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Erosion Risk Level at Cameron Highlands with Regards to Soil Erosion Loss

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The agricultural activities and urban developments in Cameron Highlands have made them vulnerable to erosion. This situation has been supported by the fact that many ongoing and new proposed development projects have taken place in the Cameron Highlands. Thus, this study evaluates soil loss risk levels by catchment and sub-districts (mukim) in Cameron Highlands using the USLE model with GIS application. The USLE model covers the six factors namely rainfall erosivity, soil erodibility, slope length and steepness, cover management, and conservation practice. In earlier studies, PLANMalaysia and the Department of Agriculture Malaysia recorded land use and land cover have produced different soil loss risk levels in Cameron Highlands. Land-use data from PLANMalaysia represents town construction and development, while land-use data from the Department of Agriculture represents agricultural impact. Based on the result, the soil loss risk level produced by REDAC USM has predicted that 6.72 per cent in Cameron Highlands possess 'HIGH' risk or higher. On the other hand, soil loss risk levels produced using data from PLANMalaysia and the Department of Agriculture have predicted 10.08 per cent and 5.95 per cent, respectively. This new soil loss risk level could guide farmers and local authorities to control current land-use practices, encouraging soil conservation, and minimising soil loss in Cameron Highlands.

Keywords: erosion risk; soil erosion; soil loss; USLE

I. INTRODUCTION

Soil can be eroded from its present state by water and wind (Raj, 2002). Soil erosion by water is the process of soil particles detachment by the impact of rainfall and runoff and its transport down the slope (Raj, 2002; Parveen & Kumar, 2012). Erosion from mountainous areas and agricultural lands is the major sediment source transported by streams and deposited in reservoirs, flood plains, and deltas (Parveen & Kumar, 2012). Malaysia cannot avoid having erosion and sedimentation problems as many parts of the country are experiencing rapid development, e.g. land clearing for housing, logging, and agriculture plantation (Razali *et. al.*, 2018; Samat & Mahamud, 2018). While these activities are necessary for the country's development, regulatory efforts to minimise erosion and sedimentation problems should not stifle economic development planned for attaining a developed country's status in the future.

Plantation agriculture is a form of commercial farming that grows crops for profit (Raj, 2002). Large land areas are needed for this type of agriculture. Agriculture in Malaysia makes up twelve per cent of the nation's GDP (Vijith *et al.*, 2018), and sixteen per cent of the population of Malaysia is employed through some sort of agriculture (Razali *et. al.*, 2018; Vijith *et al.*, 2018). Large-scale plantations were established by the British, and these plantations opened an opportunity for new crops such as rubber (1876), palm oil (1917), and cocoa (1950). Many crops are grown for domestic purposes, such as bananas, coconuts, durian, pineapples, rice and rambutan (Parveen & Kumar, 2012). Most of the

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plantation agriculture mentioned will undergo the deforestation stage, an act of forest clearing for establishing agricultural development. Deforestation alters climate, vegetation and animal ecology. Non-sustainable logging activities can also lead to environmental problems such as soil erosion, landslides and flooding (Hsiang *et al.*, 2018).

Lands in Cameron Highland have been opened and levelled for agricultural cultivation, intensive crop production and urban development for many years (Razali *et. al.*, 2018; Vijith *et al.*, 2018). A highland refers to a region with slope gradients of more than 25° at an altitude greater than 500 m above the mean sea level and has a high potential to cause soil erosion and landslides if not properly managed (Parveen & Kumar, 2012; Razali *et. al.*, 2018; Vijith *et al.*, 2018). Cameron Highlands' total agricultural coverage is relatively limited and is mainly achieved on steep slopes. High levels of soil degradation and environmental contamination have resulted from the high use of fertilisers and pesticides by local farmers, followed by an increased frequency of major storm events (Wulandry *et. al.*, 2018; Noh *et al.*, 2019). Recent agricultural practices have led to significant soil erosion due to wind or flow, or both (Raj, 2002; Parveen & Kumar, 2012; Razali *et al.*, 2018). Therefore, this phenomenon is crucial, and a better accuracy prediction of soil loss risk should be developed for future planning. Thus, the main research objective is to evaluate the soil loss risk level using the USLE model with GIS by catchment and district in Cameron Highlands. The advantage of using the USLE model is that it has been widely used and checked for several years; its validity and weaknesses are already known (Parveen & Kumar, 2012). This study follows the USLE model guidelines for Malaysia (DOA, 2020).

