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Original Article

# Vulnerability of potential soil erosion and risk assessment at hilly farms using InSAR technology

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**ABSTRACT**

Soil erosion is a serious environmental challenge which is persistently diminishing the available land resource in many places around the world, particularly the highlands areas. The traditional approach of estimating the magnitude of erosion is tedious, costly, and considerably time consuming. This study is aimed at assessing the risk level associated with soil erosion at hilly areas of Cameron Highlands through Interferometric Synthetic Aperture Radar (InSAR). The digital elevation model with 5 m resolution was utilized to generate the slope map for the highlands. Soil erosion rates was estimated using universal soil loss equation, while information about land use and cover were sourced from relevant government agencies. The analysis shows that, there was about 217.5 km2 (30.5%) of highlands fall under severely steep zone with slope ≥ 45-degree. Moreover, erosion risk assessment indicated that; 66.3%, 11.4%, 11.7% and 10.8% of the severe sloppy lands are classified as very low to high susceptible to soil erosion respectively. In general, the risk of soil erosion is relatively low and could be attributed to large vegetation coverage despite steep slopes. However, there is need to deploy a control measures to reduce soil disturbance activities on highlands with extremely steep slope as a proactive measures to minimize the effect of potential soil erosion.



## 1. 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 two main processes: detachment of individual particle from the soil mass and transportation of those detached particles by erosive agents such as wind and water [2,3]. Soil erosion affects ecology negatively with consequences of reducing available lands and other natural resources. The commonly affected resources 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 [6,7,8].

Human activities on 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 [9,10,11]. Soil erosion has become an environmental challenge in recent years particularly in

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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, and reservoirs. 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 cover and interactions between two or more factors [5], [15]–[17]. Ref [11] shows that, terrain characteristics is particularly key 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 space, the expansion of farming has been started on hills with considerable high slopes [8]. Thus, farmers mostly 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 magnitude 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, improved the processes by making it easier 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 inaccessible like hilly or bushy regions. Study conducted by Ref [21] discloses the ranges of degree of accuracy which the hilly areas can be effectively studied through geospatial approach. Accurate and timely detection of land deformation by effects of the soil erosion phenomenon is important and can be achieved through utilizing multi-temporal ground data measurements and satellite data. Change detection using remote sensing data is available via rapid data acquisition and wide coverage. Thus, imaging radar interferometry such Synthetic Aperture Radar Interferometry (InSAR) is one of the technologies used to measure small-scale land deformation. Imaging radar interferometry is the process whereby radar images of the same location on the ground are recorded by antennas at either different locations or different times [22].

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

## 2. Materials and method

### *2.1. 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 $24^{o}$C and $14^{o}$C during the day and night, respectively. The elevation ranges between 1070 m and 1830 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 normally occurs 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. The highland 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 primary business and attracts many tourists. However, the gradual deterioration of the weather conditions coupled with other environmental issues raised an alarm for investigation [12].

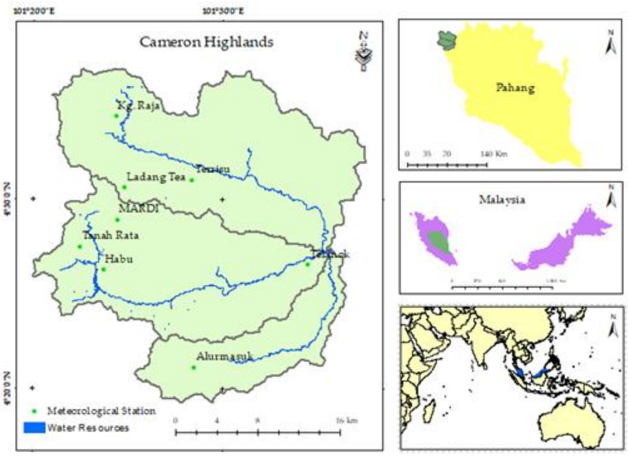


Fig 1. Study Area

*2.2. Assessment of Soil Erosion*

Study area have been used for agricultural activities which characterized with rampant soil disturbance operations on 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. The study area has been reported that, more than 80 percent of the highlands are above 15-degree slope [24]. Meanwhile, the agricultural area that have 45-degree slopes and above are selected for the purpose of this assessment using appropriate extension of ArcGIS.

