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The Development of a Soil Erosion Risk Map for Perak, Malaysia

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Abstract

Soil erosion in the state of Perak has long been identified as a problem, and soil erosion due to water is one of the main causes of land degradation in this state. If this problem is not seriously addressed, it will result in soil erosion affecting a vast area and suitable soil erosion risk map has to be developed to ensure effective implementation of soil conservation in a particular area. The purpose of this study was to prepare a soil erosion risk map for the state of Perak which can be used to prioritize the areas that are highly exposed to soil erosion for conservation efforts. This study used the Universal Soil Loss Equation (USLE) model integrated with a Geographic Information System (GIS) to produce a soil erosion risk map for the state of Perak. Soil erosion risk mapping was carried out using a map overlay of USLE parameters within Arc GIS which was used to identify risky areas for soil erosion and estimate soil loss in the study area. The results of the study showed that the risky areas for soil erosion were scattered all across Perak, especially on steep slopes. The development of this soil erosion risk map for Perak state is very important for conducting good environmental management and land use planning strategies.

Keywords: Soil Erosion, Soil Erosion Risk Map, Gis, Perak State.

Introduction

Soil erosion is one of the most serious environmental issues facing the world (Rahman, Shi & Chongfa, 2009a). Serious soil erosion may jeopardise the environment, agricultural activities and water resources, reducing reservoir storage capacity and the sustainability of the environment (Julio, Eunice, Pedro, Helba & José, 2017). Soil erosion is one of the most serious global environmental problems because it causes soil degradation and the loss of soil nutrients while simultaneously leading to many secondary environmental problems such as floods, river silting and water pollution (Rahman et al., 2009b). Soil erosion often leads to a reduction in the supply function of the land in three ways: removal of organic matter, changes in the depth to the

root barrier and increased soil compaction resulting in the loss of soil structure to hold water, nutrients and air required for plant root activity (Rabia, 2012; United States Department of Agriculture, 2012).

Soil erosion is caused by water which initiates the detachment process of soil particles via raindrops and flowing water and then transports soil particles downslope (Yusof, Abdullah, Azamathulla, Zakaria & Ghani, 2011). Soil erosion occurs as the result of high amounts of water, especially when the soil is exposed for a long period of time during rainstorms (Bagarello, Di Stefano, Ferro & Pampalona, 2017). According to the German Advisory Council on Global Change (WBGU) (1994), soil erosion by water is a major cause of land degradation in the world, covering 1.1 billion hectares (56%) worldwide. Soil may be eroded from its original state by water and wind action. Water erosion accelerated by anthropogenic activities through changes in land use is the main process that occurs in tropical and humid areas (Diyabalanage, Samarakoon, Adikari & Hewawasam, 2017).

The rapidly growing world population is a factor that is predicted to put pressure on future land use and soil sustainability (Reitsma, Dunn, Mishra, Clay, DeSuttere & Clay, 2015). The study conducted by Ouyang, Hao, Skidmore and Toxopeus (2010) showed that soil erosion is primarily caused by human activity and land use change, making this one of the most important factors in the occurrence and intensity of soil erosion. Human-induced land use or soil cover change has a significant impact on soil degradation, including soil erosion, soil acidification and reduction of organic matter (Sharma, Tiwari & Bhadoria, 2011). Over the last century, soil erosion accelerated by human activities such as land clearing, agricultural practices, construction and urbanisation has been the source of serious environmental problems. A change in land use causes a geomorphic reaction that leads to a high rate of soil erosion in the exposed area. Traditionally, land use such as forests results in less soil erosion, whereas agricultural land use tends to accelerate erosion (Ouyang, Wu, Hao, Zhang, Bu & Gao, 2018).

