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Estimation of the Rate of Soil Erosion in the Tasik Chini Catchment, Malaysia Using the RUSLE Model Integrated with the GIS

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Abstract: The Tasik Chini Catchment, located at the southeast region of Pahang, Malaysia is experiencing soil erosion problems which are of environmental concern. So a study was conducted that involved the integration of the Revised Universal Soil Loss Equation (RUSLE) with the Geographic Information System (GIS) to estimate potential soil loss and identify erosion risk areas. Values for the model on rainfall erosivity (R), topographic factors (LS), land cover (C) and management factors (P) were calculated from rainfall data, together with the use of topographic and land use maps. Soil was analyzed for obtaining the soil erodibility factor (K). Physical properties such as particle size distribution, texture, hydraulic conductivity and organic matter content (OM) were analyzed to support the erosion rate analysis. The mean soil erodibility factors varied from 0.03 to 0.30 Mg h MJ^{-1} mm^{-1}. From a total of eleven soil series studied, soil erosion results showed that the five soil series with low rate of soil loss were: Tebok, Lating, Bungor, Kekura and Gong Chenak. Two soil series with moderate soil loss were Serdang and Prang. Two soil series with moderately high rate of soil loss were Kuala Brang and Rasau. The Malacca soil series had high erosion rate. The worst-case scenario was the Kedah soil series. The soil erosion potential zones were classified into five classes namely very low, low, moderately high, high and very high soil loss. The results indicated that 71.54% of the study area lay within the very low erosion risk class, 2.94% in the low erosion risk class, 3.38% in the moderately high erosion risk class, 1.45% in the high erosion risk class and 13.25% in the very high erosion risk class. This high erosion rate is expected to generate high sediment yield influx into the water bodies of Tasik Chini making the lake shallower and perhaps even non existent in the near future if precautionary measures are not taken.

Key words: High risk erosion, Rainfall erosivity, RUSLE and GIS, Tasik Chini Catchment

INTRODUCTION

Soil erosion is considered one of the most important forms of soil degradation worldwide (Morgan, 2005). Soil erosion has been recognized as a serious problem arising from agricultural intensification, land degradation and possibly global climatic changes (Yang *et al*., 2003; Bhattarai and Dutta, 2007). The deposition of sediments transported by a stream into a reservoir not only reduces the reservoir's capacity, but sediment deposition on the lake and river beds also effects the widening of flood plains during floods. Soil erosion is the most significant contributor to surface and off-site ground water pollution on a global scale with most of the contaminants originating from agricultural activities (Marsh and Grossa, 1996). Watershed erosion has been and is a worldwide phenomenon and a never ending problem. Erosion is also a natural process, and began long before the history of man's existence on earth. It involves a two-phase process, consisting of the detachment of individual particles from the soil mass and transportation by the erosive agents namely wind and water (Morgan, 2005). Disturbance by human activities further aggravates the soil erosion process especially on steep slopes. Erosion and the associated sediment flux rates can also be triggered or accelerated by climatic change, tectonic activities, human influence or a combination of all the above (Bocco, 1991).

In Malaysia, soil erosion has become an important environmental problem in recent years especially in areas where intensive use of land for development, including urbanization and agricultural activities are being carried out. The encroachment of development into environmentally sensitive areas has resulted in accelerated soil erosion, water pollution, sedimentation and consequently flooding in downstream areas. It has also had tremendous impact on the communities in and around the affected areas. The effects of timber harvesting on soil erosion and sedimentation in Malaysia have been reported by a number of investigators including Burgess (Burgess, 1971), Salleh *et al*. (1981), Baharuddin (1988) and De Neergaard *et al*. (2008). Soil erosion affects not only soil productivity of upland fields but also the water quality of the streams in the catchment areas. Severe euthrophication in reservoirs and canals is associated with nitrogen and phosphorus losses in the surface runoff, and this has recently been the focus of intense research in Malaysia.

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The Tasik Chini Catchment area has undergone rapid economic growth over the last decade. Land use activities in the areas surrounding Tasik Chini have been transformed from forests to agricultural and ecotourism areas, mines and settlements. This type of developmental activities has significantly affected the ecological, biological and hydrological functions of the lake system. Logging activities in the steep land areas have also created serious environmental and ecological problems. Due to these changes, the rate of erosion and sedimentation has subsequently increased.

These conditions have been created by the runoff phenomenon in the bare and half bare slope surfaces to the streams and finally to the lake, and they will undoubtedly decrease the lake depth in the long-term. The chemical influx from pesticides and fertilizer compounds due to agricultural activities has increased the concentration of elements such as nitrogen and phosphorus as well as the heavy metal content in the water and sediments of the lake. Two kinds of surface erosion take place around the Tasik Chini. For the land areas, erosion is dominated by sheet and rill erosion due to surface runoff, initiated by heavy rainfall, and for the lake system, it is dominated by bank erosion partly due to the impact of ripples created by moving motorboats. These unsustainable land use patterns within and around the catchment have over the years resulted in the erosion and sedimentation of the Tasik Chini Catchment, thereby depleting the lake of its original aquatic and terrestrial biodiversity (Sujaul *et al*., 2010).