Soil erosion was estimated using Universal Soil Loss Equation (USLE) model as proposed by ref [25]. This model was developed by the Department of Agriculture, United States of America, to support decision in soil conservation planning and management (Equation 1). The model was further modified by many researchers to improve the prediction accuracy and to have wider range of applicable [26].

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

Where:

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

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

*2.3 Rainfall factor*

As a numerical index, the rainfall factor (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 several methods available for estimating R-factor all of which utilized different rainfall record series. Some methods used both annual and monthly rainfall data while some used total annual data for computing the R-factor [28], [29]. This study uses equation proposed by ref [30] for calculation of the R factor based on empirical study developed in Indonesia (Equation 2). This equation is applicable to Malaysia because of similar climatic conditions to Indonesia and data for annual precipitation is available.

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

Where.

R = Rainfall Erosivity ($MJmmha^{-1}\ hr^{-1}\ yr^{-1}$)

P = Annual amount of precipitation (mm)

*2.4. Soil erodibility*

Tendencies of soil erosion depend largely on soil resistance to both detachment and transportability of removed particles [31]. Some types of soil are not inherently resistant and are susceptible to erosion more than the others. Erodibility (K-factor) of each soil type is a function of its grain size, drainage or permeability, structure, organic matter content and cohesiveness. K factors is a function of percentage of silt and coarse sand, soil structure, permeability, the percentage of organic matter 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 for Cameron Highland area [18]. The K-factor value for those classes of the soil are extracted from the Agricultural Handbook and presented in Table 1. 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 by respective values of K factor using the reclassify tool of Spatial Analyst extension and subsequently raster layer of K factor was generated.

Table 1. Soil Erodible factor in the Study Area (DID, 2014)

| **Physical properties** | **Soil series** | **Code** | **K-Factor** |
|---|---|---|---|
| Red - 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 |

### 2.5. Topography (LS-factor)

LS-factor commonly regarded as a topographic factor has a profound influence on sediment transmittance and runoff characteristics throughout the runoff pathway. Substantial number of 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. USLE model shows the combined effects of rill and inter-rill erosion. Rill erosion is mainly initiated by surface runoff and growths in downslope. 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 using parameters such as flow accumulation, cell size and slope (Equation 3). It is observed that, the steeper and longer the slope more the risk of higher erosion in many existing studies [33]. In this study, high resolution (5 m) digital elevation model has been calculated to determine the extent area coverage with hills. Thus, to attain the desirable degree of resolution, InSAR data was acquired from satellite imagery and determined flow accumulation in ArcGIS environment.

$$LS = \left( F_A \times \frac{Cell}{22.13} \right)^{0.4} \left( \frac{\sin\theta}{0.0896} \right)^{1.3} \qquad (3)$$

Where.
*LS* = Slope length and Steepness factor
$F_A$ = Flow Accumulation
$\theta$ = Slope on degrees