II. LITERATURE REVIEW

The development of erosion-prediction technology began in the USA with analyses such as those by Cook (1936) to identify the major variables that affect soil erosion by water, such as soil susceptibility to erosion, potential erosivity of rainfall and runoff, and soil protection afforded by plant cover. Zingg (1940) published the first equation for calculating field soil loss, which described slope steepness and slope length on erosion. Smith (1941) added factors for a cropping system and support practices to the equation. The effort was continued by Browning *et al.* (1947), that added soil erodibility and management factors to the Smith (1941) equation and prepared more extensive tables of relative factor values for different soils, crop rotations, and slope lengths. This approach emphasised evaluating slope-length limits for different cropping systems on specific soils and slope steepness with and without contouring terracing or strip cropping. Smith & Whitt (1947) presented a method for estimating soil losses from fields of claypan soils. Soil loss ratios at different slopes were given for contour farming, strip cropping, and terracing.

Recommended limits for slope length were presented for contour farming. Relative erosion rates for a wide range of crop rotations were also given. Then Smith and Whitt (1948) presented a 'rational' erosion-estimating equation:

$$A = C \,.\, S \,.\, L \,.\, K \,.\, P \tag{1}$$

where

A - Annual soil loss, in tonnes ha $^{-1}$ year $^{-1}$.

C - average annual soil loss from claypan soils for a specific rotation, slope length, slope steepness, and row direction,

S - slope steepness,

L - slope length,

K - soil erodibility,

P - support practice

Musgrave (1947) added a rainfall factor, and thus resulting Musgrave equation included factors for rainfall, flow characteristics of surface runoff as affected by slope steepness and slope length and vegetal cover effects. A further study carried out by Lloyd & Eley (1952) contributed to graphs and tabulated values to solve the Musgrave equation.

To hasten the development of a national equation, joint conferences of key researchers and users were held at Purdue University in February and July of 1956. The participants concentrated their efforts on reconciling the differences among existing soil loss risk equations and extending the technology to regions where no erosion measurements by rainstorms had been made. The resulting equation had seven factors: crop rotation, management, slope steepness, slope length, conservation practice, soil erodibility, and previous erosion. The group established the maximum permissible loss for any soil as 5 tons per acre per year but set lower limits for many soils. A subsequent study also showed that the equation's crop rotation and management factors could be combined into one factor (Wischmeier *et al.*, 1958).

Based on considerable experience with more than 10,000 plots over 20 years, Wischmeier, Smith, and others developed the Universal Soil Loss Equation, USLE (Wischmeier & Smith, 1965; Wischmeier & Smith, 1978). The USLE quantifies soil erosion as the product of six factors representing rainfall and runoff erosiveness, soil erodibility, slope length, slope steepness, cover-management practices, and support conservation practices. The USLE overcame many of the deficiencies of its predecessors. The form of the USLE is similar to that of previous equations, but the concepts, relationships, and procedures underlying the definitions and evaluations of the erosion factors are distinctly different.

Major changes include (i) a complete separation of factor effects so that results of a change in the level of one or several factors can be more accurately predicted; (ii) an erosion index that provides a more accurate, localised estimate of the erosive potential of rainfall and associated runoff; (iii) a quantitative soil-erodibility factor that is evaluated directly from research data without reference to any common benchmark; (iv) an equation and nomograph that are capable of computing the erodibility factor for various soils from soil survey data; (v) a method of including the effects of interactions between cropping and management parameters; and (vi) a method of incorporating the effects of local rainfall patterns throughout the year and specific cropping conditions in the cover and management factor (Wischmeier, 1972).

III. STUDY AREA AND METHODOLOGY

A. Study Area

Cameron Highlands is a district in Pahang, Malaysia, with an area approximately of 68,156.74 hectares. Figure 1 shows the district of the Cameron Highlands.

