Preliminary Assessment of Erosion Hazard using Open Source Geographical Resources Analysis Support System (GRASS) for Langkawi Island

Mohammad Firuz Ramli, Choo Siet Mei, Mohd Kamil Yusoff and Ahmad Makmom Abdullah
Department of Environmental Sciences, University Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia, tel. +60389466753, fax +60389438109.

ABSTRACT

The open source Geographic Information System (GIS) and Revised Universal Soil Loss Equation (RUSLE) were used to predict the soil erosion hazard for Langkawi Island, Malaysia. Secondary raster data for the following parameters; rainfall erosivity (R), slope length-steepness (LS), soil erodibility (K), cover management (C), and conservation practices (P) were used to generate soil erosion map. The results predicted that about 58 percent of the Langkawi has very low to moderate erosion risk and about 32 percent of the study area is of high to extreme erosion risk. This study demonstrates the effectiveness of open source GIS in generating quantitative information on soil erosion studies.

Keywords: RUSLE, GIS, erosion prediction, soil loss, erosion hazard

1 INTRODUCTION

Land degradation and erosion processes are induced by a combination of human and physical factors, particularly the denudation of vegetation by man and domestic animals, and the infrequent and irregular distribution of precipitation (Garg and Harrison, 1992). In order to map the soil erosion, Geographic Information System (GIS) could be used to identify areas that are at potential risk of extensive soil erosion, and to provide information on the estimated value of soil loss at various locations. It can also provide answers to spatial queries; for instance whether the erosion is associated with specific factors such as the loss of continuous vegetation cover (Kertész, 1993).

GIS is a system for spatial data management and analysis. Spatial data consist of a spatial geometry as well as the characteristics or “attributes” of the objects being managed or analyzed. GIS provides a relatively easy construction and handling of digital elevation model (DEM) which allows the calculation of the unit contributing area so that the complex nature of the topography may be fully accounted for (Desmet and Govers, 1996). Within a raster based Geographical Resources Analysis Support System (GRASS) GIS, the RUSLE model can be applied to predict erosion potential of a particular area (Shi *et al*., 2004). GRASS is an open source raster/vector GIS combined with integrated image processing and data visualization subsystems. It includes more than 350 modules for management, processing, analysis and visualization of geo-referenced data (Neteler and Mitasova, 2002). As an open source software, it can be downloaded free from the internet, thus make it a really good option for a budget constraint research. Furthermore, it runs on the Linux platform which is also an open source software.

Revised Universal Soil Loss Equation (RUSLE), is an erosion prediction and conservation planning tool based on large part of the Universal Soil Loss Equation (USLE) and its supporting data, but also including major improvement and updates (Renard *et al*., 1994). USLE was developed initially as a tool to estimate soil loss on specific slopes in specific fields. It was used to tailor erosion control practices to specific sites (Renard *et al*., 1991).

RUSLE is a major revision of the USLE. Whilst retaining the equation structure of the USLE, several concepts from process-based erosion modeling have been incorporated in RUSLE to improve erosion prediction. The RUSLE predicts soil loss for a given site as a product of five major factors [Equation 1], whose values at a particular location can be expressed numerically.

The soil loss is calculated as follows:

$$A = R \times K \times LS \times C \times P \quad (1)$$

where A is annual soil loss (tons/ha/yr),
R is rainfall erosivity factor,
K is soil erodibility factor,
LS is slope length and steepness factor,
C is cropping and management factor,
and P is conservation supporting practices factor (Yoder and Lown, 1995).

In Langkawi, two soil erosion studies have been conducted using GIS and USLE model, such as by Buyong and Suratman (2000) and by Yusof and Baban (1999). However, both of them used commercial GIS software, not the open source GIS, and USLE model, not the RUSLE model. The comparison between the results of their studies and this study is a subject for another research.
Langkawi Island was selected for this study due to the rapid physical development in the island since its declaration as a duty free port in 1987. Development without proper planning and management will inevitably leads to land degradation that will normally increase the soil erosion. The main objectives of this study were to produce erosion hazard assessment map for Langkawi island and to evaluate the application of open source GRASS to estimate an annual soil loss rate in Langkawi Island using RUSLE.

2 METHODOLOGY

The study area is located in the largest island of the Langkawi island group, which comprises of 99 tropical islands (Figure 1). The main lithologies are limestone, quartzite and granite. The lowlands are characterized by sandy beaches, alluvial plains and mangrove swamps. The highlands are concentrated in the middle of the island and at the north-western part of the island bordering the sea. Originally, the study area was planned for the whole island, however, a problem encountered where digital sheet 3069d of the east of the island did not contain any contour data for the LS factor to be extracted (Figure 1). Thus the east of the island is omitted from the study area. The climate of Langkawi is characterized as equatorial monsoon. There are two main seasons: a southwest from April to September and a northeast monsoon from October to March. The mean daily maximum temperature is 32°C. Mean annual precipitation ranges from 1750 to 2510 mm. Langkawi Island has a strongly rainfall pattern with over 25 % of its annual rain falling in December and January (Morgan, 1979).

