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Integration of remote sensing, RUSLE and GIS to model potential soil loss and sediment yield (SY)

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Abstract

Land use activities within a basin serve as one of the contributing factors which cause deterioration of river water quality through its potential effect on erosion. Sediment yield in the form of suspended solid in the river water body which is transported to the coastal area occurs as a sign of lowering of the water quality. Hence, the aim of this study was to determine potential soil loss using the Revised Universal Soil Loss Equation (RUSLE) model and the sediment yield, in the Geographical Information Systems (GIS) environment within selected sub-catchments of Pahang River Basin. RUSLE was used to estimate potential soil losses and sediment yield by utilizing information on rainfall erosivity (R) using interpolation of rainfall data, soil erodibility (K) using field measurement and soil map, vegetation cover (C) using satellite images, topography (LS) using DEM and conservation practices (P) using satellite images. The results indicated that the rate of potential soil loss in these sub-catchments ranged from very low to extremely high. The area covered by very low to low potential soil loss was about 99 %, whereas moderate to extremely high soil loss potential covered only about 1 % of the study area. Sediment yield represented only 1 % of the potential soil loss. The sediment yield (SY) value in Pahang River turned out to be higher closer to the river mouth because of the topographic character, climate, vegetation type and density, and land use within the drainage basin.

1 Introduction

In need for better quality of life and human development, vast amounts of forest areas are explored. As a consequence, environmental degradation becomes common. Development of new areas has resulted in many forest areas being cleared for housing, agriculture, recreation, mining and industrial activities. Widespread deforestation for agricultural purposes has resulted in the disruption of ecological environments. Changes in land uses if unchecked could contribute to accelerated widespread soil erosion. It has long been recognised that the adverse influences of widespread soil erosion such as on soil degradation, agricultural production, water quality, hydrological systems, and environments are serious problems for human sustainability (Lal, 1998). Erosion or soil loss is the action of climatic or environmental agents such as wind, rain, rivers, and glaciers; nevertheless, human actions and activities such as logging or the clearing of farms could also lead to the elimination of the surface layer of soil, loose rocks and cliffs. In additional, water erosion is a serious and continuous environmental problem in many parts of the world (Deniz et al., 2008).

Recently, about 80 % of the world's agricultural land suffers from moderate to severe erosion (Ritchie et al., 2003). The concern over these global environmental issues such as excessive land use, massive conversion of natural landscapes into agriculture areas, town planning, and also natural disasters such as land slide and flood has resulted in the use of remote sensing technique becoming one of the famous alternatives. Remote sensing information, together with available enabling technologies such as GPS and GIS, can form the information base upon which sound planning decisions can be made, while remaining cost-effective (Franklin et al., 2000). In Revised Universal Soil Loss Equation (RUSLE), which is an empirical model frequently used to assess erosion risk (Renard et al., 1997; Angima et al., 2003; Fernandez at al., 2003; Lu et al., 2004; Shi et al., 2004; Fu et al., 2006; Schiettecatte et al., 2008), the rate of erosion is determined using satellite images, while GIS is used to calculate potential soil loss based on the RUSLE equation. Hence, by integrating RUSLE and GIS, the spatial distribution of erosion location and intensity can be obtained. This technique makes potential soil loss estimation and its spatial distribution feasible with reasonable costs and better accuracy for larger areas (Millward and Mersey, 1999; Wang et al., 2003). Soil erosion model is a necessary tool to predict excessive soil loss and to help in implementation of erosion control strategy (Ismail, 2008).

Soil loss and sedimentation are processes closely related to each other. Dislodged soil particles are often stored within depressions in the land but may be dislodged during storm events. The amount of silt and sediment delivered into water systems through

the processes of entrainment, transportation, and deposition is a function of changes in surface drainage patterns, terrain roughness, vegetation, and climate conditions. Suspended sediment is empirically one of the best indicators of sediment delivery into the drainage system or watercourse from the land during land clearance and earthwork activities.

This study was carried out in the catchment area of Pahang River, bordered by the latitude 2°59′ N–3°47′ N and longitude 102°28′ E–103°28′ E (Fig. 1). The study area is about 5120 km^2 in size which is dominated by oil palm plantations, rubber estates, forest and other land uses such as logging, paddy cultivation, horticulture, as well as town and settlement areas with tropical bimodal precipitation. The catchment of Pahang River is characterized by hilly areas in the western portion and low land toward the coastal area in the eastern portion. Pahang river is the longest river in Peninsular Malaysia and flows through seven districts in Pahang namely, Maran, Jerantut, Bentung, Lipis, Temerloh, Bera and Cameron Highlands, covering a total area of 27 000 km^2 (Weng and Mokhtar, 2004). River sub-catchments within the Pahang River basin are Mentiga River, Lepar River, Chini River, Lekur River, Jempol River, Jengka River, Luit River and Temerlong River. These rivers flow into Pahang River and eventually drain into the South China Sea.