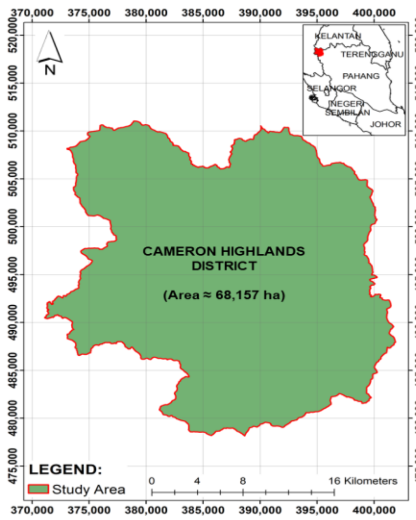

Figure 1. Cameron Highlands District (Source: DOA, 2020)

B. Land-use Activities

Land-use involves managing and modifying natural or wilderness into built environments such as fields, pastures, settlements, military, leisure, and transportation. Land-use data provides essential information for analysing and planning the study area. The surface characteristic of the catchment can greatly influence the flow rate and other runoff characteristics. Various activities can affect the soil, leading to various problems such as flooding and landslide. With land-use information, soil loss risk can be modelled and calculated to provide planners and local authorities guidance.

There are two land-use data received from the Malaysia agency: PLANMalaysia for 2018 and from the Department of Agriculture for 2015. Figure 2 shows the land-use activities in Cameron Highlands. Forest is the major land use in Cameron Highlands with 87.88 per cent (based on PLANMalaysia data) and 91.85 per cent (based on Department of Agriculture). At the same time, agriculture is the highest activity in Cameron Highlands. Table 1 shows the area of each land-use activity in Cameron Highlands. Major agriculture activities in Cameron Highlands are tea, vegetables and decorative plants. This information obtained from both agencies is used for analysis and assessment.

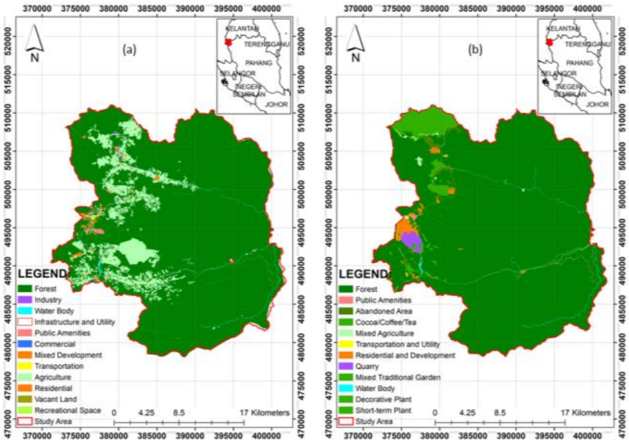

Figure 2. Land-use of Cameron Highlands from (a) PLANMalaysia, and (b) Department of Agriculture (Source: PLANMalaysia, 2018; DOA, 2015)

Table 1. Area for Each Land-use in Cameron Highlands (Source: PLANMalaysia, 2018; DOA, 2015)

PLANMalaysia (2018)		DOA (2015)	
Land-use	**Area (ha)**	**Land-use**	**Area (ha)**
Water Body	263.39	Forest	62600.13
Forest	59788.65	Public Amenities	34.69
Industry	20.99	Abandoned Area	476.59
Infrastructure and Utility	28.39	Cocoa/Coffee/ Tea	201.59
Public Amenities	162.84	Mixed Agriculture	154.72
Commercial	61.48	Transportation and Utility	264.39
Mixed Development	1.36	Residential and Development	692.58
Transportation	43.28	Mixed Traditional Garden	3.59
Agriculture	7212.93	Quarry	455.82
Residential	351.82	Water Body	253.86
Vacant Land	43.28	Decorative Plant	79.26
Recreational Space	57.64	Short-term Plant	2939.51
Total	**68036.03**	**Total**	**68156.74**

C. Topographic Features

Cameron Highlands is surrounded by a hilly area with steep slopes with more than a 20° gradient (DOA, 2020). Cameron Highlands have different elevations ranging from 200 meters to 2069.85 meters. Figure 3 shows the elevation in Cameron Highlands.

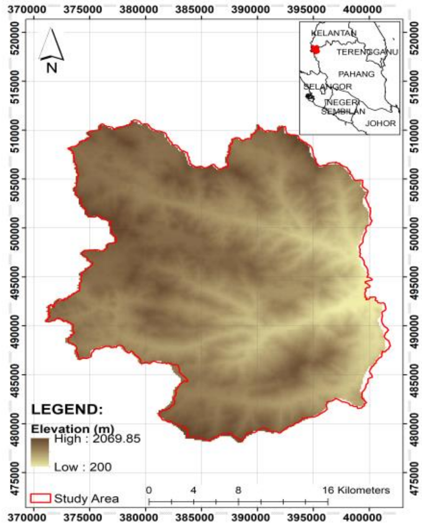

Figure 3. DEM for Cameron Highlands (Source: JUPEM, 2020)

D. Soil Map

There are two major soil groups based on the Department of Agriculture Malaysia, steep land and urban land. Department of Agriculture also identified four soil series in Cameron Highlands: Teringkap Series, Ringlet Series, Tanah Rata Series, and Gunong Berinchang Series. Figure 4 shows the location of major soil groups and soil series in Cameron Highlands.