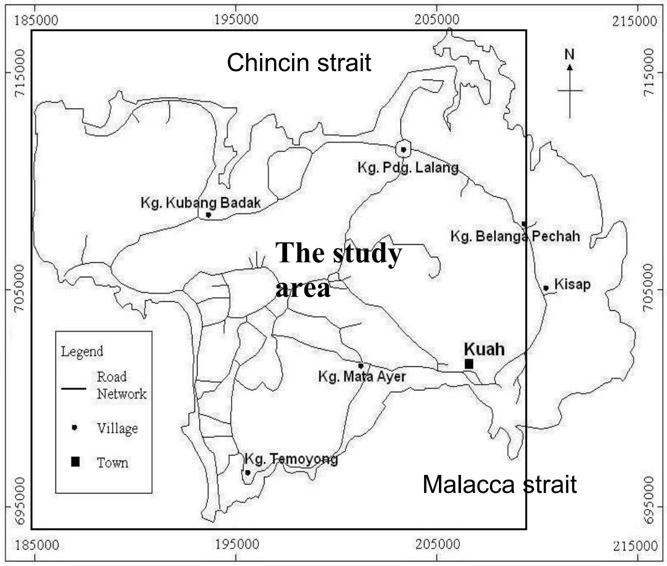
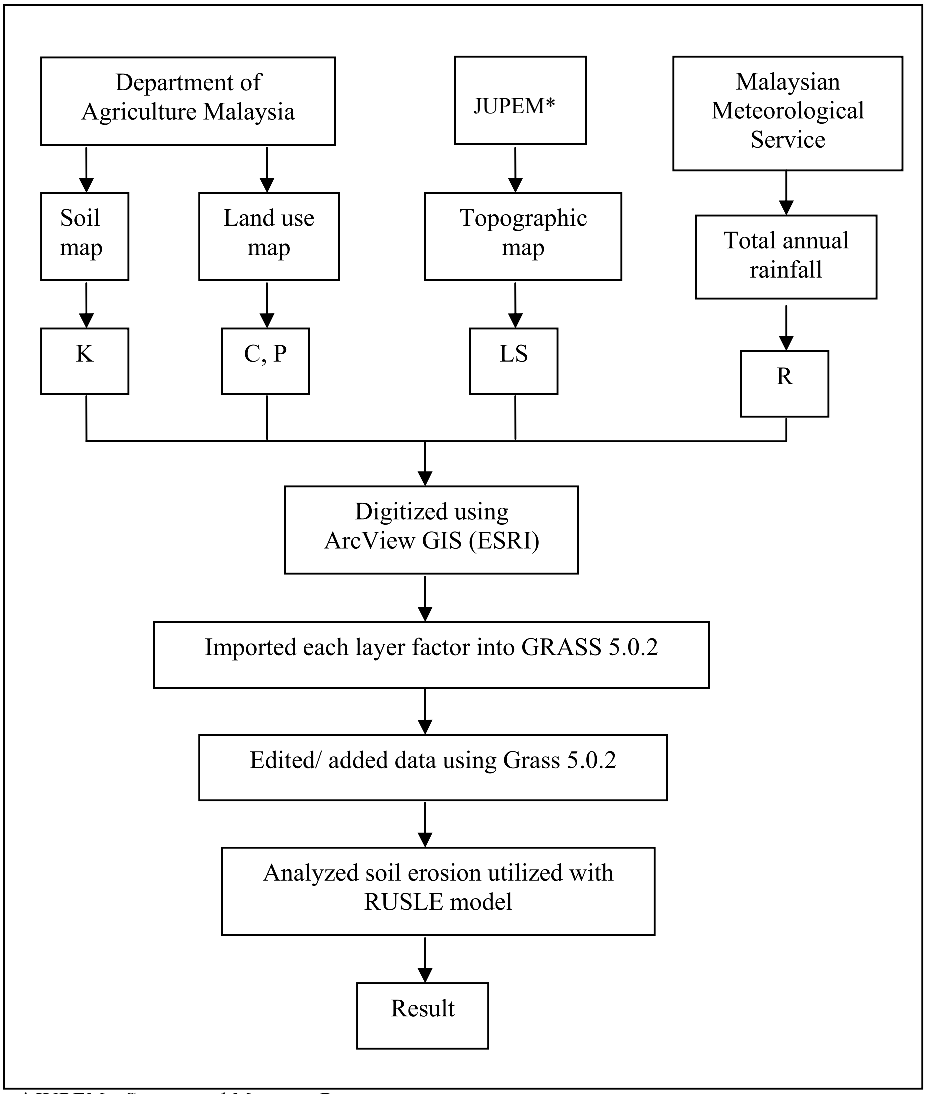


Fig. 1: The study area.