Soil erosion is a complex problem with multiple related factors, and this requires an integrated and systematic approach. Spatial technologies such as remote sensing and Geographical Information System (GIS) as well as modelling techniques are powerful tools for catchment area management (Zare, Panagopoulos & Loures, 2017). In order to produce a map of the areas at risk for soil erosion in Perak, an integration of the Universal Soil Loss Equation (USLE) and GIS was conducted to assess soil erosion risk in the study area. Soil erosion assessment has gained considerable attention as it can be used as a basis to develop plans for effective soil and water conservation as well as to reduce soil degradation (Ali & Hagos, 2016). Implementation of effective soil conservation can be prioritized with a spatial assessment of the soil erosion risk in a particular area (Moussa, Voltz & Andrieux, 2002; Souchère, Cerdan, Dubreuil, Le Bissonnais & King, 2005). Therefore, a suitable soil erosion risk map needs to be developed to ensure that an effective implementation of soil conservation can be done in the area. In this context, the purpose of this study was to provide a soil erosion risk map for the state of Perak which can be used to prioritize the areas that have a high risk of soil erosion for conservation efforts.

Study Area

The size of the study area is 20,656 km² (Figure 1), equivalent to 6.30% of the total area of Malaysia (Department of Statistics Malaysia, 2014). The state of Perak is located between latitude 3°60'N to 5°90'N and longitude 100°30'E to 101°70'E. It is divided into 12 administrative

districts and is the second largest state in Peninsular Malaysia. The state of Perak lies on the west coast of Peninsular Malaysia, bordering Kedah and southern Thailand in the north, Penang in the north-west, Kelantan and Pahang in the east and Selangor in the south.