2 Materials and methods

2.1 Model structure

Potential soil loss in basin areas depends on the configuration of the basin, the soil characteristics, the local climate conditions and the land use and management practices implemented in the basin. Soil erosion rates within basins can be measured using Revised Universal Soil Loss Equation (RUSLE). According to Renard et al. (1997), RUSLE calculation can be presented based on climate, soil, topography and land use which influence the occurrences of stream and inter-rill soil erosion by direct rainfall impact and surface runoff. It has been used extensively to estimate soil loss, assess the risk of soil loss and also as a guide to development and conservation plan to control erosion. The formula in RUSLE is as follows (Renard et al., 1997):

$$A = R \cdot K \cdot \mathrm{LS} \cdot C \cdot P \quad (1)$$

where, A = the computed spatial average soil loss and temporal average soil loss per unit area (ton ha^{-1} yr^{-1}), R = rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K = soil erodibility factor (Mg h MJ^{-1} mm^{-1}), LS = slope length and steepness factor, C = cover management factor and P = the conservation practice factor.

In GIS environment, five types of analyses can be used to analyse potential soil loss (A) in connection to the RUSLE parameters. Rainfall factors are derived from geostatistical method such as kriging estimators (Goovaerts, 1999), soil erodibility factors are derived from experimental models based on soil properties (Wischmeier and Smith, 1978), topography factors are estimated from actual field measurements of length and steepness (Wischmeier and Smith, 1978) and calculated from DEM data with various approaches (Hickey, 2000; Van Remortel et al., 2001), land use is derived from a combination of individual C factors from empirical models and remote sensing classification images (Millward and Mersey, 1999) while land cover factors are obtained from experimental data (Renard et al., 1997). The flow chart of the research approach of this study is shown in Fig. 2.

2.2 Data sources and factor generation

2.2.1 The Digital Elevation Model (DEM)

The generation of a DEM for the catchment area of Pahang River involved digitizing 10 m interval contour lines which were provided by the Department of Survey and Mapping Malaysia (JUPEM). The spatial elevations were derived from the contour lines data using interpolation method in GIS. The DEM was derived from the spatial elevation data and projected to the Kertau RSO Malaya Meters (Fig. 3a).

Length and slope factor (LS) was calculated through a series of equations. The equations can be used in single index, which expresses the ratio of soil loss as defined by Bizuwerk et al. (2008).

$$\mathrm{LS} = \frac{X}{22.1}\, m\, (0.065 + 0.045S + 0.0065S^2) \quad (2)$$

where:

- X = slope length (m),
- S = slope gradient (%), and
- m = refer Table 2.

The value of X and S can be derived from the Digital Elevation Model (DEM) (Fig. 3a). Calculation of the X value was derived by multiplying the flow accumulation with cell value. Flow Accumulation was derived from the DEM after conducting the Fill and Flow Direction value. The value of X was calculated using Eq. (3).

$$X = (\text{Flow accumulation} \times \text{cell value}) \quad (3)$$

By substituting the X value, LS equation will be:

$$\mathrm{LS} = \frac{(\text{Flow accumulation} \times \text{cell value})}{22.1}\, m\, (0.065 + 0.045S + 0.0065S^2) \quad (4)$$

The slope (%) was also derived directly from the DEM. The value of m varied from 0.2 to 0.5 depending on the slope (Table 2).

2.2.2 The precipitation surface and rainfall runoff factor (R)

Pahang is a productive agricultural state in Malaysia; therefore, there are many meteorological stations which monitor climate conditions in the area. A total of 18 climate stations used in this study area are randomly distributed across the Pahang River catchment. Daily rainfall data for five years were obtained from these gauging stations through the Malaysian Meteorological Department. All daily rainfall data provided by each station were composited to generate annual data. Spatial annual rainfall data were derived from each station using Simple Kriging estimator technique with Spherical Semivariogram Model (Fig. 3b). The spatial rainfall data results were compared and validated with the precipitation map from the Department of Irrigation and Drainage Malaysia (JPS).

The erosivity factor (R) was calculated by using the equation from Morgan (1974) and Roose (1975). Erosivity factor was derived by averaging the results of both Eqs. (5) and (6). The formulas are as follows:

$$R = \frac{(9.28P - 8838.15 \times 75}{1000} \qquad \text{Morgan(1974)} \tag{5}$$

$$R = 0.5P \times 17.3 \qquad \text{Roose(1975)} \tag{6}$$

where, P value = the mean annual precipitation.

2.2.3 The soil erodibility factor (K)

Erodibility factor (K) includes the effect of soil properties such as soil texture, aggregate stability, shear strength, infiltration capacity, organic content and chemical composition on soil loss. The formula for soil erodibility is as follows:

$$K = \frac{2.1 \times 10^{-4}(12 - \mathrm{OM}\,\%)(\mathrm{N1} \times \mathrm{N2})^{1.14} + 3.25(S - 2) + 2.5(P - 3)}{100} \tag{7}$$

where,

- OM = organic matter (%),
- N1 = clay + very fine sand (0.002–0.125 mm),
- N2 = clay + very fine sand + sand (0.125–2 mm),
- S = soil structure, and
- P = hydraulic conductivity (cm h^{-1}).

Distribution of soil series within the study area was extracted from the soil map produced by the Department of Agriculture Malaysia. Soil erodibility factor (K) was determined using a combination of actual field sample measurements and secondary data. The individual attribute table of soil series in the digitized soil map were converted to K value. This soil series data were classified into 22 different soil series in the study area (Fig. 3c) (Table 1).