The methodology involved the application of a soil erosion model, the RUSLE in a GRASS GIS environment. Land use and soil maps with the C, P, and K factors were obtained from the Department of Agriculture, Malaysia (Figure 2). Rainfall data from 1997 to 2002 for R factor supplied by the Department of Meteorological from a meteorological station located in Langkawi Island International Airport (6°20'N, 99°44'E). A digital topographic map of sheets 3069a, 3069b, 3069c and 3069d of 1 : 25000 scale for LS factors derivation is obtained from The Survey and Mapping Department (JUPEM). Whilst the spatial data for C and P factors were digitized on screen from the land use map with a scale of 1:50 000, K factor was from the soil map of Langkawi Island with a scale of 1:126 720. LS factor was generated using digital elevation model (DEM) from digital topographic map. The digitisation of landuse and soil map were undertaken using ArcView software. All the vector data were then imported into GIS. The related attributes were then input to the GIS, and then, the vector maps were converted into raster format.



**JUPEM= Survey and Mapping Department*

Fig. 2: Flow chart of soil erosion assessment in the study area

The R, K, LS, C and P factors are multiplied as in Equation 1 to get the erosion potential of the study area. The calculation is easily undertaken using the *r.mapcalc* module in GRASS GIS.

2.1 Rainfall erosivity (R) factor

R is the rainfall-runoff erosivity factor or index. It is the average annual summation values in a normal year's rain (EI). This index measures the erosion force of specific rainfall.

The relationship between rainfall erosivity index and mean annual precipitation for the Peninsular Malaysia can be represented by following regression equation (Morgan, 1974):

$$R = P/2 \quad (2)$$

where P is in mm of annual total rainfall. This equation was used to estimate mean annual erosivity from mean annual rainfall (Morgan, 1974). After analyzing the 6 year rainfall data, P is found to be 2278.7 mm, and R is calculated as 1139.4 .

2.2 Soil erodibility (K) factor

The soil erodibility factor (K) represents the average long-term soil and soil-profile response to the erosive power associated with rainfall and runoff (Milward and Mersey, 1999). K is also the mean annual soil loss per unit of R for a standard condition of bare soil. The K factor values for the study area varies from 0.3 to 0.6 (Table 1).The digitised soil data consist of seven soil series and their respective K values are shown in Table 1 and Figure 3).

TABLE 1
The adopted value of K different soils (Department of Agriculture)

Soil Series	K.Factor
Rengam Tampin Association (RGM-TPN)	0.5
Serdang Munchong Malacca Association (SDG-MUN-MCA)	0.5
Baging Permatang Association (BAG-PMG)	0.3
Local Alluvium Colluvium Association (LAA-COL)	0.6
Kranji Series (KNJ)	0.6
Urban Land (ULD)	0.5
Steep Land (STP)	0.5

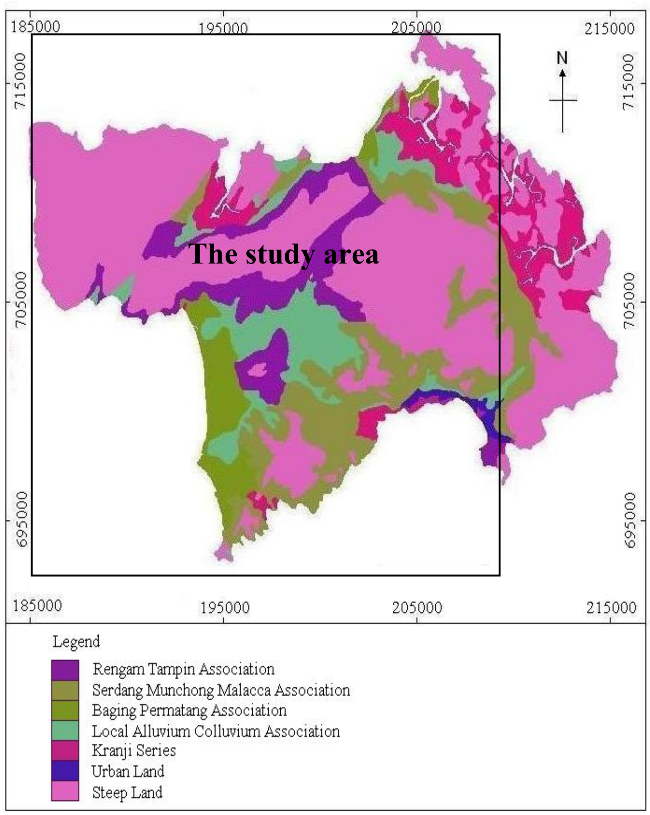


Fig. 3: Soil Series in Langkawi Island (Department of Agriculture, 1997)