Modeling can provide a quantitative and consistent approach to estimating soil erosion and sediment yield under a wide range of conditions. For assessing soil erosion from the catchment area, several empirical models based on geomorphological parameters have been developed in the past to quantify the sediment yield (Jose and Das, 1982). Simple empirical methods such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965) and the Modified Universal Soil Loss Equation (MUSLE) (William, 1975), have been frequently used for the estimation of surface erosion and sediment yield from catchment areas (kothyari and Jain, 1997). For nearly 40 years, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and its principal derivative, the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al*., 1997) have been used throughout the world for estimating the average annual soil loss per unit land area resulting from rill and sheet erosion (Bhattarai and Grossa, 1996). In the present study, RUSLE was used to estimate the potential soil loss and develop an erosion risk map for the Tasik Chini Catchment area with the help of the GIS.

Study Area:

Tasik Chini is located in the southeastern region of Pahang, Malaysia, and is situated approximately 100 km from Kuantan, the capital of Pahang. The lake system lies between 3°22′30″ to 3°28′00″N and 102°52′40″ to 102°58′10″E and comprises 12 open water bodies that are referred to as "laut" by the local people and is linked to the Pahang River by the Chini River (Fig. 1). A few communities of the indigenous Jakun tribe live around the lake. Tasik Chini is the second largest natural fresh-water lake in Peninsula Malaysia, encompassing 202 hectares of open water, as well as 700 ha of Riparian Peat and Lowland Dipterocarp forest (Wetlands International Asia Pasific, 1998). Tasik Chini is surrounded by variously vegetated low hills and undulating land which constitute the watershed of the region. There are three hilly areas surrounding the lake: (1) Bt. Ketaya (209 m) located southeast; (2) Bt. Tebakang (210 m) in the north and (3) Bt. Chini (641 m) located southwest. The study area has humid tropical climate with two monsoon periods, characterized by the following bimodal pattern. The southwest and northeast monsoons, that brings an annual rainfall of 1488 to 3071 mm. The mean annual rainfall is 2,500 mm and the temperature range is from 21 to 32°C. Potential evapotranspiration (PE) is between 500 to 1000 mm. However, the open water area has expanded since 1994, as a result of increased water retention after the construction of a barrage downstream Chini River. The lake drains northwest into the Pahang River via the Chini River, which meanders for 4.8 km before reaching the Pahang River.

MATERIALS AND METHODS

Soil sampling was carried out at selected sampling stations located around the Tasik Chini catchment area (Fig. 1). The 2006 monthly rainfall data was obtained from the Climatology Station of Felda Chini Dua. Physical conditions such as slope, plant cover and conservation practices were considered when selection of sampling stations was done. The GIS software was used in spatial data analysis to determine erosion potential, spatial distribution and for development of the erosion risk map of the study area. The study area was digitized by Ilwis 3.3 and ArcView GIS 3.3 for the soil series, topography and land use. For the measurement of the soil erodibility factor using RUSLE, a soil map was obtained from the Department of Agriculture. Topographic and land use maps of the study area were used as the basis for determining the LS factor, C factor and P factor values. Particle size distribution was determined by the pipette method together with dry sieving (Abdulla, 1966). The texture of the soils was obtained by plotting the percentage ratio of sand, silt and clay using the soil texture triangle. Organic matter content was determined by weight loss using the ignition technique. Soil erosion and sediment yield were estimated for the year 2006 using the Revised Universal Soil Loss Equation (Renard *et al*., 1997). A flow chart showing the preparatory steps for estimation of soil erosion is presented in Fig. 2.

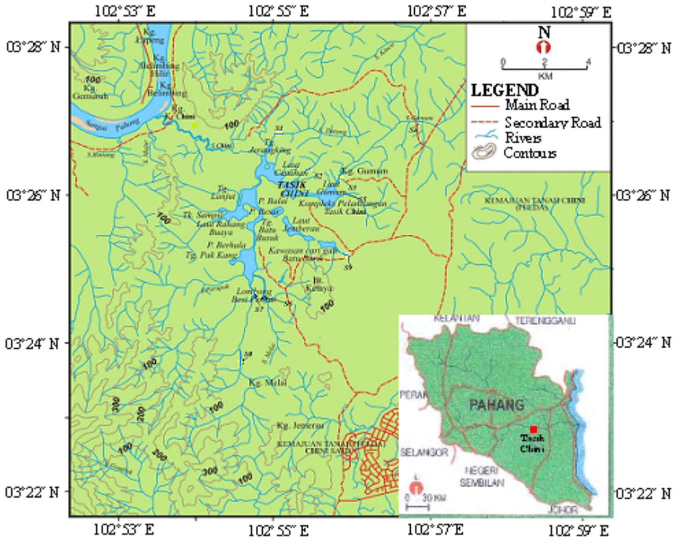

Fig. 1: Location of the study area

The formula for the RUSLE calculation is as follows:

$A = R*K*LS*C*P$

where,

A is the computed soil loss (t/ha/year);
R is the rainfall erosivity index (MJ mm/ha/h/year);
K is the soil erodibility index (Mg h MJ^{-1} mm^{-1});
L is the slope length factor (m);
S is the slope steepness factor (%);
C is the vegetation/cover factor and
P is the soil conservation practice factor.