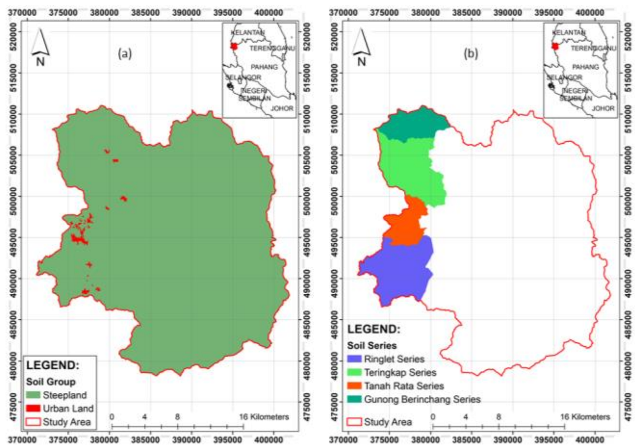

Figure 4. (a) Major Soil Groups, and (b) Soil Series in Cameron Highlands (Source and Edited: DOA, 2020)

E. Methodology

Spatial data collection is very important at the preliminary stage of developing a soil loss risk map. Spatial data were acquired from various agencies, namely the Department of Agriculture, Malaysia, PLANMalaysia, Department of Survey and Mapping, Malaysia, etc. Spatial data were input into ArcGIS 10.4, then tabulate and/or produced graphical representation for significant analysis. Data collection involves acquiring, collating, and cleaning up existing information and data from various agencies' sources in completing this research. This information and data will be formatted to form an integrated database for ease of use and reference in the later stage of the study. Gaps and discrepancies between these data will be identified and rectified accordingly. Additional data required to bridge the gap or solve discrepancies can be obtained via further data collection or fieldwork.

The proposed study's main data collection will involve hydrological data, geospatial data, including the Digital Elevation Model (DEM), soil properties, and land use of the proposed study area. Most government agencies have developed their GIS databases to store spatial data under their custody. Where the data is not available, the study will acquire data based on some secondary hardcopy data, such as maps, reports and satellite images, to capture the required information. Spatial data is one of the most important pieces of information required for any analysis and planning. It gives information on the variability of properties through space. As no single locality is the same as another, this variability needs to be carefully observed.

Soil loss risk-related information varies through space, e.g., land-use, topography, rainfall pattern, and even soil condition. Over-generalizing of such information would lead to a model that does not represent the actual situation on site. Therefore, spatial variability must be considered.

F. Determination of Soil Loss Risk

This semi-empirical equation is developed (Musgrave, 1947; Wischmeier & Smith, 1978) for long-term assessments of soil losses (sheet and rill erosion rates) under different cropping systems and land management practices.

$$A = R \,.\, K \,.\, LS \,.\, C \,.\, P \qquad (2)$$

where

- A - Annual soil loss, in tonnes ha^{-1} $year^{-1}$.
- R - Rainfall erosivity factor, An erosion index for the given storm period in $MJmmha^{-1}h^{-1}$.
- K - Soil erodibility factor, the erosion rate for a specific soil in continuous fallow condition on a 9% slope having a length of 22.1 m in tonnes/ ha/ ($MJmmha^{-1}h^{-1}$).
- LS - Topographic factor which represents the slope length and slope steepness. It is the ratio of soil loss from a specific site to that from a unit site having the same soil and 9% slope but with a length of 22.1m.
- C - Cover management factor, which represents the protective coverage of canopy and organic material in direct contact with the ground. It is measured as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled land under clean-tilled continuous fallow (bare soil) conditions.
- P - Conservation practice factor which represents the soil conservation operations or other measures that control the erosion, such as contour farming, terraces, and strip cropping. It is expressed as the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope culture.