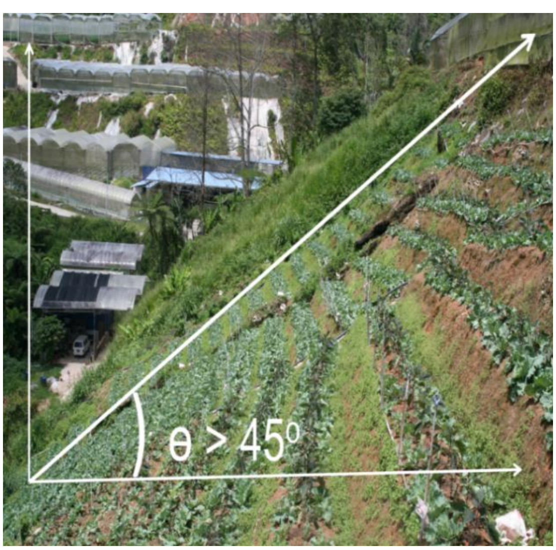


Fig 2. A typical Hilly Farm slope > $45^o$

### 2.6. Vegetation cover

Soil erosion can be effectively reduced by increasing the amount of vegetation through reforestation to increase amount of vegetation coverage. In this study, eight categories of vegetation covers were identified as Forest, water body, scrub, flower, mixed horticulture, urban settlement, bare land, and tea farm. The vegetation cover factor (C-factor) for each vegetation class were excerpted from *Tenaga National Berhad Research* [34] and reports of investigations established by previous studies in the study area [35], [36].

### 2.7. Support practice

Conservation practices factor (P-factor) explains the effect of conservation 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 could 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 shelter area was digitized from the 2 m resolution orthophoto for the entire project area. [24]. Thus, the practice will help to reduce the cost of data acquisition on soil erosion affected area. Moreover, the study obtained values of P for some surface covers from Department of Agriculture [18].
Fig. 3 presents major activities involved in the study which comprised of four main input variables: Land cover, digital elevation model (DEM), Soil Map and Rainfall data acquisition. To validate the model, field verification was conducted to ensure all farmlands are located within the slope of interest for the successful risk assessment.

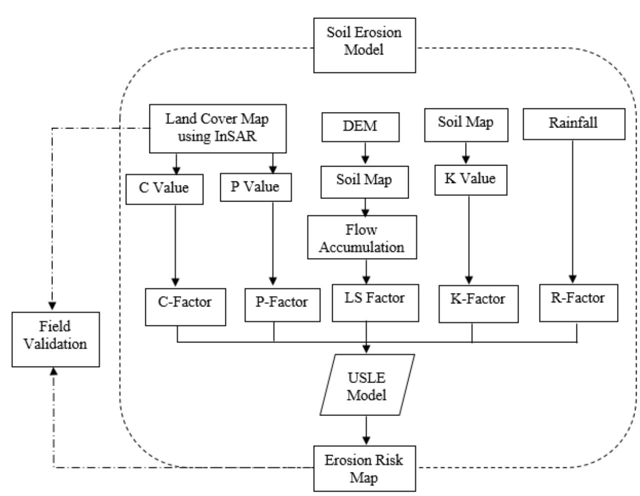


Fig 3. Experimental Flow Diagram

## 3. Results and discussion

### *3.1 Classification of hilly lands based the Slopes*

The result of slope analysis shows that there is 217.5 $km^2$ (30.5%) of the highlands area under high potential erosion area whose slopes is 45 degree and above (Fig. 4). It is clearly observed during field survey that, the region is either developed or undergoing process of development. Moreover, major crops planted on these hilly farms comprised of tea, fruits and vegetables. Major towns in the area include Tanah Rata, Kanjin Habu, Complex Partania, Mardi, Terrisu and Alurmusuk. 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 Ref [21] and is in agreement with the reports provided by ref [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]. It is understood that the high the slope, the more runoff velocity since 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 same. Nevertheless, erosion is bound to take place in both cases and that, protection measures are required to minimize the degree of the incidences.