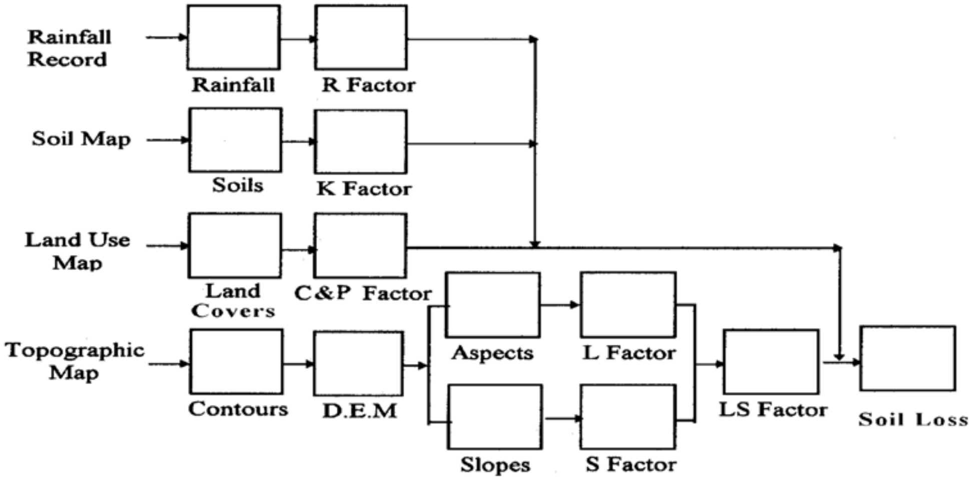

Fig. 2: Steps for estimation of soil loss via RUSLE (Fistikoglu and Harmancioglu, 2002)

Soil Erosion Factor Assessment:

Some factors were required in order to utilize RUSLE (Renard *et al*., 1997) for calculation of soil loss in the study area. The factors used in RUSLE, namely the R, K, LS, C and P are described below:

Rainfall Erosivity Factor (R):

The Rainfall Erosivity Factor (R) is the erosion potential of rainstorms to be expected in a given locality. It is related to the kinetic energy and intensity of the rain and occasionally used synonymously as erosivity (E). The product of EI_{30} reflects the potential ability of rain to cause erosion, where E = total kinetic energy of rain and I_{30} = peak 30 minutes intensity. In the following study, the rainfall erosivity index was calculated based on the Morgan and Roose calculation (Morgan, 2005; Baban and Yusof, 2001). According to Morgan (2005) two R-values can be present in any area; therefore the best estimate of the erosivity index for any study area is to take an average of the two calculations. Wischmeier and Smith (1978) recommended a maximum intensity (I_{30}) value of 75 mm/hr for tropical regions because research has indicated that the erosive raindrop size decreases when intensity exceeds this threshold value. The R factor value calculation in the current study is shown in Table 1.

Table 1: Erosivity (R) factor calculation

Method	Calculation	R Value MJ mm ha^{-1} h^{-1} yr^{-1}
Morgan (2005)	$\frac{(9.28P - 8838.15)x75}{1000}$ in metric unit	1108.11
Roose (1977)	$Px0.5x1.73$ in metric unit	2200.99
	Best estimation	1654.55

P is the total annual rainfall and for Tasik Chini, it was 2544.50 mm in 2006. The best estimate of the R factor value calculated for the study area was 1654.55 MJ mm ha^{-1} h^{-1} yr^{-1}.

Soil Erodibility Factor (K):

Soil Erodibility is the ability of the soil to be eroded by moving water. It depends on the soil structure, organic matter percentage, size composition of the soil particles and soil permeability measured as hydraulic conductivity. The K value can be obtained using a nomograph (Wischmeier *et al*., 1971; Morgan, 1980). For estimation of soil erodibility or the value of the K factor in the study area, soil samples from eleven sampling stations (Fig. 3) were collected and analyzed for their organic matter content, hydraulic conductivity, particle size distribution and textural classification. In this exercise, the K value of the soil in the study area was calculated using the following equation as given by MASMA (2000).

$$K = \frac{\left[2.1x10^{-4}(12 - OM\ \%)(N1xN2)^{1.14} + 3.25(S-2) + 2.5(P-3)\right]}{100}$$

Where;
OM is percentage organic matter,
N1 is percentage silt + very fine sand,
N2 is percentage silt + very fine sand + sand (0.125 – 2 mm),
S is soil structure code (Scwab *et al*., 1993) and
P is soil permeability class (Hydraulic Conductivity) (Renard *et al*., 1997).

Hydraulic conductivity values were classified to determine the K values and their rank (Table 2).