The simple structure of the USLE formula (2) makes it easy to formulate transparent policy scenarios by changing the land-use types (C and P factors) under given ecological conditions (R, K, L, and S factors). This formula, together with the low data requirements compared with physical-based models, such as WEPP and EUROSEM, explains the popularity of the USLE in small-scale water erosion studies at a continental (Van der Knijff *et al.*, 2000), nationwide (Van der Knijff *et. al.*, 1999; Schaub & Prasuhn, 1998; UNEP/RIVM/ISRIC, 1996; Bissonnais *et al.*, 1999), state-wide (Hamlett *et al.*, 1992), regional (Folley, 1998), and catchment level (Mellerowicz *et. al.*, 1994; Merzouk & Dhman, 1998; Dostal & Vrana, 1998). The USLE is also popular in (nationwide) land evaluation studies where it is linked with rule-based procedures to determine the decrease in productivity (Kassam *et. al.*, 1991; Struif-Bontkes, 2001) or to estimate changes in nutrient balances (Smaling, 1993).

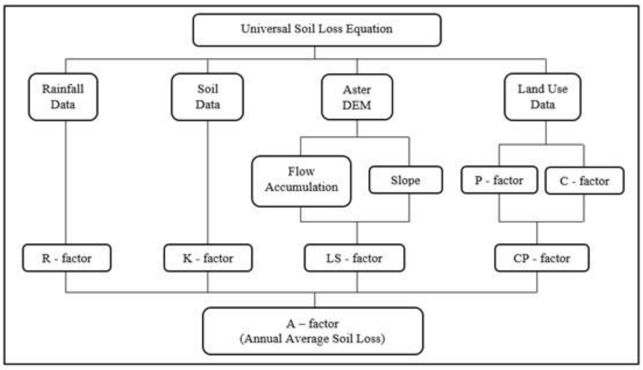

Figure 5. USLE Framework Model of Soil Loss Risk
(Source: Renard *et al.,* 1997)

Soil loss risk is calculated based on Equation (2), which was internationally and widely used in many countries including Malaysia specifically adopted by the Department of Agriculture and PLANMalaysia. The *R*-factor, *K*-factor, *LS*-factor, and *CP*-factor are derived from the data which has been published by the respective agencies. Figure 5 shows the framework of the soil loss risk used in the study. The unit of *A*-factor (Annual Average Soil Loss) is tons/hectares/year. Based on the literature review (Mahamud, Saad, Zainal Abidin, Yusof, Zakaria, Mohd Amiruddin Arumugam, Mat Desa, and Md. Noh, 2022), the permissible soil loss for any situation of soil degradation is 11.2 tons/hectares/year. By using that as a benchmark, *A*-factor calculated from this study is categorised into soil loss class category as presented in Table 3.

Table 3. Soil Loss Class Category

Soil Loss (*A)*-factor (tonnes/hectare/year)	**Category**
≤ 10	Low
11 – 25	Moderate
26 – 50	High
51 – 100	Very High
≥ 101	Critical

IV. RESULTS AND DISCUSSIONS

Soil loss was evaluated and adapted to the bio-physical environment comprising soil, rainfall, topography, land cover, and interactions. In this study, USLE is used to calculate soil loss/erosion by identifying *A*-factor, which requires obtaining *R*, *K*, *LS*, *C*, and *P*. As provided by the Department of Agriculture Malaysia, *LS*-factor, average annual rainfall, and *K*-factor for the Cameron Highlands district is mapped as shown in Figure 6, Figure 7, and Figure 8, respectively. The *R*-factor of the USLE was determined by knowing the rainfall intensity and energy in the study area as published by the DOA.

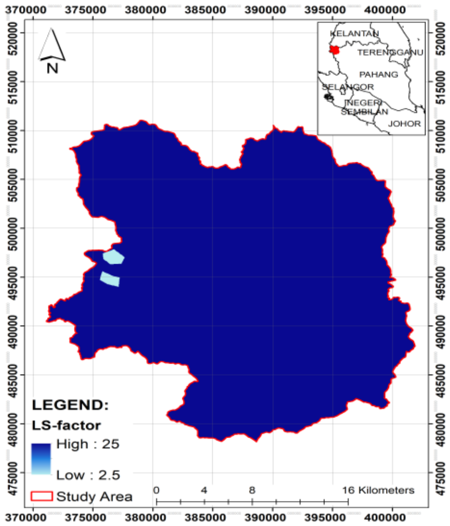

Figure 6. *LS*-factor in Cameron Highlands District
(Source: DOA, 2015)