2.3 Topographic factors (L and S)

LS factors are the slope length factor. L and S compute the effect of slope length and slope steepness on erosion. Values of L and S are relative and represent the relative erodibility of the particular slope length and steepness (Wang *et al.*, 2001). LS value for the study area is found to be between 0 to 237.

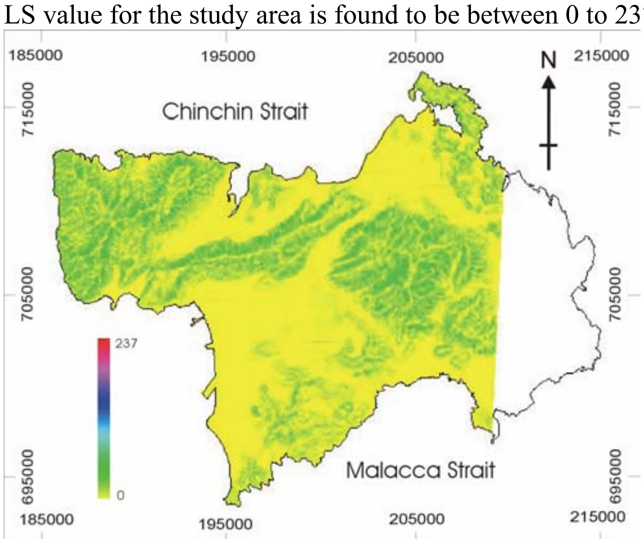


Fig. 4: Topographic factor for the study area

2.4 Conservation practices (P) factor

P is the support practice factor. P reflects the impact of support practices on the average annual erosion rate. It indicates the fractional amount of erosion that occurs when any special practices are used compared with what would occur without them (Troeh *et al.,* 1999). The P value in the study area ranging from 0.1 in the forest to 1.0 in the other mining areas, and urban and other associated areas (Table 2).

TABLE 2

The adopted value of P for different land use (Troeh *et al*., 1999)

ID	Land Use	P.Factor
1	Agriculture Stations	0.4
2	Coconut	0.5
3	Diversified Crops	0.45
4	Estate Buildings and Associated Areas	0.4
5	Fish and Hyacinth Ponds	0.5
6	Forest	0.1
7	Lalang	0.6
8	Mixed Horticulture	0.4
9	Newly Cleared Land	0.7
10	Orchards	0.4
11	Other Mining Areas	1.0
12	Paddy	0.5
13	Reclaimed Areas	0.7
14	Recreational Areas	0.6
15	Rubber	0.4
16	Scrub	0.2
17	Swamp	0.5
18	Unused Land	0.45
19	Urban and Associated Areas	1.0
20	Water	0.5

2.5 Crop and management (C) factor

C is the cover management factor used to reflect the effect of cropping and management practices on erosion rates. C is often used to compare the relative impacts of management options on conservation plans. It indicates the effect of the conservation plan to the average annual soil loss and distributed of soil loss potential during construction activities, crop rotations or other management schemes. The C values were applied to the land use map of 1997 (Figure 5). The value ranges from 0.003 in forest to 1.0 in a newly cleared land, other mining area and water (Table 3).

TABLE 3

The adopted value of C and area for different land use (Department of Agriculture)

No	Plant Cover	C.Factor
1	Agricultural Stations	0.5
2	Coconut	0.2
3	Diversified Crops	0.45
4	Estate Buildings and Associated Areas	0.35
5	Fish and Hyacinth Ponds	1.00
6	Forest	0.003
7	Lalang	0.3
8	Mixed Horticulture	0.5
9	Newly Cleared Land	1.00
10	Orchards	0.35
11	Other Mining Areas	1.00
12	Paddy	0.45
13	Reclaimed Area	0.8
14	Recreational Areas	0.8
15	Rubber	0.2
16	Scrub	0.3
17	Swamps	0.9
18	Unused Land	0.45
19	Urban Associated Areas	0.8
20	Water	1.00