Table 2: Hydraulic conductivity classification for the K value

Hydraulic Conductivity (cm/hr)	Permeability Class	Rank
<0.125	Very slow	7
0.125-0.50	Slow	6
0.50-2.00	Moderately slow	5
2.00-6.25	Moderate	4
6.25-12.50	Moderately rapid	3
12.50-25	Rapid	2
>25	Very rapid	1

Source: Mustafa Kamal (1984)

Topographic Factor (LS):

Within the Revised Universal Soil Loss Equation (RUSLE), the LS-factor reflects the effect of topography on erosion, the slope length factor (L) represents the effect of slope length on erosion, and the slope steepness factor (S) reflects the influence of slope gradient on erosion (Lu *et al*., 2004). The slope factor (LS) is combined with the slope gradient and the length of the eroding surface into a single factor. Under RUSLE, the LS refers to the actual length of the overland flow path. It is the distance from the source of the overland flow to a point where it enters a major flow concentration. This definition is particularly relevant for forested or vegetated catchment areas where the overland flow seldom exists on hill slopes (Bonnel and Gilmour, 1978; Bruijnzeel, 1990). In forested catchment areas the subsurface storm flow is more dominant than the overland flow and the latter only exists at limited areas near the channel margins or on shallow soil as the return flow or saturated overland flow (Bruijnzeel, 1990). Consequently, the overland flow path in the forested catchment is expected to be shorter than the slope length identified from the map. The slope length and gradient were calculated from the topographical map of the study area (Fig. 4). Upon obtaining the L and S values, the topographical factor (LS) values were calculated for each soil series using the formula as provided by Wischmeier and Smith (1978) and Kirkby (1980):

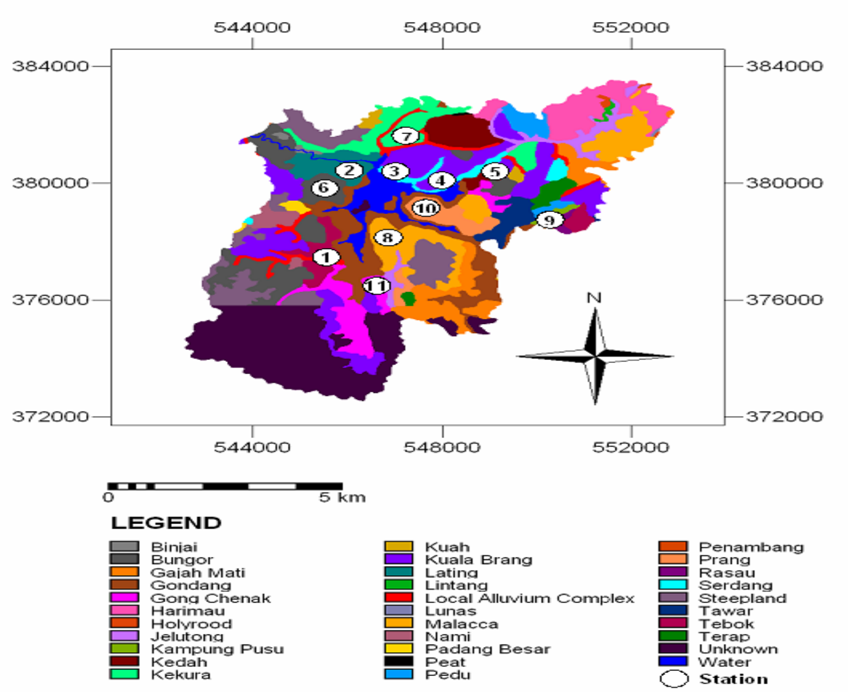

Fig. 3: Soil series map and location of soil sampling stations around the Tasik Chini Catchment area

$$LS = (0.065 + 0.045\,S + 0.0065\,S^2) \times \sqrt{\frac{L}{22.13}}$$

Where,
L is slope length in m and
S is slope gradient in percent
The variation in value is caused by variation in gradient and length of the slope.

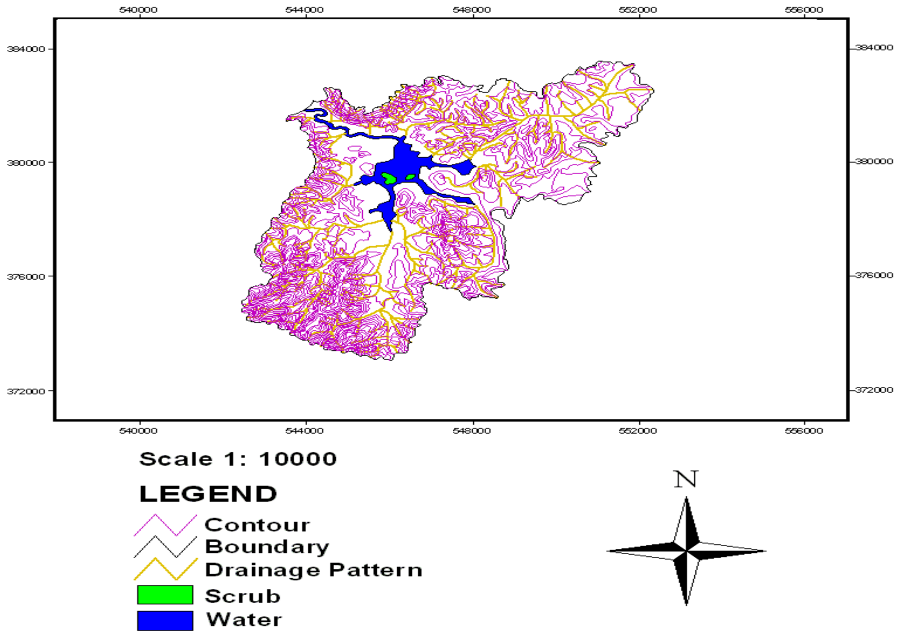

Fig. 4: Topographical map of the Tasik Chini Catchment

Vegetation Cover Factor (C):