2.2.4 The land cover and cover management factor (C)

The land cover map was derived from Système Pour I' Observation de la Terra 5 satellite (SPOT 5) scene on 2010 provided by the Malaysian Remote Sensing Agency (ARSM). The SPOT 5 image was then subseted to include the study area. The image of the study area was geo-located to the Kertau RSO Malaya Meters. The Cover Management represents the ratio of soil loss under a given crop cover to that of bare soil (Morgan, 2005). It has a close linkage to land use types. Satellite imagery is also a source of information on percentage vegetation cover, which can be related with an acceptable degree of accuracy to the Normalized Difference Vegetation Index (NDVI) (Mathieu et al., 1997). NDVI is a simple graphical indicator that can be used to analyse remote sensing measurements and assess whether the target being observed contains live green vegetation or non-vegetation area. The NDVI value is in the range of −1 to 1 where −1 is the range for bare soil and 1 for forest (Fig. 3d). The C factor value is opposite to the NDVI value. Normalized Difference Vegetation Index (NDVI) analysis was applied to identify the land cover type. The NDVI values were then converted to C factor using linear regression (Fig. 3d). This is because many researchers have used regression analysis to determine the classification of the C factor in estimating the potential for soil loss (Lin et al., 2006; Zhou et al., 2008).

2.2.5 Support practice factor (P)

The support practice factor is the ratio of soil loss with a specific practice to the corresponding loss with upslope and downslope tillage (Renard et al., 1997). Some control measure and conservation practice should be applied to control soil erosion particularly in sloping and agricultural area. The given values of P factor range from 0.10 to 1.00. The value of 0.10 indicates a forest, 0.40 value indicates an agricultural area, mixed horticulture, orchards, and rubber, 0.70 value is for newly cleared land, and 1.00 value is for bare land and urban associated area (Troeh et al., 1999). Information on P factor was extracted from the land use map.

2.3 Sediment Yield (SY)

Sediment Yield (SY) was calculated using the Sediment Delivery Ratio (SDR).

The formula used for the study area was adopted from the USDA SCS as shown below:

$$\mathrm{SDR} = 0.51A^{-0.11} \tag{8}$$

where A is the area in km^2.

Using the SDR value from Eq. (8), SY values can be calculated using the formula by Wischmeier and Smith (1978):

$$\mathrm{SY} = \mathrm{SDR} \times \mathrm{SE} \tag{9}$$

where,

- SY = sediment yield (ton ha^{-1} yr^{-1}),
- SDR = sediment delivery ratio, and
- SE = annual potential soil loss (A) (ton ha^{-1} yr^{-1}).

3 Results

3.1 Condition of the sub-catchments of Pahang River based on the RUSLE parameters

3.1.1 Slope length and steepness factor (LS)

The L and S factors in RUSLE reflected the effect of topography on erosion. The slope steepness ranged from 0 % in the flat zones (near to the river mouth) to 100 % on the steep slopes in the middle of the river catchment (Fig. 4a). Calculation of LS factor using L (length) and S (slope steepness) showed that the range of LS value is between 0 to 100. Lower LS factor (0–5) covered about 96 % of the study area. The rest of the study area are covered by LS value of between 6–100. Very low LS factor values (0–1) were observed to occur in the eastern part of the study area which includes the Lepar and Mentiga sub-catchments (Fig. 4a). The sub-catchments of Chini, Jempol, Jengka, Lekur, Luit and Temerlung showed a low LS value which ranged from 2.5 to 10. The very low and low LS factor represents about 83 % and 13 % of the study area, respectively.

3.1.2 Rainfall erosivity factor (R factor)

The Rainfall erosivity factor (R) can be defined as an aggregate measurement of the amounts and intensities of individual rain storms over the year and is related to total rainfall (Hudson, 1981; Wenner, 1981). The Rainfall erosivity factor (R) was determined from rainfall intensity data obtained from the National Meteorology Department of Malaysia. The average annual rainfall of the Pahang river catchment is approximately 2370 mm. The result showed that R factor value in the catchment of Pahang River ranged between 1418 to 2323 MJ mm ha^{-1} yr^{-1} with higher values occurring in the northeast of the catchment and decreasing toward the southwest of the catchment area (Fig. 4b). The distribution of the rainfall is higher in the northwest area and decreases toward the southwestern part of the catchment.

3.1.3 Soil erodibility factor (K)

The soil erodibility factor (K) represents the effect of soil properties and soil profile characteristics on soil loss (Renard et al., 1997). There are 22 soil series in the basin and each soil series has different K values. Soil erodibility value in the study area ranged from 0.035 Mg h MJ^{-1} mm^{-1} to 0.50 Mg h MJ^{-1} mm^{-1}. Most of the soil series are characterised by low K values (0.035 Mg h MJ^{-1} mm^{-1} to 0.128 Mg h MJ^{-1} mm^{-1}) (Fig. 4c). The high value of K (0.50 Mg h MJ^{-1} mm^{-1}) covered about 20 % of the study area occupying Luit, Chini and Temerlung sub-catchments (Fig. 4c). Verification using actual field sample measurement showed that the K value ranged from 0.004 to 0.37 Mg h MJ^{-1} mm^{-1}. The highest K value is dominated by very fine sand with silt particle which gives rise to higher soil erodibility.

