Soil loss assessment in the Tasik Chini catchment, Pahang, Malaysia

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Abstract — The Universal Soil Loss Equation (USLE) model is used to estimate average soil loss generated from splash, sheet, and rill erosion in agricultural plots at the Tasik Chini catchment. Use of the USLE has recently been extended for predicting soil loss and plan control practices in agricultural catchment by the effective integration of Geographic Information Systems (GIS) based on procedures to estimate the factor values in a grid cell basis. This study was performed to predict the soil erosion risk by the USLE/GIS methodology for planning conservation measures in the site. Rainfall erosivity (R), topographic factor (LS) and land cover management factor (C) values for the model were calculated from rainfall data, topographic and land use maps. Soil was analyzed for the soil erodibility factor (K). Soil samples were selected from the eleven soil series around the Tasik Chini area. A total of 55 samples were collected from the eleven soil series namely Tebok, Lating, Serdang, Kuala Brang, Kedah, Bungor, Kekura, Malacca, Rasau, Prang and Gong Chenak. Physical properties such as particle size distribution, texture, hydraulic conductivity and organic matter content (OM) were analyzed in order to support the erosion rate analysis. Results shows that five soil series have low rates of soil loss, i.e. Tebok, Lating, Bungor, Kekura and Gong Chenak series, having an average soil loss of 0.65, 0.10, 1.61, 4.23 and 0.53 ton/ha/year, respectively. Two soil series have moderate rates of soil erosion namely Serdang and Prang series (average of 47.41 and 41.10 ton/ha/year, respectively). Two soil series with moderately high rates of soil loss are Kuala Brang and Rasau soil (average of 57.16 and 57.93 ton/ha/year, respectively). Malacca Series has high rate of soil loss, ranges from 21.44 to 348.7 or average of 130.26 ton/ha/year. Kedah soil series has very high soil loss, ranges from 79.99 to 319.75 or average of 180.49 ton/ha/year. This high erosion rate is expected to generate higher sedimentation rate into the Tasik Chini water body, elevating the lake fills and eventually forming an extinct lake.

Keywords: erosion rate, soil loss assessment, soil series, Tasik Chini catchment

Penilaian kehilangan tanih di lembangan Tasik Chini, Pahang, Malaysia

Abstrak — Pemodelan menggunakan Universal Soil Loss Equation (USLE) adalah bertujuan untuk menganggarkan purata kehilangan tanih yang ditimbulkan oleh percikan hujan, hakisan permukaan dan hakisan alur di kawasan pertanian di Lembangan Tasik Chini. Kebelakangan, penggunaan USLE telah dipanjangkan sebagai perkakasan serbaguna dalam peramalan kehilangan tanih dan perancangan langkah kawalan dalam kawasan pertanian dengan keberkesanan bersepadu Sistem Maklumat Geografi (GIS) berdasarkan tatacara penganggaran faktor nilai berdasarkan grid lajur. Kajian ini dijalankan untuk meramal resiko hakisan tanih dengan penggunaan kaedah USLE/GIS dalam perancangan penilaian pemuliharaan dalam kawasan kajian. Erosiviti hujan (R), faktor topografi (LS) dan nilai faktor pengurusan litupan permukaan (C) daripada model ini kemudian dikira berdasarkan data hujan, peta topografi dan peta guna tanah. Sampel tanih dianalisis untuk mendapatkan nilai faktor kebolehhakisan (K). Pensampelan tanih terpilih telah dilakukan mewakili sebelas siri tanih di sekitar Tasik Chini. Sebanyak 55 sampel tanih telah dikutip daripada kedalaman (0-20 cm) yang mewakili sebelas siri tanih, iaitu Tebok, Lating, Serdang, Kuala Brang, Kedah, Bungor, Kekura, Malacca, Rasau, Prang dan Gong Chenak. Sifat fizikal tanih seperti taburan saiz butiran, tekstur, kekonduksian hidrolik dan kandungan organik telah dianalisis bertujuan untuk menyokong analisis kadar hakisan. Hasil kajian menunjukkan bahawa lima siri tanih mempunyai kadar kehilangan tanih yang rendah, iaitu: Tebok (purata 0.65 ton/ha/tahun), Lating (purata 0.10 tan/ha/tahun), Bungor (purata 1.61 tan/ha/tahun), Kekura (purata 4.23 tan/ha/tahun) dan Siri Gong Chenak (purata 0.53 tan/ha/tahun). Dua siri tanih mempunyai kadar hakisan tanih sederhana; Serdang, purata 47.41 tan/ha/tahun dan Siri Prang purata 41.10 tan/ha/tahun. Dua siri tanih mempunyai kadar kehilangan tanih sederhana tinggi, iaitu: Kuala Brang, purata 57.16 tan/ha/tahun dan Siri Rasau, purata 57.93 tan/ha/tahun. Siri Malacca mempunyai kadar kehilangan tanih yang tinggi dengan purata 130.26 tan/ha/tahun. Siri Kedah merupakan siri tanih yang terburuk, mempunyai kadar kehilangan tanih yang tertinggi iaitu purata 180.49 tan/ha/tahun. Kadar hakisan yang tinggi diramalkan akan menggalakkan berlakunya proses sedimentasi yang tinggi ke Tasik Chini, akhirnya tasik akan menjadi penuh dan menyebabkan kepupusan tasik.