The vegetation cover factor (C) represents the ratio of soil loss under a given vegetation cover as opposed to that on bare soil. The C factor is used to reflect the effect of cropping and management practices on soil erosion rates in agricultural areas and the effects of the vegetation canopy and ground cover on reducing soil erosion in the forested regions (Renard *et al*., 1997). The effectiveness of a plant cover for reducing erosion depends on the height and continuity of the tree canopy as well as the density of the ground cover and root growth. The vegetation cover intercepts raindrops and dissipates its kinetic energy before it reaches the ground surface. The relative impact of management options can easily be compared by making changes in the C factor which varies from near zero for well protected land cover to one for the barren areas (Lee and Lee, 2006). In the current study, the C values were extracted from the Morgan (2005) estimates and assigned to the corresponding land cover based on the 2002 land use map of the Malaysian Department of Agriculture (Fig. 5).

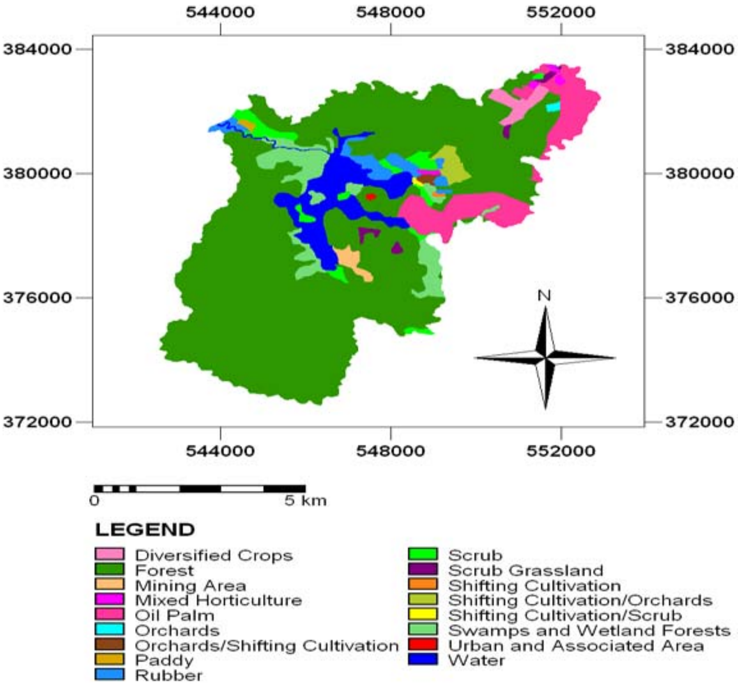

Fig. 5: Land use map (2002) of the study area (Department of Agriculture)

Conservation Factor (P):

The effect of contouring and tillage practices on soil erosion is described by the support practice factor P within the RUSLE model (Renard *et al*., 1997). Wischmeier and Smith (1978) defined the support practice factor P as the ratio of soil loss with a specific support practice to the corresponding soil loss due to up and down cultivation. The lower the P value, the more effective the conservation practice is deemed to be at reducing soil erosion. If there are no support practices, the P factor is 1.00. Contemporary agricultural practices consist of up and down tillage without the presence of contours, strip cropping, or terracing. The P factor depends on the conservation measure applied to the study area. In Malaysia the most common conservation practice is contour terracing in rubber and oil palm plantations. In the present study, it was assumed that the contour terracing practice on slopes was carried out for both the rubber and oil palm plantations.

RESULTS AND DISCUSSION

K factor of the RUSLE:

Based on the relative proportion of sand, silt, clay and organic matter, the soil erodibility factor was estimated in Mg h MJ^{-1}mm^{-1}. The spatial distribution of soil erodibility (K values) is given in Table 3. The mean soil erodibility (K factor) in the study area varied from 0.03 to 0.30 Mg h MJ^{-1} mm^{-1}, giving an average and standard deviation of 0.16 Mg h MJ^{-1} mm^{-1} and 0.02 Mg h MJ^{-1} mm^{-1} respectively. Statistical analysis indicated that the mean K value was significantly different ($P<0.001$) among the sampling stations.