3.1.4 Cover management factor (C)

The cover management factor (C) represents the effect of cropping and management practices in agricultural system, and the effect of ground cover, tree canopy, and grass covers in reducing soil loss in non-agricultural condition. In this study, vegetation cover was analysed using NDVI. The NDVI thematic map that was derived from the SPOT 5 satellite image of the sub catchment area was applied to derive the cover management value. The value for forest or dense shrub is 0.001, grass is 0.10, horticulture is 0.21, rubber is 0.28, oil palm is 0.30, paddy is 0.50, urban area and recreational area is between 0.80–0.90 and bare soil is 1.00 (Morgan, 2005). The results indicated that the

study area is dominated by agricultural activities represented by cultivation of rubber at 39 % and oil palm at 52 % (Fig. 4d). Other areas apart from agriculture are covered by urban (2 %), recreational (2 %) and bare lands (5 %).

3.1.5 Support practice factor (P)

The study area is dominated by agricultural activities with P factor value of 0.40 (Fig. 4e). Field observation indicated that most of the areas are covered by rubber and oil palm with a few areas for horticulture. The bare land area (P value of 0.70) was observed to occur in the catchment as a result of replanting of oil palm and rubber. Small patches of urban area (2 %) were observed at the south western part of the study area with P factor value of 1.00.

3.2 Potential annual soil loss (A) and sediment yield (SY)

This study shows the effectiveness of the GIS usage in determining potential soil loss, sediment delivery ratio (SDR) and sediment yield (SY) for the wide area based on qualitative and quantitative results. This tool is capable of showing sensitivity in irregular land management and changes in land use i.e. from forestry to agricultural land, which asserts the influences of topography, rainfall distribution and different soil types to high erosion.

Potential annual soil loss (A) value was computed by overlaying five grid surfaces over the catchment of Pahang River. The grid surfaces represented the values of rainfall erosivity factor (R), cover management factor (C), soil erodibility factor (K), topographic factor (LS) and practice management factor (P). The soil loss values obtained for the Pahang River catchment ranged from 0 to 95.5 ton ha^{-1} yr^{-1} with mean values of less than 1 ton ha^{-1} yr^{-1} (Fig. 5).

Derivation of the ordinal categories of soil erosion potential showed that about 93.60 % of the study area is classified as having very low potential for erosion (Fig. 5, Table 3). The middle part of the area is classified as having low (5.40 %), moderate

(0.60 %), high (0.20 %), severe (0.10 %) and extreme (0.001 %) potential for erosion. The area that stretches from the north to the south on the map increases about 5 % in slope gradient; thus, it was observed to have moderate erosion potential. The sub-catchments included in this part of the study area are Luit, Lekur, Temerlung and Chini (Fig. 5). Erosion potential analysis using actual field data measurement shows that some part of Temerlung and Chini sub-catchments have a moderate erosion potential with values of 6.80 ton ha^{-1} yr^{-1} and 7.20 ton ha^{-1} yr^{-1}, respectively, Luit and Mentiga having high erosion potential with values of 13.20 ton ha^{-1} yr^{-1} and 19.10 ton ha^{-1} yr^{-1}, respectively, and Chini and Lepar having severe erosion potential with values of 32.50 ton ha^{-1} yr^{-1} and 36.30 ton ha^{-1} yr^{-1}, respectively. Areas with severe erosion are characterized by high topography, have more than 10 % slope and no vegetation cover. These areas are currently involved in logging activities which contribute to severe erosion in this vicinity (Table 3). There is a high correlation ($r = 0.84$) between predicted soil loss potential with the measured data; it is evident that with the lack of canopy cover, the impact of rainfall on the soil surface increases, thus weakening the natural structure of the soil layers, promoting higher erosion.

The sediment delivery ratio (SDR) for each sub-catchment into the Pahang River was observed to be very low to high. However, the SDR value is dominated by very low (99.4 %), followed by low (0.5 %), moderate (0.06 %) and high (0.04 %). The values of sediment yield (SY) ranged from 0 to 13.79 ton ha^{-1} yr^{-1}. The higher SY values are located at the centre of the study area which includes the Luit, Lepar, Temerlung and Chini sub-catchments (Fig. 6). The highest SY value was observed at the Chini sub-catchment with value of 5.36×10^{-5} ton ha^{-1} yr^{-1} and the lowest at the Jempol sub-catchment with value of 2.68×10^{-7} ton ha^{-1} yr^{-1} (Table 4). Chini sub-catchment contributes about 50.65 % SY to Pahang River, whereas only 0.25 % SY is derived from the Jempol sub-catchment (Fig. 7). The values of SY in the Pahang River were found to increase when approaching the river mouth (Fig. 8). The maximum SY produced from the river mouth of Pahang River Basin to the South China Sea in August 2010

was 1.18×10^{-5} ton ha^{-1} yr^{-1}, in October 2010, it was 3.54×10^{-6} ton ha^{-1} yr^{-1} and in April 2011, it was 5.40×10^{-5} ton ha^{-1} yr^{-1}.

4 Discussion

The highly elevated area in the northern to southern part of the study area contributes to high potential soil loss in the study area. Toward the downstream of Pahang River catchment, a variety of land use activities which is dominated by agriculture contributes only slightly to the soil loss potential and sediment yield to Pahang River. The results generated from the five factors in RUSLE are intertwined with each other in the process of acquiring the values of potential soil loss and sediment yield (SY). The dominant factors which in combination will simultaneously generate higher potential soil loss and sediment yield (SY) in Pahang River Catchment are the topographic (LS) and soil erodibility factor (K). The land cover and rainfall erosivity factors contribute to a higher potential soil loss and sediment yield (SY) only if they occur concurrently with both of the dominant factors.