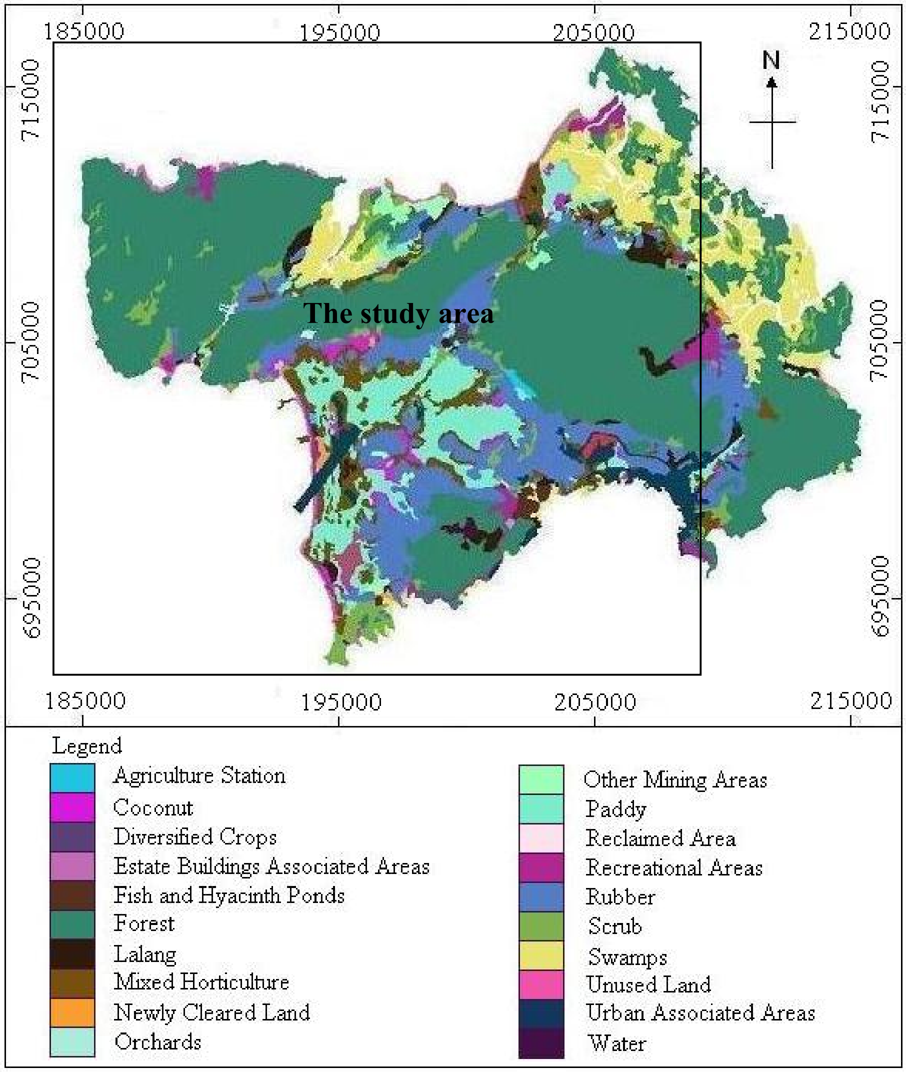


Fig. 5: Landuse in Langkawi Island (Department of Agriculture, 1998)

Majority of the landuse in the study area is of forest which accounted of about 47 % of the study area (Figure 6). It is followed by paddy and mixed horticulture of about 8 % and 7% respectively(Figure 6).

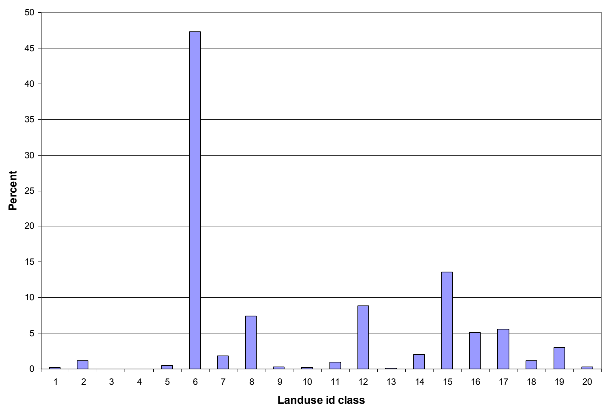


Fig 6: Percentage of landuse area in the study area

3 RESULTS AND DISCUSSION

The range of erosion value for the study area was found to be between 0 to 135 000 tons/ha/year. However the extreme value of 135 000 ton/ha/year are only in 40 pixels which covers about 0.004 km^2 . The other extreme values of between 20 000 to 100 000 ton/ha/year covers only about 0.111 km^2 which is about 0.04 % of the study area. These extreme value are very likely due to extreme value in LS factor which is probably due to the problems in DEM extrapolation. However, these values can only be confirmed with field-checking.