Table 3: Calculation of the erodibility value (K) of different soil series in the study area

Station	Soil Series	USDA Soil Taxonomy	Average of Five Replications and Standard Deviation (SD)				
			N1 (%)	N2 (%)	OM (%)	P (cm/hr)	K_{erod}
1	Tebok	Ultisols	36.84±4.24	61.59±3.20	4.93±0.20	0.86±0.20	0.15±0.02
2	Lating	Ultisols	32.02±2.84	35.51±2.84	7.26±1.51	0.75±0.25	0.09±0.01
3	Serdang	Ultisols	51.15±2.98	78.40±2.29	3.36±0.13	0.73±0.28	0.29±0.02
4	Kuala Brang	Ultisols	19.50±1.83	32.38±1.87	7.35±0.78	1.40±0.08	0.07±0.01
5	Kedah	Ultisols	62.77±1.92	74.33±2.73	4.47±0.66	0.72±0.20	0.30±0.03
6	Bungor	Ultisols	61.08±1.59	67.34±1.72	3.95±0.49	0.88±0.17	0.27±0.01
7	Kekura	Entisols	39.58±1.65	85.60±1.85	2.90±0.19	3.21±1.62	0.20±0.02
8	Malacca	Oxisols	20.35±2.30	50.62±5.76	7.16±0.96	4.91±1.74	0.04±0.02
9	Rasau	Entisols	45.35±4.28	86.43±1.74	2.76±0.38	3.00±0.83	0.24±0.03
10	Prang	Oxisols	8.03±1.78	19.08±1.86	8.73±0.85	5.36±0.75	0.09±0.01
11	Gong Chenak	Ultisols	27.31±7.28	29.07±7.35	11.55±1.64	0.71±0.10	0.03±0.01

The results of the soil analyses showed that the Kedah, Serdang and Bungor soil series have low organic matter content and are clay loam in texture. These soils have lower infiltration rates than the other soil series. Lating, Tebok, Kuala Brang, Malacca, Prang and Gong Chenak soil series are clayey in texture, have high organic matter content and low K values, ranging from 0.03 to 0.15 Mg h MJ^{-1} mm^{-1}. The effects of sand and organic matter that increased the infiltration and decreased the K values have been reported by Santos *et al.* (2003), Evrendliek *et al.* (2004), Tejada and Gonzalez (2006), and Rodriguez *et al.* (2006). The K values of the Rasau and Kekura soil series were moderate, ranging from 0.20 to 0.24 Mg h MJ^{-1} mm^{-1}. This was because of the characteristics of the soil such as moderate infiltration rates and sandy loam texture. In general, clay soils have low K values because they are resistant to detachment. Sandy soils have low K value because they have high infiltration rates and reduced surface runoff, resulting in the sediments getting eroded from these soils and not easily transported. Silt loam soils have moderate to high K values because the soil particles are moderate to easily detachable, infiltration is moderate to low thus effecting moderate to high runoff, with the sediments being moderate to easily transported. Silt soils have the highest K values because these soils crust readily, producing high quantities of runoff. Also, the soil particles are easily detached from these soils and the resulting sediments are easily transported (Vaezi *et al.*, 2008).

LS factor of the RUSLE:

The Tasik Chini catchment is characterized by decreasing elevation value from northwest to southeast with a maximum drop of 420 m. The southwest area of the catchment has the highest variability in elevation, the steepest slopes and the greatest LS values. The LS factor value in the study area varied from 2.73 to 22.89. The LS factor values calculated for each soil series are tabulated in table 4.

Table 4: Distribution of the LS factor values calculated for the study area

Station	Soil Series	Average of Five Replications and Standard Deviation (SD)				
		Map Distant cm	Contour Difference m	L Distant m	S %	LS
1	Tebok	0.90±0.35	41.00±4.18	450±176.78	13.31±5.75	7.76±3.43
2	Lating	0.96±0.32	21±2.24	480±160.47	6.24±2.77	2.73±1.17
3	Serdang	0.90±0.29	37±10.37	450±145.77	10.61±1.44	5.66±1.15
4	Kuala Brang	0.74±0.21	57±9.08	370±103.68	20.55±6.69	15.25±7.15
5	Kedah	0.68±0.26	32±10.37	340±129.42	12.61±3.94	6.47±2.49
6	Bungor	0.74±0.25	43±4.47	370±125.50	15.96±4.93	9.77±3.58
7	Kekura	0.94±0.27	58±13.51	470±135.09	16.57±5.40	11.79±4.47
8	Malacca	0.78±0.38	61±12.94	390±188.41	21.58±4.93	16.02±2.81
9	Rasau	0.60±0.27	30±7.91	300±136.93	15.09±8.65	8.14±6.05
10	Prang	0.52±0.23	44±9.62	260±114.02	23.09±6.73	15.13±5.35
11	Gong Chenak	0.38±0.13	48±22.80	190±65.19	30.57±6.02	22.89±11.00

C factor of the RUSLE:

The C factor value varied from 0 to 0.50 and the mean value was 0.18. The highest C factor value that occurred in the study area came from mining activities. The C values extracted based on the land use map are shown in Table 5.

Table 5: Crop practice and vegetation management factors for the studied catchment

Vegetation	C
Oil Palm	0.50
Rubber	0.20
Orchard	0.30
Secondary Vegetation	0.02
Urban	0.01
Diversified Crops	0.02
Mining Area	1.00
Forest	0.001
Grass Land	0.01
Scrub	0.01
Wetland Forest	0.001
Mixed Horticulture	0.20
Shifting Cultivation	0.20
Water	0.00

P factor of the RUSLE:

In the current study, the value of P was assigned by overlaying the slope map and land use map. The rubber and oil palm plantations on slopes were assigned a P value according to the slope steepness as shown in Table 6, while other agricultural activities were given a value of 1, assuming no conservation practices were adopted.