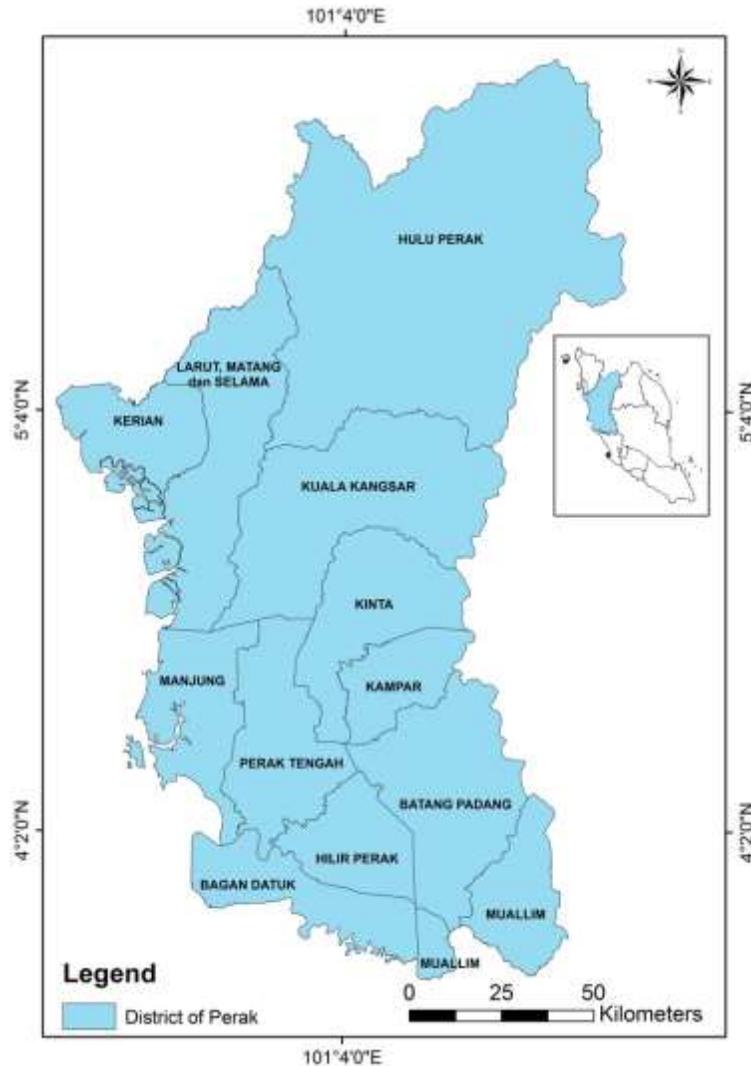


Figure 1. District in Perak state

Perak's topography is low and undulating especially in the Kinta Valley area. However, hilly areas can be found in the eastern and northern parts of Perak which led to the construction of four multi-function dams on the upstream portion of the Perak River. The hills are the result of three mountain ranges oriented roughly: the Titiwangsa Range in the east, Bintang Range in the north and the Keledang Range lying between them in the middle, forming the eastern divide for the central portion of the Perak River. The lowland area of Perak lies along the coast stretching from the border with Kedah to the border with Selangor and has become the focus of various activities such as agriculture, industry, settlement and transport. Perak's land use is mixed and can be classified into 17 main types. Details of the land use in the study area are shown in Table 1 and Figure 2.

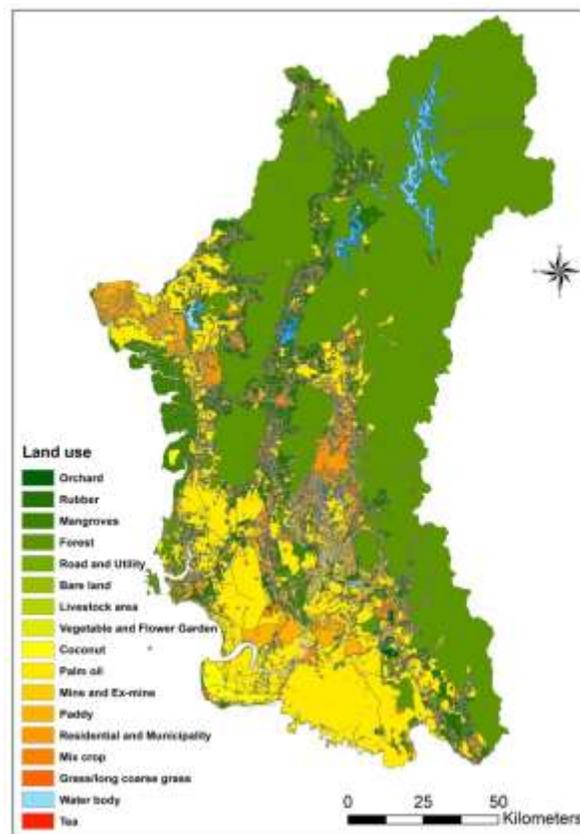


Figure 2. Land use of the study area

Table 1. Land use area of the study area

Land use	Area (km ²)	Percentage area (%)
Orchard	173.44	0.84
Rubber	1939.26	9.39
Mangroves	766.10	3.71
Forest	10550.42	51.08
Road and Utility	134.93	0.65
Bare land	69.62	0.34
Livestock area	53.61	0.26
Vegetable and Flower garden	20.50	0.10
Coconut	276.50	1.34
Palm oil	4050.90	19.61
Mine and Ex-mine	363.10	1.76
Paddy	487.40	2.36
Residential and Municipality	476.44	2.31
Mix crop	656.10	3.18
Grass/long coarse grass	266.30	1.29
Water body	370.00	1.79
Tea	2.05	0.01

The state of Perak is generally located in a tropical region with high frequency and intensity of rain. These climatic characteristics cause Perak in particular and Malaysia in general, to have uniform temperatures, high humidity and abundant rainfall. This is because Malaysia is located in the equatorial doldrums region. Its annual temperature difference is less than 2°C except for the east coast of Peninsular Malaysia which is often influenced by cold winds from Siberia during the Northeast Monsoon (NEM). On average, the temperature in Perak is 27.2°C to give the average high and low recorded temperatures of 28°C and 26.6°C. This is influenced by the Southwest Monsoon (SWM) wind that usually blows between May and September and the NEM wind that blows from November to March. In general, the NEM brings heavy rain to the east coast states of Peninsular Malaysia and western Sarawak whereas the SWM is drier. The monsoon transition begins at the end of March until early May and October through mid-November (Malaysian Meteorological Department, 2017).