For ease of interpretation, the values of erosion potential were divided into 7 classes (Table 4).

TABLE 4
Derivation of the ordinal categories of soil erosion potential

Erosion Class	Numeric Range (ton/ha/year)	Erosion Potential
1	0 –1	Very Low
2	1 – 5	Low
3	5 – 10	Moderate
4	10 – 20	High
5	20 – 50	Severe
6	50 – 100	Extreme
7	>100	Exceptional

Generally, 58% of the island are of very low to moderate erosion rates (Figure 7). 12 % of the study area are of high to severe erosion rates and about 30 % are of extreme to exceptional erosion rates. Most of the erosion risk of class 4 to 7 of high to exceptional concentrated at the south of the island around Kuah and Kg. Mata Ayer, northwest, and northeast of the study area. (Figure 8). The results showed that Langkawi Island is generally a fragile island where any development must be taken into consideration of the erosion risk factor. There is a problem encountered during the generation of landuse map which has resulted in a null value in certain areas of the study area (it shows as white colour in Figure 8). Thus, this area is not included in the statistical analysis in the study area.

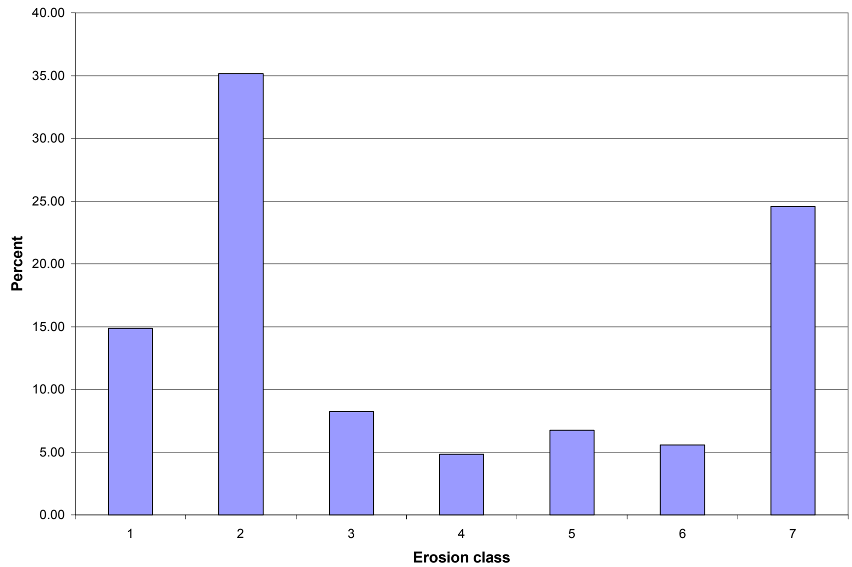


Fig.7 : The percentage of erosion class in the study area.

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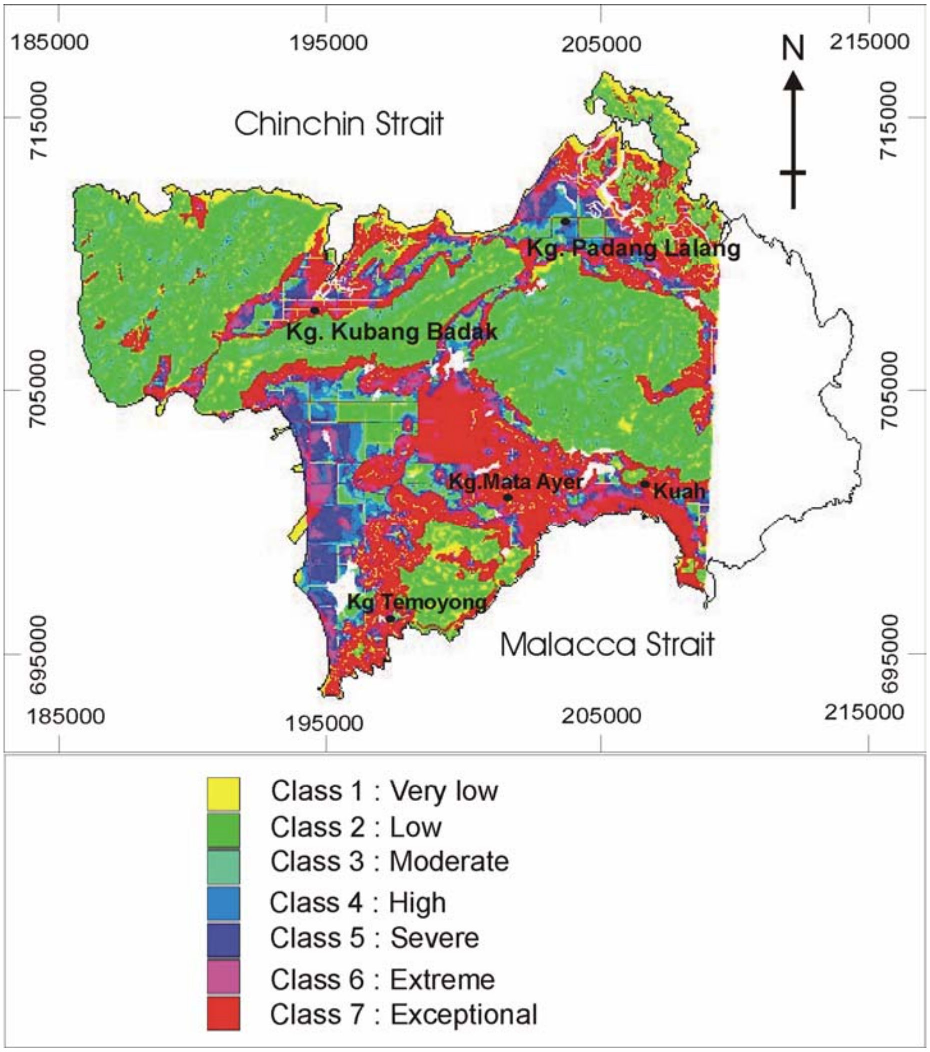