Table 6: P values with corresponding slope steepness for the Tasik Chini Catchment

Erosion-control practice	P factor value
Contouring: 0-1° slope	0.60*
Contouring: 2-5° slope	0.50*.
Contouring: 6-7° slope	0.60*
Contouring: 8-9° slope	0.70*
Contouring: 10-11° slope	0.80*
Contouring: 12-14° slope	0.90*
Level bench terrace	0.14
Reserve-slope bench terrace	0.05
Outward-sloping bench terrace	0.35
Level retention bench terrace	0.01
Tied ridging	0.10-0.20

* 50% of the value for contour bunds or if contour strip cropping was applied (Wischmeier and Smith, 1978; Roose, 1977)

Rate of Soil Erosion:

The calculation of soil erosion based on the RUSLE model showed that Tebok, Lating, Bungor, Kekura and Gong Chenak soil series had low rates of soil loss, ranging from 0.26 to 1.43 t/ha/year or an average of 0.65 t/ha/year, 0.06 to 0.17 t/ha/year, with an average of 0.10 t/ha/year, 0.66 to 2.65 t/ha/year, with an average of 1.61 t/ha/year, 1.27 to 9.57 t/ha/year, with an average of 4.23 t/ha/year and 0.17 to 0.90 t/ha/year, with an average of 0.53 t/ha/year respectively (Table 7). Forested areas were mostly in the western and northern parts of the Tasik Chini Catchment and human activities were localized in the eastern and southern regions. The steepest slopes were in the western and northern parts of the catchment area. Relatively low steep areas were located in the eastern and southern parts of the study area. The Tebok, Lating, Bungor, Gong Chenak and Kekura soil series were located in the forested areas with low C values (0.001) and low erosion yields. Similar results were also reported by Shallow (1956) for areas under natural forests in Malaysia. Soil Loss Tolerance Rates (DOE, 2003) were prepared for standard evaluation of soil loss in the study area (Table 8). The Serdang and Prang series had a moderate rate of soil loss, ranging from 0.56 to 144.90 t/ha/year, averaging 47.41 t/ha/year and 1.11 to 102.05 t/ha/year, averaging 42.62 t/ha/year. These soil series were located in the oil palm, rubber and forested areas; the value of the erosion yield was moderate. The Kuala Brang and Rasau soil series had a moderately high rate of soil loss, ranging from 1.25 to 97.86 t/ha/year averaging 57.16 t/ha/year and 3.35 to 100.46 t/ha/year, averaging 57.93 t/ha/year. The Kuala Brang and Rasau soil series were located under oil palm, rubber and forests but the LS factor values for the Kuala Brang and the K values for the Rasau soil series were found to be higher than those of the others. The Malacca soil series had a high rate of soil loss, ranging from 21.44 to 348.75 t/ha/year, or an average of 130.26 t/ha/year. On the basis of the land use map, the Malacca series was located under oil palm, scrub, mining and forested areas. Most of the Malacca soil series were under oil palm plantations, and had high erosion yield. The worst-case scenario was observed for the Kedah soil series which had very high erosion yield, ranging from 79.99 to 319.75 t/ha/year, or an average of 180.49 t/ha/year. The C value for the Kedah soil series was considered very high (0.20) because it was located under rubber, oil palm and shifting cultivation areas. Tania Del Mar Lopez *et al*. (1998) mentioned that soil erosion varied with the land use pattern and the highest values are in areas of bare soil and the lowest in forested areas.

Table 7: Prediction of the potential rate of soil loss in the study area

Station	Soil Series	R	Average of Five Replications and Standard Deviation (SD)				
			K	LS	C	P	A
1	Tebok	1654.55	0.15±0.02	7.75±3.43	0.001±0	0.30±0.07	0.65±0.50
2	Lating	1654.55	0.09±0.01	2.73±1.17	0.001±0.0	0.25±0.0	0.10±0.05
3	Serdang	1654.55	0.29±0.02	5.66±1.15	0.08±0.11	0.27±0.03	47.41±66.68
4	Kuala Brang	1654.55	0.07±0.01	15.24±7.15	0.12±0.11	0.37±0.05	57.16±49.81
5	Kedah	1654.55	0.30±0.03	6.47±2.49	0.20±0.0	0.28±0.05	180.49±89.64
6	Bungor	1654.55	0.27±0.01	9.77±3.59	0.001±0.0	0.35±0.06	1.61±0.81
7	Kekura	1654.55	0.20±0.02	11.79±4.47	0.02±0.01	0.35±0.06	4.23±3.51
8	Malacca	1654.55	0.05±0.02	16.02±2.81	0.32±0.38	0.39±0.06	130.26±126.27
9	Rasau	1654.55	0.24±0.04	8.14±6.04	0.12±0.10	0.32±0.08	57.93±41.66
10	Prang	1654.55	0.09±0.0	15.13±5.35	0.08±0.11	0.41±0.08	42.62±50.78
11	Gong Chenak	1654.55	0.03±0.01	22.89±11.00	0.001±0.0	0.45±0.0	0.53±0.28