Study Methods

Universal Soil Loss Equation (USLE)

The procedures and steps required to calculate the annual soil loss of the study area are basically derived from the method found in the USLE developed by Wischmeier and Smith (1978) and shown in Equation 1. The actual estimate of soil loss is carried out with a map overlay, pixel by pixel. This allows the multiplication of USLE parameters to be performed accurately.

$$A = R \times K \times L \times S \times C \times P$$

Equation 1

Where, A = Soil loss, in tonne ha⁻¹ year⁻¹

R = Rainfall erosivity factor

K = Soil erodibility factor

LS = Slope length factor

C = Cropping management factor

P = Practice of cropping management factor

Rainfall Erosivity (R)

This factor is the most important factor in the USLE compared to the other input parameters (Jebari, 2009). Rain kinetic energy can be defined as the potential rain energy that can be transformed into soil erosion. Morgan (1974) developed the Rainfall Erosivity (R) index for Peninsular Malaysia, and it is used in the USLE based on the following equation:

$$R = (9.28P - 8,838.15) / 100$$

Equation 2

Where, P is the average annual rainfall and the equation is in SI units (J m⁻² or MJ m⁻²). The calculation of the R factor has been represented spatially using Arc GIS (Figure 3a).

Soil Erodibility Index (K)

This factor depends on the nature of the soil. The nomograph for the K index calculation for soil series can be represented by the following equation related to soil properties and soil erodibility:

$$K = \frac{2.1 M \times 1.14 \times 10^{-4} \times (12 - OM) + 3.25 \times (S - 2) + 2.5 \times (P - 3)}{100 \times 0.317}$$

Equation 3

Where, M = (% silt + % very fine sand) × (% fine sand + % medium sand + % coarse sand)

OM = % organic matter content

S = Soil structure code

P = Soil hydraulic permeability classes

The soil structure classes used in the USLE are in accordance with the Malaysia soil report prepared by the Department of Agriculture Malaysia (DOA). The soil structure classes are shown in Table 2.

Table 2. Soil structure classes used in the USLE (DOA)

Soil structure code	Definition of soil structure (nomograph)	Soil structure classes (soil report – DOA)
1	Very fine granular	Very fine branular, crumb
2	Fine granular	Fine granular / crumb
3	Medium or coarse granular	Medium granular / crumb or very fine to fine subangular blocky or very fine to fine angular blocky
4	Blocky, platy or massive	Medium to coarse subangular blocky, angular blocky, prismatic, columnar or massive

The drainage classes used for Malaysia's soil mapping are compatible with the soil hydraulic permeability used in the USLE nomograph recommended by the DOA and are shown in Table 3. From this table, soil hydraulic permeability parameters are easily determined. The final results obtained for the K factor have been determined spatially on the map (Figure 3b).

Table 3. Soil hydraulic permeability class recommended by Department of Agriculture (DOA)

Soil permeability value	Soil profile hydraulic permeability (USLE nomograph)	Soil profile drainage classes (soil report – Department of Agriculture Malaysia)
1	Rapid	Class 8 – 9 : Excessive to very excessive drained
2	Moderate to rapid	Class 5 – 7 : Somewhat imperfect to well drained
3	Moderate	Kelas 4 : Imperfectly drained
4	Slow to moderate	Kelas 3 : Somewhat poorly drained
5	Slow	Kelas 2 : Poorly drained
6	Very slow	Kelas 0 – 1 : Very poorly to somewhat poorly

Slope Length Factor (LS)

The LS factor is a combination of the slope length factor (L) and slope steepness (S). The LS factor may be calculated as these separate parts or combined into a LS index. The LS factor determines the length of the slope from the starting point of the surface runoff to the point where the reduced steepness will cause sedimentation or the point where water runoff enters into a drainage channel (Singh, 1992). The equations used to determine the LS factor vary depending on the selection of units and other conditions such as the available data (Jebari, 2009).