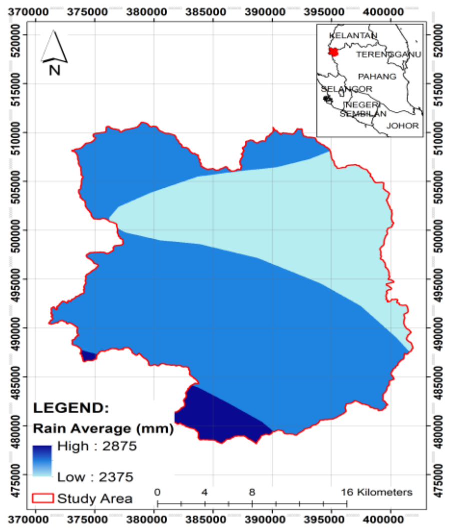

Figure 7. Average Annual Rainfall in Cameron Highlands District
(Source: DOA, 2015)

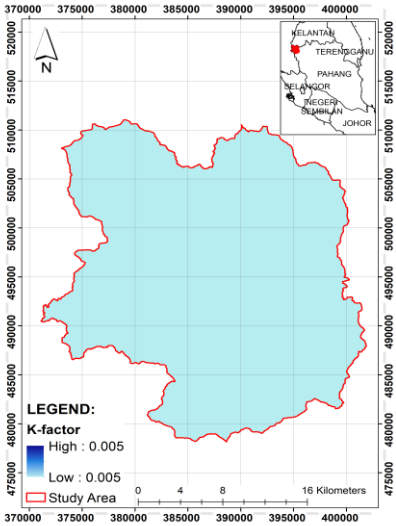

Figure 8. *K*-factor in Cameron Highlands District (Source: DOA, 2015)

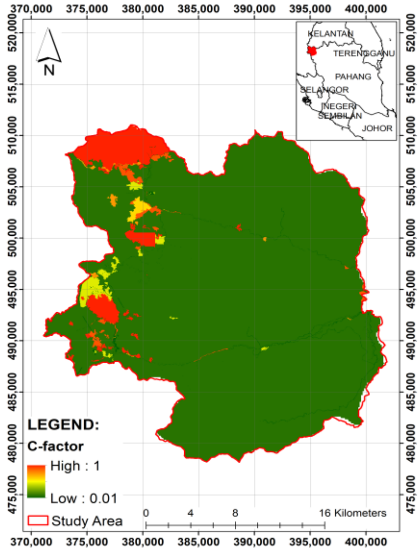

Figure 9. *C*-factor in Cameron Highlands District (Source: DOA, 2015)

Figure 6 shows that more than 98% of *LS*-factor in Cameron Highlands District is 25, and the other 2% is 2.5, which is the lowest value in Cameron Highlands District. The rain average in Figure 7 shows that the southwest part of Cameron Highlands District has the highest value of *R*-factor while the west part towards the east part of Cameron Highlands District has the lowest value of *R*-factor. Lastly, *K*-factor in Cameron Highlands District is the same in all areas, which is 0.005, as shown in Figure 8.

C-factor and *P*-factor are two important factors determining the soil loss/erosion in Cameron Highlands District, where these factors are included in the USLE equation. *C*-factor is calculated based on the land use and land cover of the Cameron Highlands District. There are two different data of land use obtained from the agency, which are from PLANMalaysia and the Department of Agriculture. Figure 9 shows the *C*-factor derived from the Department of Agriculture (2015), while Figure 10 shows *C*-factor derived from PLANMalaysia (2018). Additionally, Figure 11 shows the *C*-factor established from this study by combining data from the Department of Agriculture and PLANMalaysia to capture all inputs in deriving optimum *C*-factor for soil loss/erosion risk analysis.