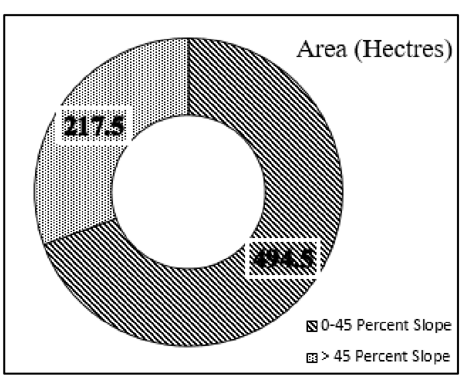


Fig 4. Classification of Highlands Area based on Slope

### *3.2 Rainfall Erosivity and soil Erodibility*

In this study, the rainfall erosivity assessment was found in the ranged from 1,540 to 2,326.7 MJ $mmha^{-1}yr^{-1}$ is at area Kea Farm. High erosivity occurs at southwestern part which includes Tanah Rata, Habu and Ringlet which the most developed towns with many agricultural farms. High erosive power indicates tendencies of the rainfall to cause erosion which requires more efforts to reduce the potential impacts on the soil. Moreover, this demonstrates that, southwestern regions are more vulnerable to erosion and therefore more attention should be directed to the area particularly where farming operations are taking palace. Hulu Tolum and Kg. Raja for example, have lowest erosivity values which shows that, there is less rainfall power to cause erosion compared to other parts. Soil erodibility on other hand, represent the soil resistance to erosion agents such as rainfall.

The Erodibility assessment in Cameron highlands revealed by two to distinctive of soil types are provided by Department of Agriculture [18]. The K-factors for soils STP and SDG-KDH-DG are 0.11 and 0.116, respectively. Some parts between Kea Farm and Tanah Rata fall within SDG-KDH-DG soil type while all other parts are dominated with STP soil as used in the present study.

### *3.3 Slope, C and P factors for soil erosion estimation*

Slope factor was calculated from DEM obtained using InSAR and processed in ArcGIS after which the LS factor was generated. As stated above, 30.5% of the total area matched this requirement and thus, proceeds to next stage of erosion risk assessment. Normally the LS factor is a dimensionless and found in the range of 0 to1. The major cover types identified are forest, agriculture, residential area, water body and roads. For the agriculture, main crop covers are tea, vegetables, fruits and varieties of lower species [5,14,24]. Moreover, this study adopts the same supporting practices (P factor) in accordance with the department of agriculture, Malaysia [18]. Both C and P values are dimensionless factors and ranged from 0 to 1 which indicates bare land and full surface vegetation cover, respectively. Nevertheless, agricultural activities are growing and expected to continue to expand because of it economic returns [24]. This operation becomes the second land use after forested area which puts the soil at risk of high erosion and other form of environmental degradations such as floods, landslides and sedimentation of rivers [5].

In this study, the soil erosion map for the Cameron Highlands were produced by clipping each R, K, LS, C and P values of the selected catchment area from the original factor. The raster calculator was used to overlay the clipped factors and produced soil loss map on annual basis (Fig. 5). The annual soil loss produced from the sub-catchments of Telom and Bertam regions are found to be 38 t $ha^{-1}year^{-1}$ and 73.9 t $ha^{-1}year^{-1}$ respectively. Erosion severity classes indicate that this rate of soil erosion in Cameron highlands is classified high and thus, control measures need to be deployed. Although, the area coverage of the catchments is almost the same, but the erosion rates were found significantly different. This could be attributed to the high erosivity of rainfall which occurred at Bertam sub-catchment. In addition, the soil type in Bertam is completely SDG-KDH-DG is marginally less erodible than STP which is present at some parts of Telom catchment such as Tanah Rata, Habu and Ringlet are those areas fall within high eroded soil zones. This could be because of intensive agricultural operation and development in this region [18]. Nonetheless, Hulu Telom, Kg. Baru and Kg. Raja are among the area under Telom sub-catchment with relatively less susceptible to potential erosion and could be explained by more resistant soil in the area.