In this study, the LS factor can be calculated from the slope length and the slope steepness obtained from the map, shown in Figure 3c. Equation 4 below shows the method used to obtain the LS factor of this study.

$$LS = \left(\frac{L}{22.13}\right) \times 0.5 \times (65.4 \sin^2 \theta + 45.56 \sin \theta + 0.065) \quad \text{Equation 4}$$

Where, L = Slope length in metres

θ = Slope gradient in degrees

Slope length is estimated by measuring the line from the starting point of the surface runoff or from the highest point to the outlet, the point below the slope where erosion ends and sedimentation takes place or the lowest point. Each line measuring the slope length of each slope must be perpendicular to the contour line.

Cropping Management Factor (C)

The Cropping management (C) factor represents the ratio of soil loss in an area with crops to soil loss in an open area (Ranya, Sarra & Abdel, 2015). Changes that occur in cropping management should be taken into account as they affect the rate of soil loss. Land covered with plants is less likely to be eroded because there are roots that keep the soil from moving. The plants act as an earth cover and protect the soil from erosion caused by rainwater (Morgan, 2005). C factor values are used as a variable data attribute for each type of land use in the land use vector map (Table 4 & Figure 3d).

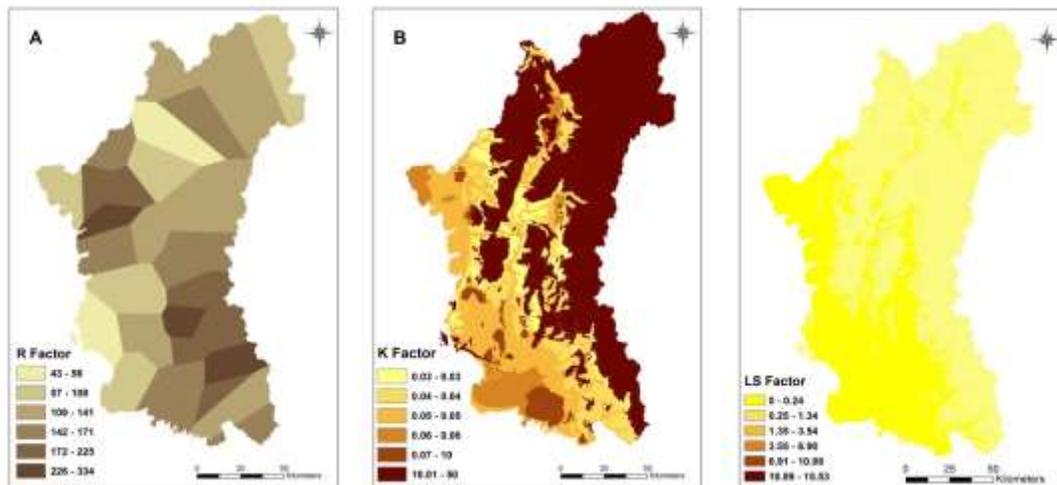
Table 4. C Factor variable value

Land use type	C factor value
Orchard	0.25
Rubber	0.20
Mangroves	0.36
Forest	0.03
Road and Utility	0.01
Bare land	1
Livestock area	0.25
Vegetable and Flower garden	0.38
Coconut	0.20
Palm oil	0.20
Mine and Ex-mine	0.01
Paddy	0.01
Residential and Municipality	0.15
Mix crop	0.25
Grass/long coarse grass	0.30
Water body	0.01
Tea	0.25

(Modified from: Ayad, 2003; Layfield, 2009; Mitchell, Bubenzer, McHenry & Ritchie, 1980; Troeh, Hobbs & Donahue, 1999; Wischmeier & Smith, 1978)

Cropping Management Practices Factor (P)

The P factor represents the practice of erosion control management that can slow down water runoff and reduce the amount of soil transported by surface water runoff. This may reduce the rate of soil loss that occurs. The P value of the study area was assumed to be one (1) for the entire study area because there were no cropping management practices applied in the area (Figure 3e). All of the factors in the USLE model were analysed in GIS to obtain the final result of the study which was an erosion risk map for Perak.