The slope gradient and slope length plays an important role in determining the potential soil loss in a certain area. The northern part to the southern part has an elevation of between 30 m to 40 m. The soil in this area has a high percentage of fine sand particles. The presence of high fine sand particles is more favourable for higher potential of soil loss (NRCS – USDA, 2002). There is a strong relationship between LS factor and K factor in this study. The distribution of high potential soil loss areas occurs on the steeper slope with dominant fine sand textured soils in the northern part and extends to the southern part of the study area. The K value of the steep land in the northern part is more than 0.40 Mg h MJ^{-1} mm^{-1}. The combination between the steep land and the high soil K value generated a high sediment yield. This area includes the sub-catchments of Lekur, Chini, Temerlung, Luit and Lepar. Coarse textured soil (sandy soil) and medium textured soil (silty clay) have a moderate K value.

Land cover and rainfall erosivity factors are minor contributors to soil loss and sediment yield (SY) in the Pahang River Basin. The main categories of land cover in this area are mostly oil palm and rubber. As a result of rubber and oil palm replantation, some areas of bare soil emerge sparsely in various parts of the area. This results in the increase of potential soil loss. Vegetation cover plays an important role in controlling splash erosion which is caused by the direct rainfall impact on soil surface, in addition to reducing run-off surface water (Troeh et al., 1991). Mature rubber canopy is able to protect the soil by 80 % only and is more susceptible to rainfall compared to the forest. The dense forest canopies are able to protect the soil up to 100 %. In combination with low topography, the forest can check the potential soil loss to be at minimum.

The rainfall erosivity factor exerts a low influence on soil erosion potential in the study area. However, the rainfall erosivity becomes increasingly a dominant factor for soil loss and sediment yield (SY) if the area is located in the higher topography with less land cover. The Lepar sub-catchment contributed about 0.46 ton $ha^{-1}\,yr^{-1}$ of sediment yield to Pahang River despite its location in the area of very low erosion potential. This happened because the upper portion of the Lepar sub-catchment is comprised of a few patches of bare soil owing to the replanting activities of oil palm, besides it receiving the highest amount of rainfall compared to the other sub-catchments. High-intensity storms falling on bare soil may produce sediment yield well above the norm. It is relatively easy for the surface-runoff to transport the eroded soil into the river because of the lack of vegetation cover and mulching on the ground.

Chini sub-catchment which contributed about 0.80 ton $ha^{-1}\,yr^{-1}$ of SY to Pahang River constitutes the area of low potential soil loss. The area is relatively moderate in topographic factor, but the soil consists of high percentage of fine sand. Based on field observation, the Chini Lake area is involved in many activities which could generate high amounts of potential soil loss; the activities among others are agriculture, tourism, urban dwelling and mining. Boating activities that carry tourists along the Chini River produce ripples that initiate river bank erosion, in addition to several recreational spots along the Chini River meant for tourism. Jempol and Jengka sub-catchments showed

low erosion potential, contributing only 0.25 % to 2.3 % of SY to Pahang River. These areas have lower potential for soil loss owing to its low topography, high percentage of clays, low rainfall and dense land covers contributed by the cultivation of rubber and oil palm.

The results have shown that the catchment of Pahang River is quite prone to soil loss especially in the high land area. High correlation ($r = 0.99$) occurred between soil loss potential and sediment delivery (SY) in the catchment of the study area. Undeniably, land reclamation will result in sedimentation and soil loss that occurs along the river will also cause sedimentation. Hence, conservation measures are encouraged in this area (Beskow et al., 2009), in which measures such as repair of drainage systems, construction of terraces, planting ground cover and increasing soil organic matter should be applied to areas of critical erosion potential.

Sediment yield (SY) from Pahang River is transported into the South China Sea. Figure 8 shows increasing SY percentage when approaching the river mouth (South China Sea). The readings of SY obtained were different because of the changes in the monsoon. The highest reading of SY was shown during the transition period that was in April 2010. However, the reading of SY was higher during the northeast monsoon due to maximum rainfall in the north eastern part of Malaysia which is adjacent to the study area.

5 Conclusions

The potential soil loss distribution at the catchment of Pahang River is highly variable in its value which ranged from very low to extreme class of potential erosion. However, the potential erosion remains dominated by low erosion potential which means that most of the sub catchment of Pahang River contributes less to sediment yield in Pahang River. The sediment yield of Pahang river catchment with an area of 5120 km^2 ranged from 0.01 ton $ha^{-1}\,yr^{-1}$. to 1.38 ton $ha^{-1}\,yr^{-1}$, averaging at 1.19 ton $ha^{-1}\,yr^{-1}$. Diversity level of potential erosion and sedimentation yield in the study area depends very much on

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topography and soil erodibility factors as the major factor, while the minor factors are land cover factor and rainfall erosivity factor. The monsoon season is associated with the accumulated sediment yield at the Pahang river mouth.

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Table 1. Soil classification and K value based on Malaysian Soil Series.