Fig. 8: Potential Erosion Class for Langkawi Island

Majority of class 1 to 3 erosion risk are of forest (ID=6) ranging for 63 % to 93 % (Figure 9). The forest also covers about 10 % of class 4 and only 1 % of class 5 (Figure 10). Thus showed that the presence of forest is important in preventing soil erosion. Soil loss under rain forest is relatively low but increase rapidly when the land is cleared for agriculture purposes, such as for rubber (ID=15), paddy (ID=12) and mixed horticulture (ID=8) (Figure 10).

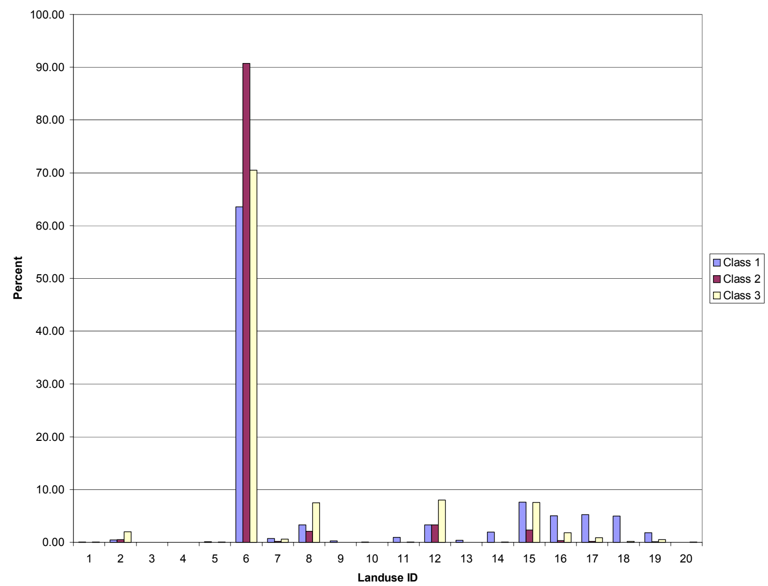

Fig.9 : Erosion class area of 1, 2 and 3 and landuse ID of the study area. The ID numbers and their corresponding landuse are in table 3.