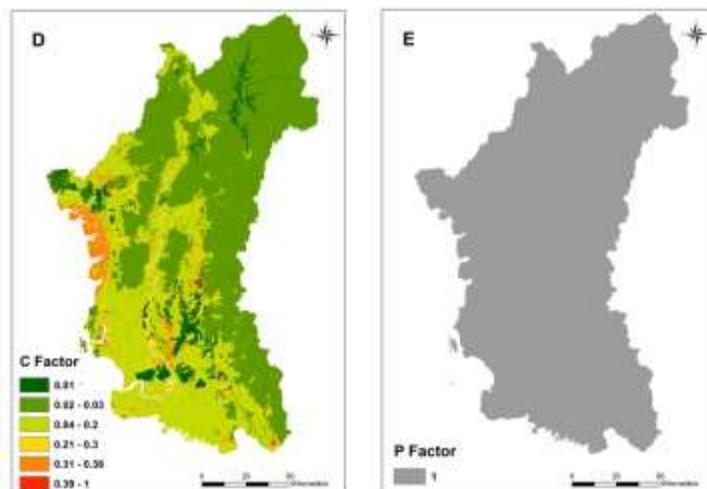


Figure 3. (a) Rainfall Erosivity, R Factor, (b) Soil Erodibility, K Factor, (c) Slope Length, LS Factor, (d) Cropping Management, C Factor, (e) Cropping Conservation Practice, P Factor

Results and Discussion

Datasets in GIS format are increasingly available and this makes soil erosion risk mapping the best alternative for erosion assessment of a region, especially when there is a lack of time, data or erosion model development. Soil erosion risk mapping based on integration of the USLE model in GIS is flexible and can be adapted to the available data for the factors and local conditions. As a result, soil erosion risk mapping can be used to prioritize the areas exposed to high erosion risk for conservation efforts.

The soil loss rate in the study area was determined based on the factors in the USLE model and was integrated with GIS. The annual rainfall data range of 1418–4522 mm was used for calculating the R factor in USLE. The values of the R factor in this study were between 43–334 MJ mm⁻¹ ha⁻¹ year⁻¹ and showed different distributions according to the boundaries of the rainfall areas (Figure 3a). The low values of the R factor were concentrated in the southwest, and the high R factor values were located in the western and eastern regions of Perak. High R factor values were detected in Kampar, Bukit Larut and Taiping which have high amounts of annual rainfall.

The K factor (soil erodibility) has values ranging from 0.03 to 50 tonnes ha⁻¹ MJ⁻¹ mm⁻¹. Figure 3b shows that high values of the K factor were calculated for steep land located at high altitudes along the eastern and northern terrains as well as the mining area located in central Perak. The low values of the K factor were located in lowland areas that extend from southern to northern Perak. This can be explained by the soil texture classes or the percentage of sand content in the soil; soils that contain a high percentage of sand are more sensitive to erosion.

There were six classes of different steepness produced from the steepness map. The difference in steepness was based on the topographic features in the study area. The main steepness range of the study area was located between 0–0.24, 0.25–1.34 and 1.35–3.54 (Figure 3c). The values of the LS factor were set based on each class of steepness. The slope length and the slope steepness factor can greatly affect the potential amount of soil erosion produced. Soil erosion increases with increased gradient due to the increase in water runoff velocity (steep

slopes produce higher flow velocity). In addition, longer slopes can accumulate a greater amount of runoff resulting in both steep slopes and longer slopes allowing water runoff to move at high velocities. A high rate of water runoff will cause pressure on the soil surface and this will increase the capacity of the water runoff to transport more sediment (Ali & Hagos, 2016).