Kata Kunci: kadar hakisan, penilaian kehilangan tanih, siri tanih, lembangan Tasik Chini

INTRODUCTION

Soil erosion is a worldwide phenomenon and never-ending problem in all over the world. Soil erosion is a two-phase process, consisting of the detachment of individual particles from the soil mass and transported by erosive agents such as wind and water (Morgan, 2005). It is a natural process, and started before the history of man's existence on the earth. Disturbance from human activities has further aggravated the process of soil erosion especially on steep slopes. Erosion can also be triggered or accelerated by climatic change, tectonic activities, human influence or a combination of them (Bocco, 1991). Soil erosion has become an important environmental problem in recent years especially in areas where there has been intensive use of land for development net urbanization and agricultural activities accentuating the problem. Soil erosion affects not only on soil productivity of upland fields but also the water quality of the streams in the catchment area. The chemical influx from pesticides and fertilizers due to agricultural activities increased the chemical concentration such as nitrogen, phosphorus and heavy metals contents in the lacustrine water and sediment. The encroachment of development into the environmental sensitive areas has resulted in accelerated soil erosion, water pollution, sedimentation and consequently the flooding in the downstream areas. Land use in the surrounding of Tasik Chini has changed into agriculture, tourisms, mining and settlements. Due to these transformations, the rate of erosion and sedimentation has increased. These activities were generated by runoff phenomenon in the bare and half bare slope surface to the streams and finally to the lake, and it will decrease the lake depth in a long-term basis.

STUDY AREA

Tasik Chini is located in the southeast region of Pahang, Malaysia. It is located approximately 100 km from Kuantan, the capital of Pahang (Figure 1). 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 called "laut" by the local people and linked to the Pahang River by the Chini River. A few communities of the indigenous Jakun tribe settlements are scattered around the lake. Tasik Chini is the second largest natural fresh-water lake in Malaysia covering 202 hectares of open water and 700 ha of Riparian, Peat, Mountain and Lowland Dipterocarp forest (Wetlands International Asia Pacific, 1998). Tasik Chini is surrounded by variously vegetated low hills and undulating lands which constitute the watershed of the region. There are three hilly areas surrounding the lake: (1) Bt. Ketaya (209 m) located at the southeast; (2) Bt. Tebakang (210 m) at the northern and (3) Bt. Chini (641 m) at the southeast region. The climate of Tasik Chini is typical for the equatorial climate of Peninsular Malaysia, which is characterized by moderate average annual rainfall, temperature and humidity. The area has a humid tropical climate with two monsoon periods, characterized by bimodal pattern: southwest and northeast monsoons bringing an annual rainfall which varies between 1488 to 3071 mm. Potential evapotranspiration (*PE*) is between 500 to 1000 mm. However, the open water area has expanded greatly since 1995, due to construction of a small barrage at downstream of the Chini River, 4.8 km before it reaches the Pahang River. Tasik Chini is also playing a role as a big retention pond before the water stream of the Pahang River flowing into Pekan area.

MATERIALS AND METHODS

Soil sampling has been carried out from selected sites, located around Tasik Chini (Figure 2). The 2006 rainfall data is obtained from Felda Chini Dua Climatology Station, Chini. Physical condition such as slope angle, plant cover and conservation practices were considered under selection for sampling station in the field. The study catchment area was digitized using Ilwis 3.3 and ArcView GIS 3.3 software for soil series map, topographical map, land use map and drainage pattern characteristics. Particle size distribution was determined by pipette method together with dry sieving (Abdulla, 1966). Textures of soils were obtained by plotting the percentage ratio of sand, silt and clay using the triangle of texture. Organic matter content was determined by loss on ignition technique. Soil erosion and sediment yields were estimated for the year 2006 using the Universal Soil Loss Equation (Wischmeier and Smith, 1978). The formulae for USLE estimation is as follows:

A= R*K*LS*C*P

where A is the computed soil loss, R for the rainfall erosivity index, K is the soil erodibility index, L is the slope length factor, S is the slope steepness factor, C is the vegetation cover factor and P is the soil conservation practices factor.

RESULTS AND DISCUSSION

Rainfall Erosivity Factor (R)

The rainfall (R) factor represents the erosion potential of rainstorms to be expected in a given locality. It is related with the kinetic energy and intensity of the rain and occasionally used synonymously as erosivity (E). The product 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 this study, Rainfall erosivity index was calculated based on Morgan and Roose calculation (Morgan, 2005). According to Morgan (2005) two R-values can be presence in the study area; therefore the best estimate of erosivity index for the study area is the average from two calculations. Wischmeier and Smith recommended a maximum intensity (I_{30}) value of 75 mm/hr for tropical regions because research has indicated that erosive raindrop size decrease when intensity exceeds this threshold value. The R value calculation in the study area is shown in Table 1.

P is the annual rainfall mean equivalent of the study area which is 2544.5 mm for Tasik Chini. The best estimate

Table 1: Erosivity (R) factor calculation.