Table 8: Soil Loss Tolerance Rates (Erosion Risk Map of Malaysia)

Soil Erosion Class	Potential Soil Loss (t/ha/yr)
Very Low	<10
Low	10 – 50
Moderate High	50 – 100
High	100 – 150
Very High	>150

Source: DOE (2003)

Predicted Soil Erosion Risk Map:

The soil erosion risk map was created from the predicted soil loss data, which is shown in Fig. 6. There are five categories of soil erosion risk classes namely very low, low, moderately high, high and very high. It was observed that 4163.88 ha or 71.54% of the study area came under the very low risk class (<10 t/ha/yr), 171.36 ha or 2.94% of the area was in the low risk class (10 to 50 t/ha/yr), 196.48 ha or 3.38% of the area was in the moderately high risk class (50 to 100 t/ha/yr), 84.16 ha or 1.45% of the area was in the high risk class (100 to 150 t/ha/yr) and 770.96 ha or 13.25% of the area in the very high risk class (>150 t/ha/yr). The quantitative output of the predicted soil loss categories are shown in Table 9. Results showed that most of the forested areas of the Tasik Chini Catchment came under the very low erosion risk category (71.54%), and were located in the western and southern parts of the study area. About 2.94% of the catchment area was under low erosion risk, and this was mostly found in the eastern and southern region of the catchment. Areas with rubber plantations and those subject to human activities of the indigenous people came under the moderately high erosion risk class (3.38%), and these were located nearest to the water bodies of the lake. With regard to soil loss based on land use types, high erosion risk (1.45%) was observed in the shifting cultivation areas, rubber plantations and agricultural areas. These areas occurred in the north eastern part of the study area. Analysis of soil loss among the dominant land use and land cover areas showed that the very high soil loss category (13.25%) occurred in oil palm plantations, logging areas and reactivated mining areas located in the northern and eastern parts of the Tasik Chini Catchment. The reason for soil loss came as a result of the close relationship of the activities involved with land use, rainfall erosivity and topography as reported by Xu *et al*. (2008) and Wang (2001).

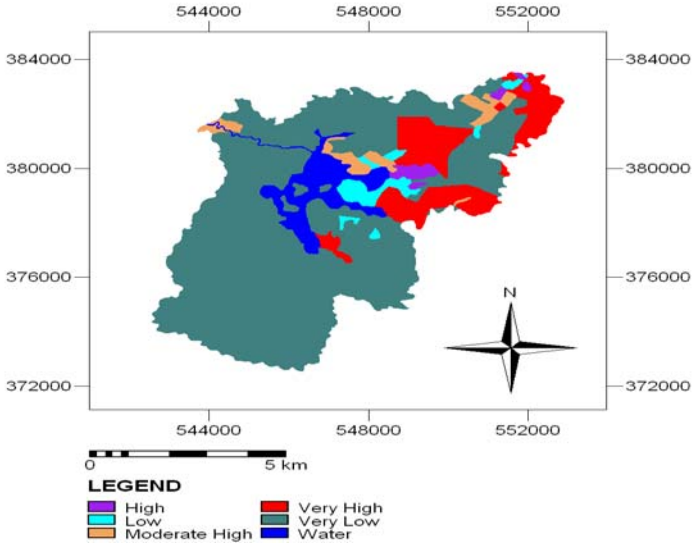

Fig. 6: Spatial distribution of predicted soil erosion risk categories in the Tasik Chini Catchment

Table 9: Predicted soil erosion risk categories of areas within the Tasik Chini Catchment

Soil Erosion Risk Categories	Area	%
Very Low	4163.88	71.54
Low	171.36	2.94
Moderate High	196.48	3.38
High	84.16	1.45
Very High	770.96	13.25

Conclusion:

The rate of potential soil loss in the area studied was very severe, in the urban, shifting cultivation and mining areas (station 5, 8 and 9). The results showed that soil erosion in the Tasik Chini Catchment was higher than that classified by the DOE as areas with severe soil loss. This was due to the heavy rainfall, high soil erodibility potential, high LS factor and the lack of conservation practices on open surfaces. It was found that moderate rate of soil loss occurred in rubber and oil palm cultivation areas (station 3, 4 and 5). Station 1, 2, 6, 7, 10 and 11 were considered as low and very low erosion prone areas which constituted a significant portion of the total catchment area, covered with forests and vegetation. The study showed that forested areas showed less soil loss compared to unprotected areas, which experienced high soil loss. Comparison of watershed-scale erosion under different land use configurations also indicated that reforestation is one of the most effective ways to reduce soil erosion in this catchment.

This research study demonstrated that the integration of RUSLE with GIS to model soil erosion potential and develop erosion maps was very effective for assessing soil loss and erosion risk. The methods and results described are valuable for understanding the relationship between soil erosion risk and environmental factors, and are useful for managing and planning land use activities that will minimize soil erosion. The study has also indicated that relevant management practices and strategies should be adopted in areas of high to very high erosion risk in order to reduce soil loss.

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