Land use is observed to have an impact on the soil erosion risk in an area. The values of the C factor ranged between 0.01 to 1 with the spatial distribution shown in Figure 3d. The soils which are highly sensitive to erosion are scattered across the map of the study area corresponding to areas with agricultural activities (rubber, palm oil and mixed crops) as well as cleared and forested areas (Figure 3d). These land uses resulted in high C factor values while low C factor values were obtained from paddy fields, roads, utilities and water bodies.

All the R, K, LS, C and P factor layers previously calculated using GIS were combined to produce the soil loss risk map shown in Figure 4. Erosion risk for the study area was divided into six categories: low, moderate, high, very high, extreme and extremely high. In the soil erosion risk map produced (Figure 4), the areas represented in red are highly eroded areas.

Based on the map, it can be observed that the areas at risk for erosion are scattered on steep slopes. A study by Raissouni, Khali, El Arrim, Maâtouk and Passalacqua (2012) for northern Morocco is in line with the results of this study. They also observed that the risk of erosion is greater for land areas with steep slopes due to water erosion which is also driven by climate action. The areas with the highest erosion risk are due to the combination of steep slopes, high rainfall rates, land renovations and clearing of land for human activities such as agriculture, deforestation and mining/quarrying activities in areas that are sensitive to soil erosion. The areas with low erosion risk (represented by yellow colour) are mostly located in the undulating slope areas.

Looking closely at Figure 4, areas covered with mangroves, paddies, roads and utilities and bodies of water are categorised as areas with low and moderate erosion risk. Regions consisting of cleared land, deforested areas, very steep slopes, grassland areas, rubber trees, palm oil trees and mixed crops have been identified to have high to extremely high erosion rates requiring immediate conservation measures.

Meanwhile, land use for the study area can be classified into 17 main types (Table 5). Based on Table 6, it can be observed that the land use types that contribute to high erosion rates are rubber, palm oil and mixed crops, whereas other land uses have moderate and low levels. Although land use is the major contributing factor for soil erosion in the study area, the spatial distribution of soil erosion risk (Figure 4) also indicates that slope steepness influences the occurrence of soil erosion with high erosion also occurring in areas with steep slopes. In order to maintain the current trends of soil erosion risk and to reduce the risk of high soil erosion in some parts of the study area, conservation priority policies need to be implemented by identifying effective measures that may help in the recovery of soil degradation.

Table 6. Soil loss rate contributed by land use type

Land use	Soil loss (t km⁻² yr⁻¹)	Soil loss (%)
Orchard	378	1.71
Rubber	6204	28.02
Mangroves	157	0.71
Forest	1704	7.70
Road and Utility	19	0.09
Bare land	1609	7.27
Livestock area	135	0.61
Vegetable and Flower garden	941	4.25
Coconut	31	0.14
Palm oil	5203	23.50
Mine and Ex-mine	112	0.51
Paddy	0.74	0.04
Residential and Municipality	1228	5.55
Mix crop	3310	14.95
Grass/long coarse grass	1011	4.57
Water body	72	0.33
Tea	20	0.09