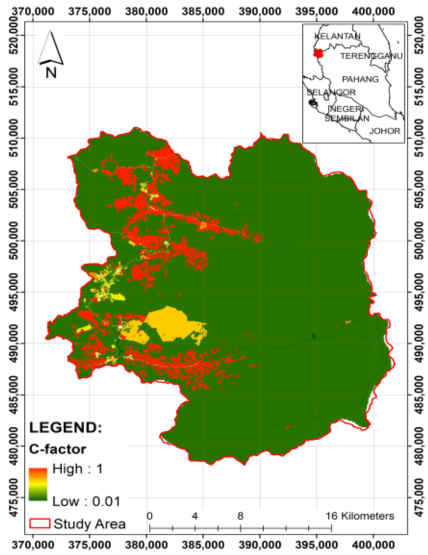

Figure 10. *C*-factor in Cameron Highlands District (Source: PLANMalaysia, 2018)

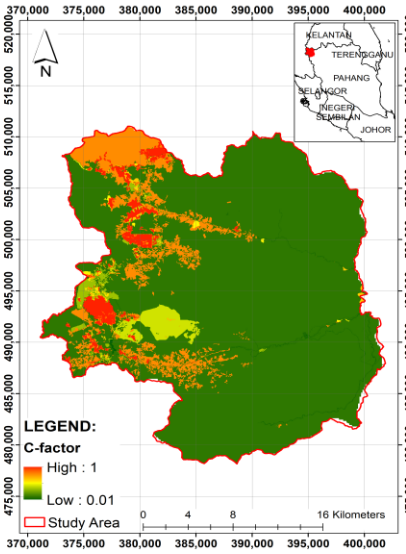

Figure 11. *C*-factor in Cameron Highlands District (Established: REDAC USM, 2020)

P-factor is derived together with the conservation practice ratio in Cameron Highlands District, as shown in Table 4. Figure 12 shows *P*-factor derived for Cameron Highlands District.

Table 4. Ratio (in percentage) of Conservation Practice in Cameron Highlands District (Source: DOA, 2018)

Contouring	Terracing	Sheltered
27%	15%	58%

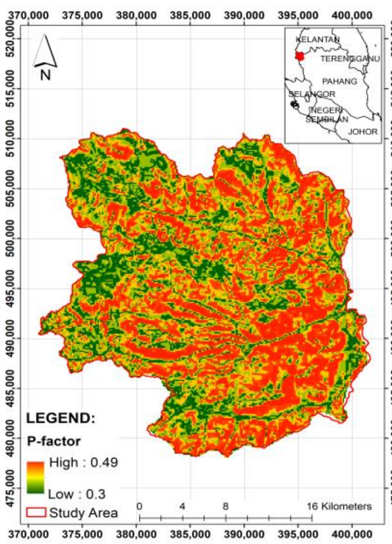

Figure 12. *P*-factor in Cameron Highlands District (Source: JUPEM, 2020; Established: REDAC USM, 2020)

Soil loss risk is determined by calculating *A*-factor using formula (2). All factor values derived from the data received by the Department of Agriculture, PLANMalaysia, and established by REDAC USM were inserted into formula (2).

There are three different soil loss risk maps for the Cameron Highlands district, as shown in Figure 13. The detail of the maps produced are as follow:

1) Soil loss risk is produced by the data received from the Department of Agriculture (2015) which is based on Agricultural impact.
2) Soil loss risk is produced by the data received from PLANMalaysia (2018) which is based on Town Construction and Development impact.
3) Soil loss risk from this study was developed and established by REDAC USM (2020), which is based on:
    a) average *C*-factor (data from the Department of Agriculture and PLANMalaysia)
    b) average *P*-factor (ratio of conservation factor in Cameron Highlands District)
    c) combine *CP*-factor from (a) and (b)