No	Soil classification	K values ($\mathrm{Mg\,h\,MJ^{-1}\,mm^{-1}}$)
1	No information	0.000
2	Holyrood Lunas	0.035
3	Serdang Kedah	0.036
4	Rudua-Rusila	0.040
5	Jempol	0.046
6	Organic, clay and muck	0.050
7	Kranji	0.051
8	Harimau Tampoi	0.056
9	Gambut (peat)	0.065
10	Renggam Bukit Temiang	0.067
11	Munchong Serdang	0.075
12	Segamat Katong	0.090
13	Bungor Munchong	0.092
14	Gajah mati – Munchong Mallaca	0.095
15	Renggam Jerangau	0.098
16	Telemong Akob	0.102
17	Briah	0.103
18	Batu Anam Durian	0.109
19	Urban Land	0.110
20	Serdang Bungor Munchong	0.114
21	Durian Munchong Bungor	0.128
22	Steepland	0.500

Source: Ministry of Natural Resources and Environment Malaysia (2010).

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Table 2. *m* value for LS factor.

m value	Slope (%)
0.50	> 5
0.40	3–5
0.30	1–3
0.20	< 1

Source: Ministry of Natural Resources and Environment Malaysia (2010).

Table 3. Derivation of the ordinal categories of soil erosion potential and sediment delivery ratio in per cent.

Numeric Range (ton ha^{-1} yr^{-1})	Erosion Potential	Soil Erosion (%)	Sediment Delivery Ratio (%)
0–0.9	Very Low	93.60	99.40
1–5	Low	5.40	0.50
6–10	Moderate	0.60	0.06
11–20	High	0.20	0.04
21–50	Severe	0.10	0
51–100	Extreme	0.01	0
> 100	Exceptional	0	0

Source: Soo Huey The (2011).

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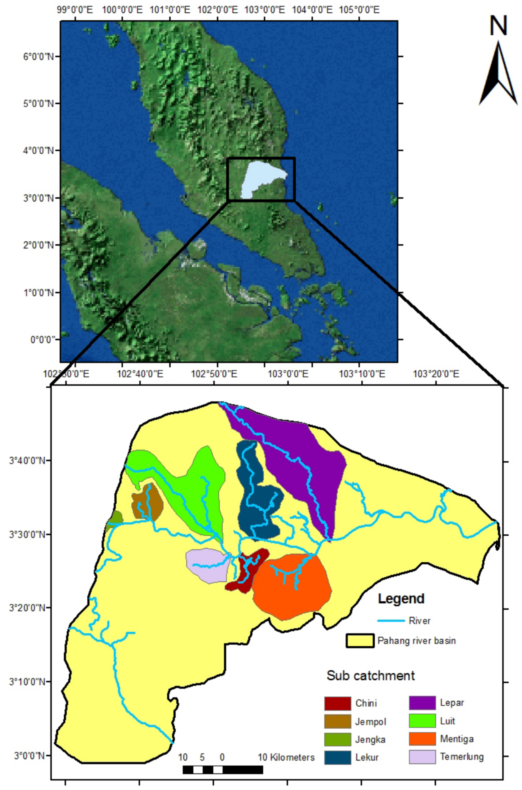

Fig. 1. The Pahang River Basin showing the 8 sub-catchments of the study area.

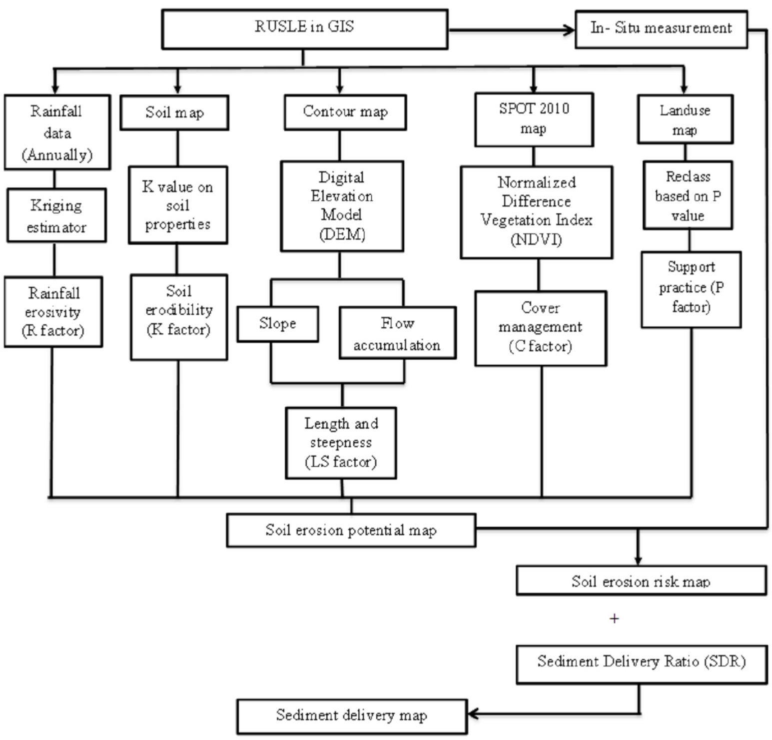

Fig. 2. Research approach flow diagram showing the methods and technique used to study soil erosion potential and sediment yield.