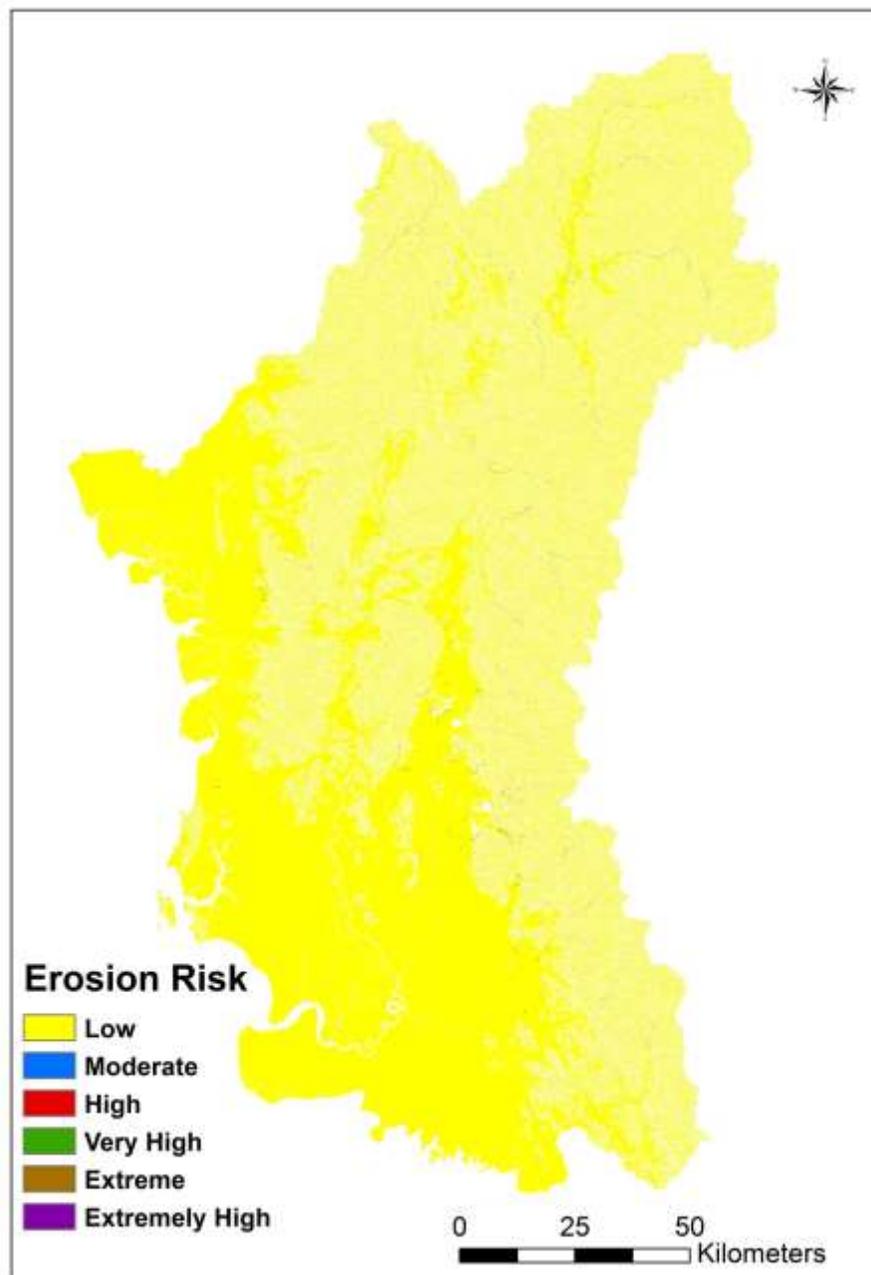


Figure 4. Erosion risk map of the Perak state

Conclusion

Application of GIS integrated with the USLE model was used to identify and assess potential areas for soil erosion as well as to estimate the value of widespread soil loss. The soil erosion risk map was produced based on the USLE model and overlays of certain parameter maps available in the USLE model. The documented results found that most of the study area indicated a low to moderate erosion risk because it was covered with mangrove, paddy fields, roads and utilities, forests and bodies of water. Areas that have a high to extremely high risk of erosion are

related to one of the following factors: high slope steepness, cleared land, deforested areas, grasslands or rubber tree, palm oil tree and mixed crop areas.

The erosion risk map of Perak can be used to estimate the zones that are vulnerable to soil erosion. It is inevitable for Malaysia in general and Perak in particular to experience soil erosion because there are many areas in Perak experiencing rapid development leading to land clearing for construction of houses, logging activities and opening of new areas for agriculture. While these activities are needed for development purposes, it is very important for consideration to be given to the formulation of strategies for soil protection that aim for the implementation of policies that control or reduce the risk of soil erosion.

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