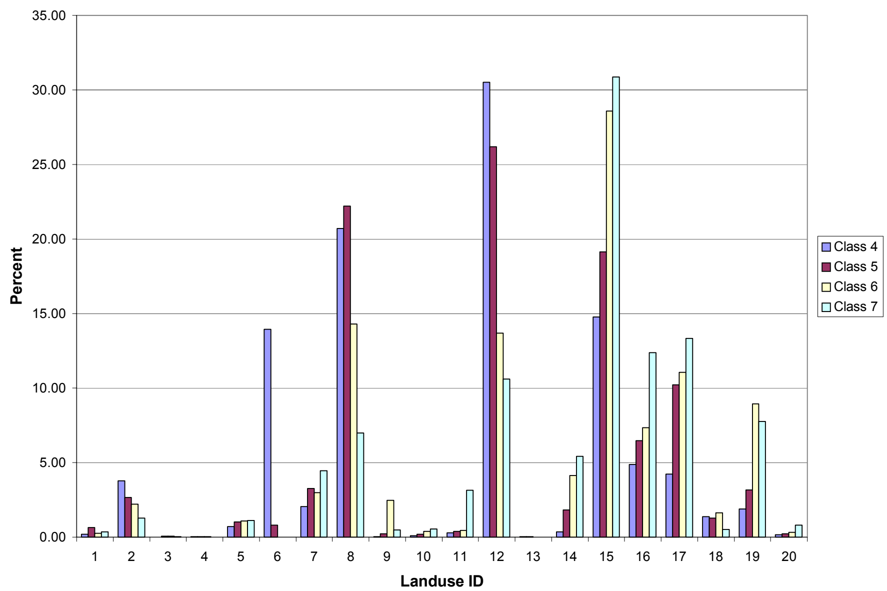

Fig. 10: Erosion class area of 4, 5, 6 and 7 and landuse ID of the study area. The ID numbers and their corresponding landuse are in table 3.

Erosion would normally be expected to increase with the increase in slope steepness and slope length as a result of respective increases in velocity and volume of surface runoff (Morgan, 1995). The slope angle was divided into five classes for easier explanation (Table 5). In the study area, slope angle were not the main factors for high erosion potential (Figure 11). Majority of the erosion class 4 (88 %), class 5 (99 %), class 6 (100 %) and class 7 (75 %) are in slope class 1 which is of 0 to 15^o slope (Figure 11). This is probably because most of the conversion of forest to other highly "erosive" landuse types such as rubber, paddy and mixed horticulture are restricted to flat areas, where most of the steep slope are still under the forest cover (Figures 4 and 5). It shows that improper land management may contribute to high erosion risk for the study area.

TABLE 5
Slope class for the study area

Slope class	Slope angle (^{o})
1	0 – 15
2	16-25
3	26-35
4	36-45
5	46-90

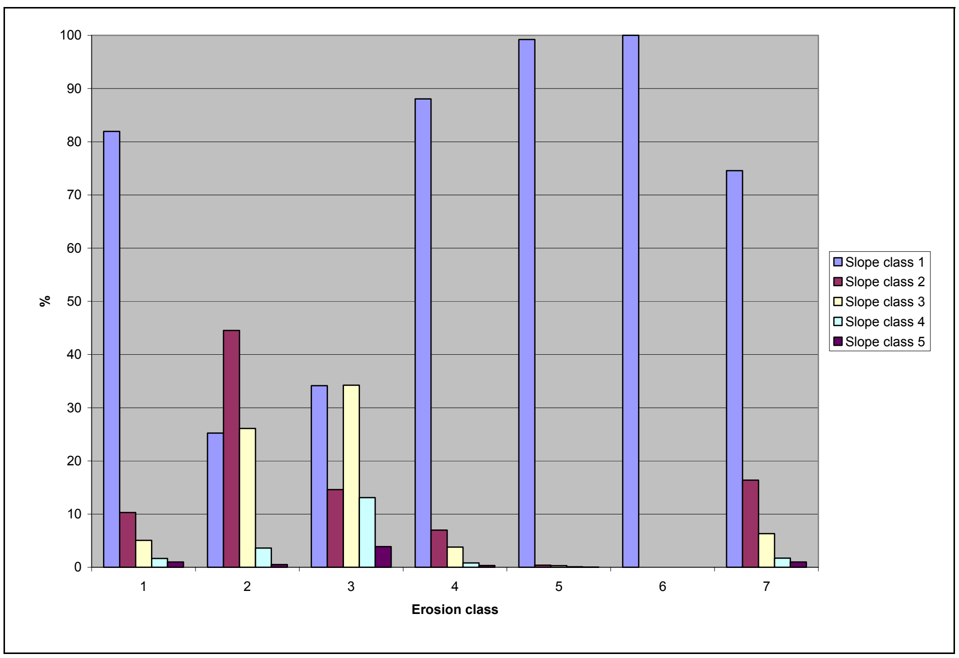

Fig. 11 : The relationship between slope and erosion classes of the study area.

Forests are the most effective in reducing erosion because of their canopy (Morgan, 1979). The height of the canopy is important because water drops from 7 m may attain over 90 percent of their terminal velocity. Thus, the erosion risk is relatively low for the steep area under forest cover (Figure 4 and 5). It shows that the forested area should be conserved to minimize the erosion risk hazard.

4 CONCLUSION

This study demonstrates the effectiveness of open source GIS for soil erosion studies. In the GRASS GIS environment, the RUSLE can be easily applied to predict erosion risk over the island. Although the result should be taken as preliminary result because the erosion map generated needs to be cross-checked against the real field data, however, it shows that improper land management and the conversion of forest into other land uses, even in relatively low slope angle may contribute to high erosion risk.

5 ACKNOWLEDGEMENT

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