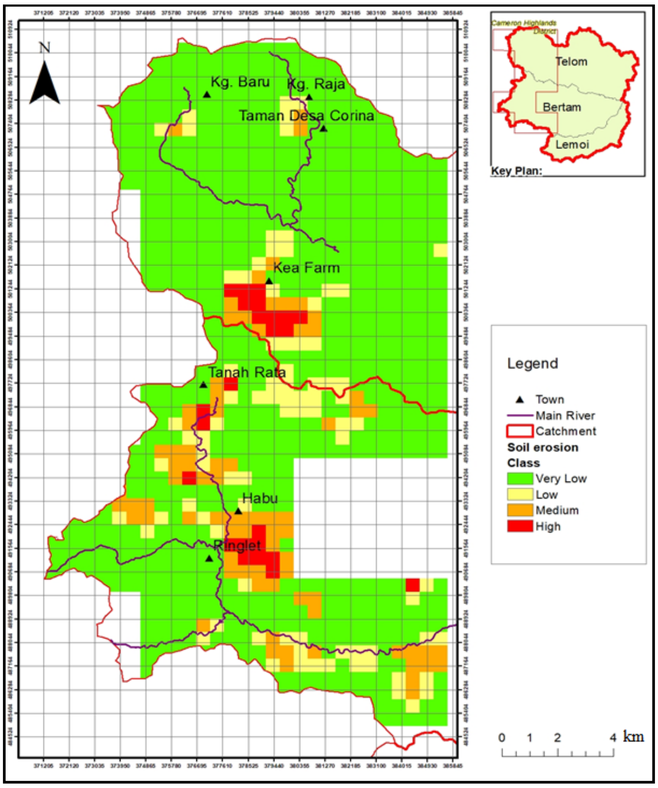

Fig. 10. Susceptibility of soil erosion and risk zoning.

Moreover, the study reveals that 66% of the study area is classified as very low erosion risk with annual soil loss of 1 ton $ha^{-1}yr^{-1}$ or less as, indicated by erosion risk analysis of the selected area (Table III). Meanwhile, the area of 10.8 % is classified as high susceptible erosion zone with total annual soil loss greater than 15 ton $ha^{-1}yr^{-1}$. This finding was also found consistent with the studies conducted in the same catchments area [5, 36–39]. Reference [38] reported that the risk of soil erosion in Cameron Highlands is generally law, however, the erosion rate is on increase with a greater tendency of potential soil loss. Moreover, reference [39] simulated soil erosion related to farming activities at highlands area and arrived at the conclusion that high risk of erosion is largely influenced by agricultural activities. In addition, the outcome of this study indicated about 10% of the study watershed is under high class of soil erosion which confirmed the find of reference [36]. Furthermore, the regions indicated by high soil erosions such as Tanah Rata and Ringlets are reported by earlier study to have severe form of soil loss due to intense agricultural operations and developments for residential and recreational areas [36, 38, 39]. Thus, the current study is found relevant which supplied an updated information that is useful for the management toward effective policy making and strategies for soil conservation at the highlands regions.

Table III. Soil erosion classes in the study area.

No	Class	Soil loss (t ha^{-1} $year^{-1}$)	Area (%)
1	Very Low	0 - 1	66.12
2	Low	1 - 5	11.37
3	Medium	5 - 15	11.71
4	High	> 15	10.80

IV. Conclusion

Soil erosion risk assessment was conducted at agricultural hilly farms of Cameron Highlands. Firstly, the terrain slope of the watershed was classified into high and low susceptible slopes where the study concentrates on high susceptible for the risk level assessment. It was found that sizable portion of the study watershed is categorized as high erosion risk potential. Moreover, the study gathered that erosion zoning strategy assists for easy identification and evaluation of farmland base on erosion status. This is particularly important findings in such a way that, an effective soil conservation measures could be deployed at appropriate locations depending on the risk level. It is, therefore, eliminates waste of energy and time as well as ensuring economic use of resources. This is key step for both farms and management toward effective strategy to combat the potential soil erosion.

Acknowledgement

The authors would like to acknowledge the support by Ministry of Higher Education (MOHE) and Universiti Putra Malaysia (UPM) for funding this research under grand number LRGS-NANOMITE/5526305. The supports given by Bayero University Kano, Tertiary Education Trust Fund (TETFUND), Department of Irrigation and Drainage (DID), Malaysia, and Cameron Highlands Farmers' Association are very much appreciated.

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