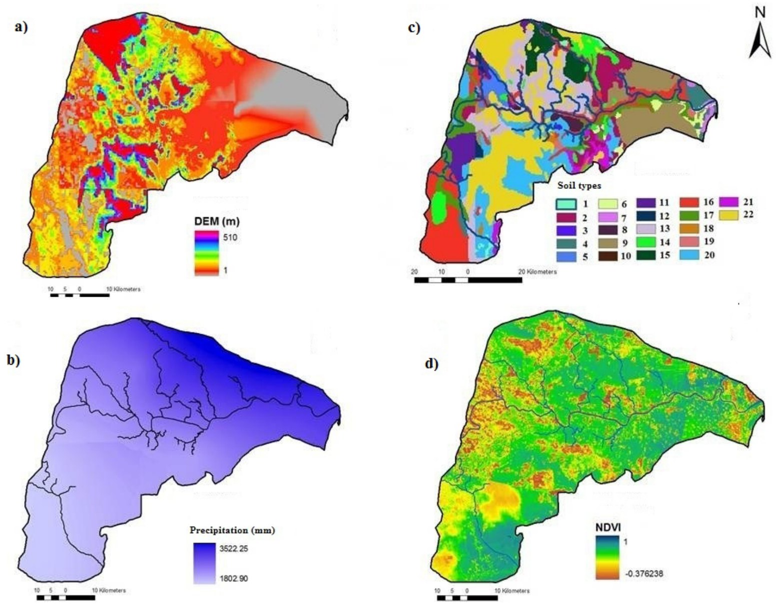

Fig. 3. GIS data layers **(a)** the DEM surface **(b)** the precipitation surface **(c)** the soil type surface **(d)** the NDVI distribution surface.

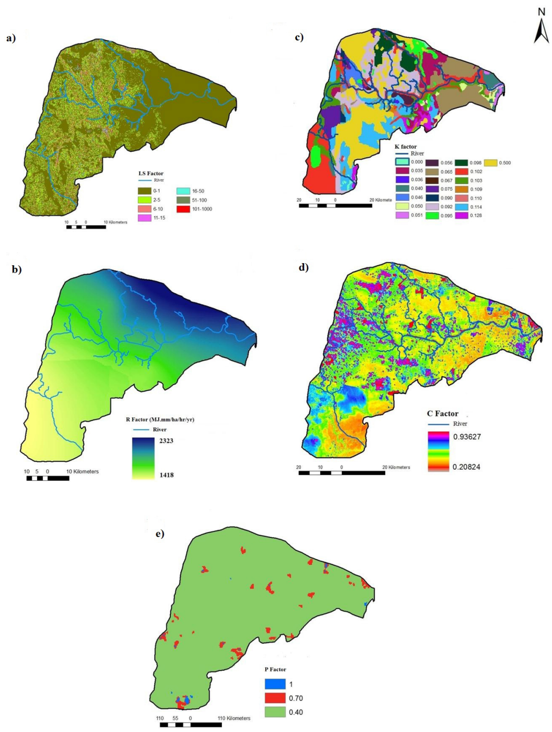

Fig. 4. The RUSLE parameter outputs: **(a)** the slope length and slope steepness (LS); **(b)** the rainfall erosivity factor (R) showing high value in the northern area and lower value in the southern area; **(c)** the soil erodibility factor (K) map showing high variability of K value; **(d)** the cover management factor (C) distribution derived from the NDVI image; **(e)** the support practice factor (P) distribution derived from the land use map.

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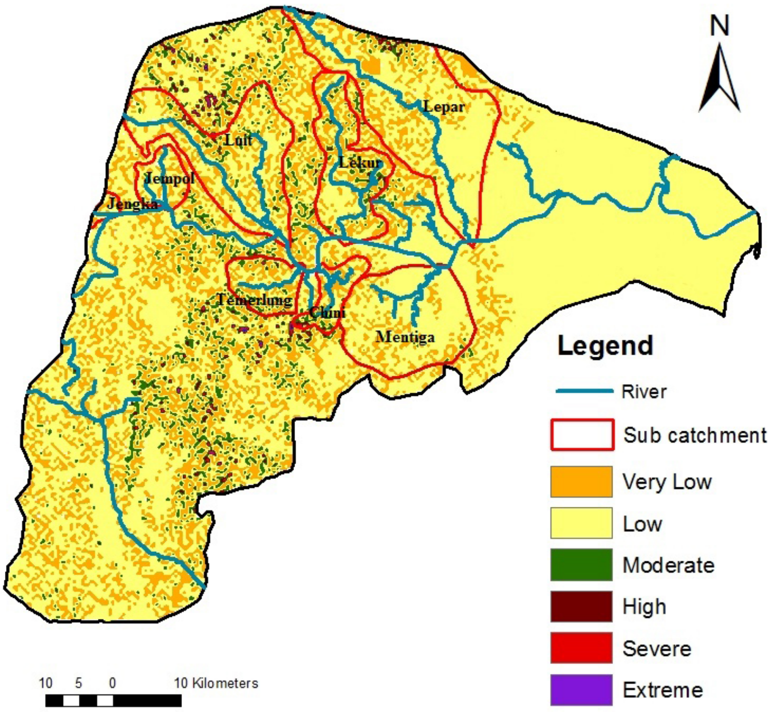


Fig. 5. Soil loss map for every sub-catchment of Pahang River, after the application of the RUSLE equation.