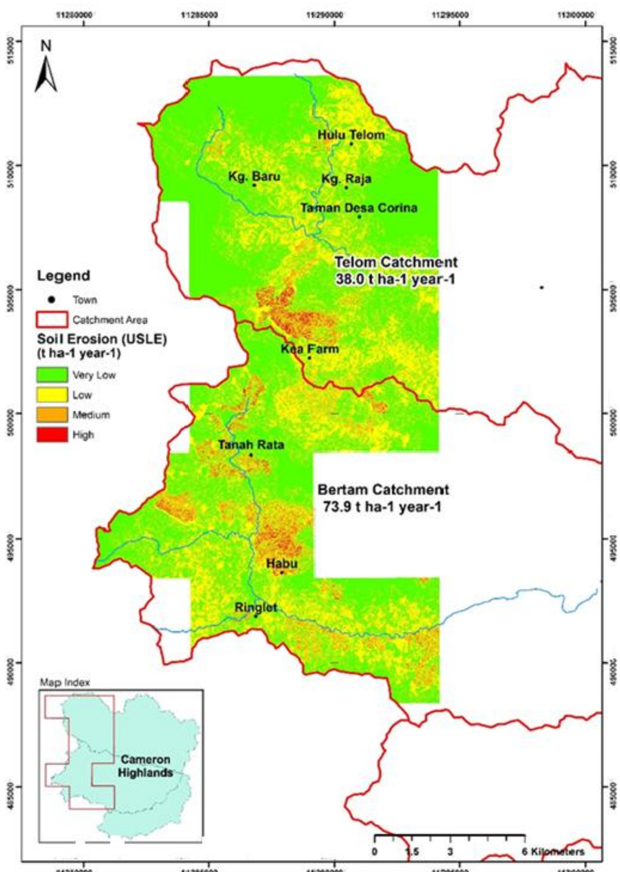


Fig 5. Soil Erosion Risk Map

### 3.4 Susceptibility of erosion and risk zoning

In this study, we introduced soil erosion risk zoning to ease identification and managing hilly farm erosion problems. Grid sizes of approximately 1 $km^2$ were constructed alongside with potential erosion risk map (Fig. 6). 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 to potential erosion. This agreed with the study conducted by Pradhan [5] where the same regions were reported having high potential 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 mostly classified as very low erosion prone areas.

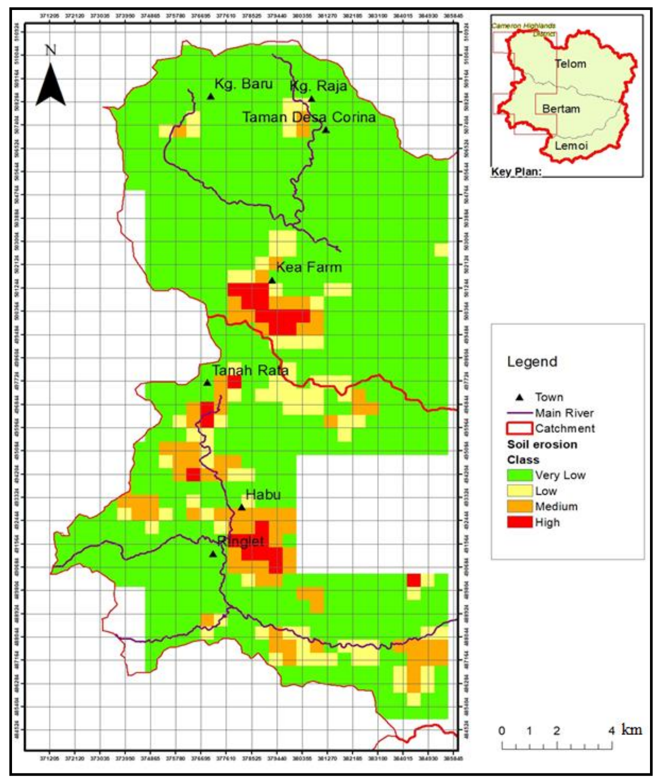


Fig 6. Susceptibility of soil Erosion and Risk Zoning

Soil erosion risk analysis from of selected area revealed that, there is 66% of total area under very low erosion risk with equivalent annual soil loss of 1.0 t $ha^{-1}yr^{-1}$ or less (Table 2). However, 10.8% is fall under high susceptible erosion zone with total annual soil loss of greater than 15 t $ha^{-1}yr^{-1}$.

Table 2. 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 |

## 4. Conclusion

Soil erosion risk assessment was conducted using InSAR as a source of soil morphology data. 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 huge portion of the study area is categorized as high erosion risk potential. Moreover, the study gathered that erosion zoning strategy can assist for easy identification and evaluation of farmland base on erosion status. This is a crucial step for both farmers and management to deploy useful strategy to combat the potential risk of soil erosion.

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