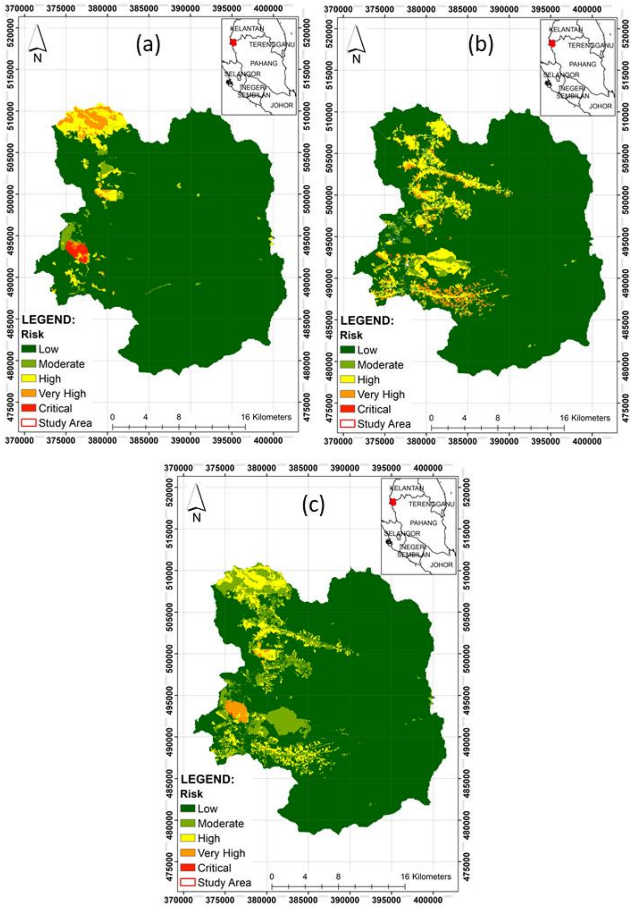

Figure 13. "Soil Loss Risk" (*A*-factor) derived from (a) DOA, 2015, (b) PLANMalaysia, 2018, and (c) REDAC USM, 2020

Table 5 compares the area (in hectares) of soil loss between three different soil loss risk maps established in the study regarding the established soil loss class category.

Table 5. Comparison of Soil Loss Risk Level between the Department of Agriculture (2015), PLANMalaysia (2018) and REDAC USM (2020)

Soil Loss Class Category	**Risk (t/ha/yr)**	**Department of Agriculture (2015)**	
		Area (ha)	**Percentage**
Low	≤ 10	62839.92	92.84
Moderate	11 – 25	815.03	1.2
High	26 – 50	2500.45	3.69
Very High	51 – 100	1152.29	1.7
Critical	≥ 101	377.2	0.56
Soil Loss Class Category	**Risk (t/ha/yr)**	**PLANMalaysia (2018)**	
		Area (ha)	**Percentage**
Low	≤ 10	59687.92	88.54
Moderate	11 – 25	925.97	1.37
High	26 – 50	4994.67	7.41
Very High	51 – 100	1798.36	2.67
Critical	≥ 101	6.26	0.01
Soil Loss Class Category	**Risk (t/ha/yr)**	**REDAC USM (2020)**	
		Area (ha)	**Percentage**
Low	≤ 10	57104.87	84.37
Moderate	11 – 25	6034.52	8.92
High	26 – 50	3945.03	5.83
Very High	51 – 100	589.66	0.87
Critical	≥ 101	12.65	0.02

According to Table 5, as per Wischmeier (1975) and Wischmeier (1976), there is a big difference in soil loss risk level when deriving the annual soil loss using data from the Department of Agriculture (based on Agricultural impact) and using data from PLANMalaysia (based on Town Construction and Development impact). Both recorded the activities that concern the most to the agency, leading to different cover management (*C*-factor) and conservation practices (*P*-factor). Due to this situation, this study implemented both *C&P* factors acquired by these two different agencies and established an optimum soil loss risk level that captures both land-use activities.

This study found that only 84.37% of the total area in Cameron Highlands district is in the category of low-risk soil loss level compared to using data only from the Department of Agriculture (92.84% low risk) or from PLANMalaysia (88.54% low risk). Local authorities should give extra attention to these two boundaries to avoid unwanted occasions in the future.

V. CONCLUSION

Evaluation of erosion risk in the Cameron Highlands was carried out using the USLE with GIS application. The final result can be used as a basis and permanent data to analyse temporal variation in soil loss rates through the study. The integration of variables of USLE such as *R*, *K*, *LS*, *C* and *P* produced an annual soil loss map which showed the soil loss between 0 and 167 t ha^{-1} $year^{-1}$ with varying spatial spread. Three different soil loss risk maps were produced, and the soil loss predicted is comparable with other studies reported from regions with similar geo-environmental and climatic conditions. Based on the study, high, very high, and critical erosion risk zones, where soil erosion exceeds 25 t ha^{-1} $year^{-1}$, occupy 6.72% of the total study area. The high, very high and critical soil erosion vulnerable zones were associated with constructing logging roads, logging, and associated terrain alteration activities. The outcome of the current study clearly shows that, while most of the area is covered by forests of various types and densities, previous and ongoing logging practices have already contributed to making the terrain vulnerable. Protective steps are warranted, such as introducing sustainable logging methods to minimise sediment delivery and the vulnerability of terrain to erosion besides limiting the number of permits to be approved by federal or state authorities for agricultural activities, including under forest reserves.

VI. ACKNOWLEDGEMENT

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