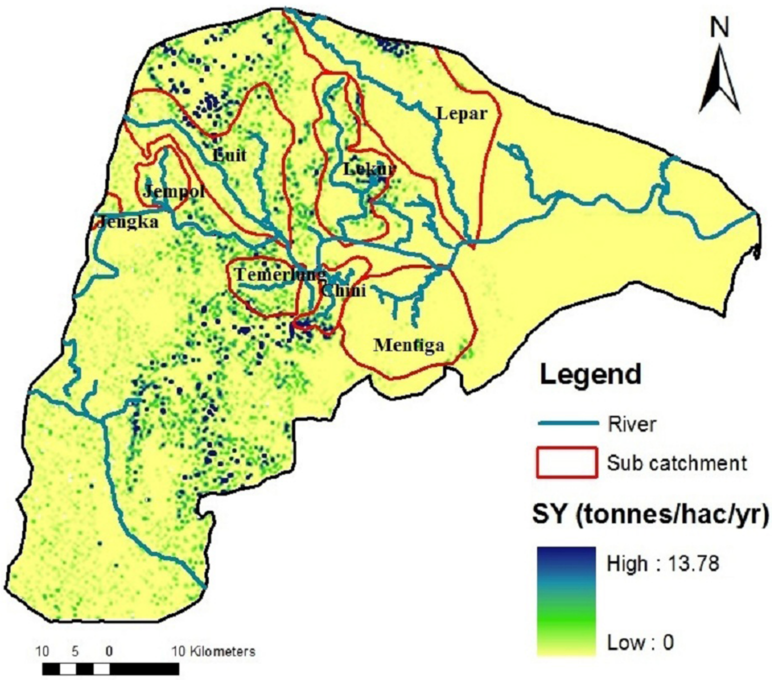


Fig. 6. Sediment yield map for every sub-catchment of Pahang River.

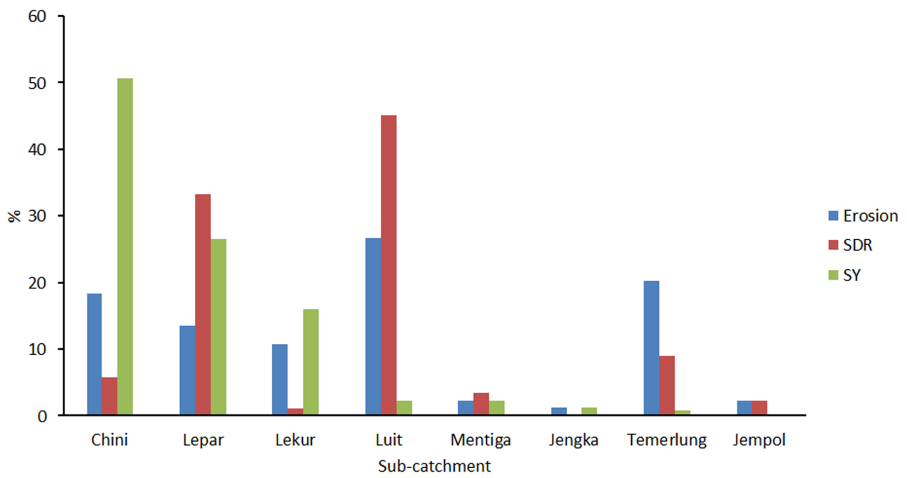
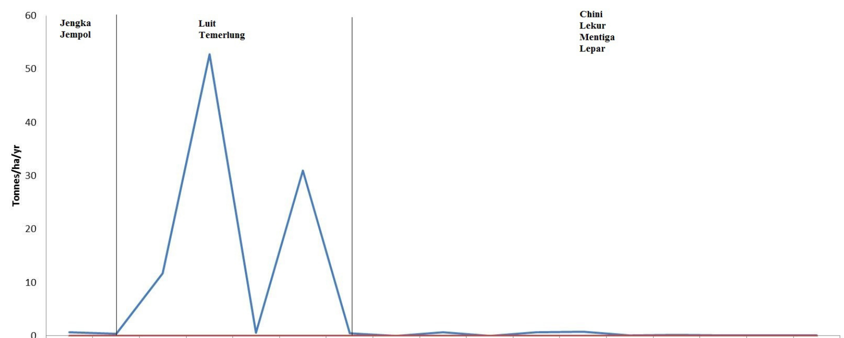


Fig. 7. Percentage of soil loss, sediment delivery ratio (SDR) and sediment yield (SY) from the sub-catchments to Pahang River.



Distance (km)	19.5	21.5	24.5	25.5	47.5	48.5	57.5	58.5	58.8	59.5	64.5	65.5	81.5	82.5	92.5	93.5
Soil loss	0.7	0.4	11.7	52.8	0.6	31	0.5	0.007	0.7	0.008	0.7	0.8	0.12	0.15	0.14	0.13	0.11
Sediment yield	0.000017	0.000013	0.000034	0.000033	0.000023	0.000031	0.000094	0.000019	0.00028	0.00024	0.00025	0.00013	0.00039	0.00049	0.00045	0.00034	0.000054

Fig. 8. The soil loss and sediment yield from headwaters to downstream (river mouth) of Pahang River to the South China Sea. Based on the field measurement, every sub-catchment delivered different rates of soil loss and sediment yield into Pahang River. The rate of soil loss and sediment yield at Jengka and Jempol sub-catchments was low (0.4 to 0.7 ton ha^{-1} yr^{-1}). The highest soil loss rate occurred at the Luit and Temerlung sub-catchments (0.4 to 52.8 ton ha^{-1} yr^{-1}) but delivered low sediment yield (0.000013 to 0.000094 ton ha^{-1} yr^{-1}). In contrast, the sub-catchments of Chini, Lekur, Mentiga and Lepar experienced low soil loss (0.007 to 0.15 ton ha^{-1} yr^{-1}) and low sediment yield (0.000019 to 0.00049 ton ha^{-1} yr^{-1}).