Method	Calculation	R value MJ mm $ha^{-1} h^{-1} yr^{-1}$
Morgan (2005)	[(9.28P-8838.15)x75]/1000 in metric unit	1108
Roose (1977)	P x 0.75 x 1.73 in metric unit	2201
	Best estimation	1655

Figure1: Location of the study area.

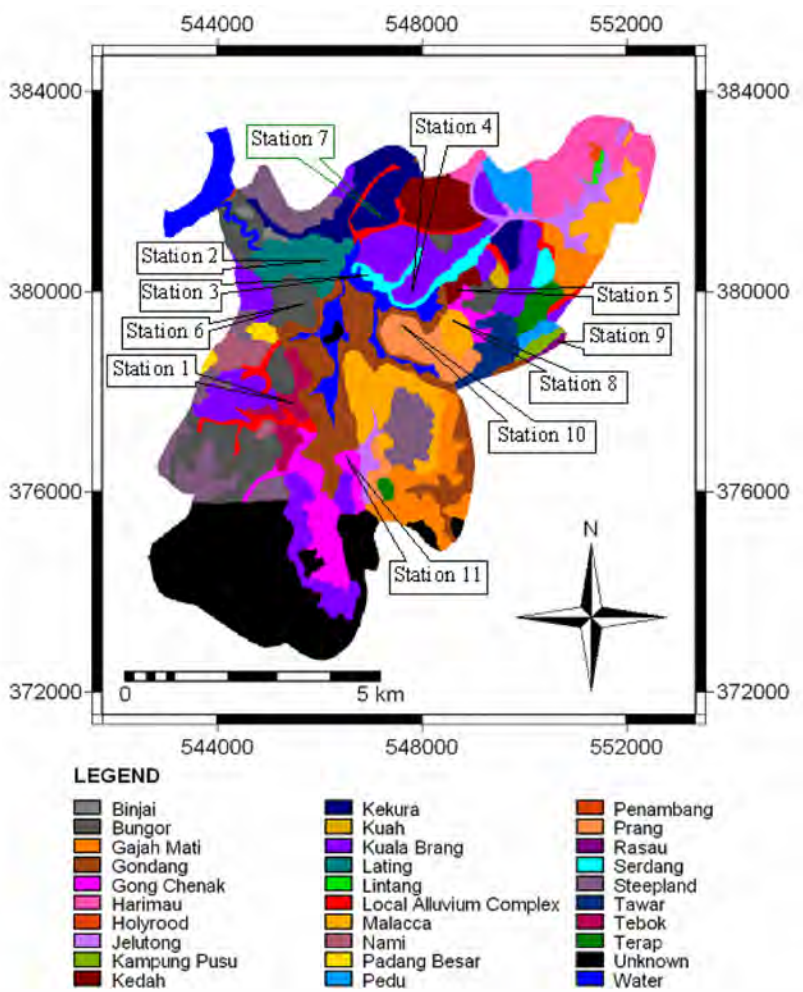

Figure 2: Soil series map and location of sampling stations around the Tasik Chini catchment area (Source: Department of Agriculture, 2007).

of the R factor value calculated for the study area was 1654.55 MJ mm ha^{-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 (Morgan, 1980; Wischmeier *et al*., 1971). In this exercise, the K value of the soil in the study area was calculated (Table 2) using the formulae and their ranks (Table 3).

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

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 and P is soil permeability class (hydraulic conductivity).

Table 2: Distribution of the erodibility value (K) of soil calculated for the study area.

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

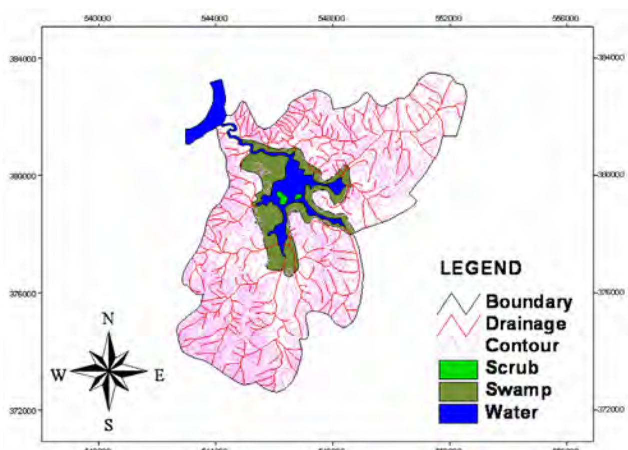

Figure 3: Topographical map of the Tasik Chini catchment area.

Topographical Factor (LS)

The slope factor (LS) is combined with the slope gradient and the length of the eroding surface into a single factor. In the Revised Universal Soil Loss Equation (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 catchments 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 forested catchment is expected to be shorter than the slope length identified from the map. The slope length and gradient were calculated from topographical map of the study area (Figure 3). Upon obtaining the L and S value, the topographical factor (LS) value was calculated for each soil series (Table 4) using the formula as provided by Wischmeier and Smith (1978).

$$LS = (0.065 + 0.045\ S + 0.0065\ S^2) \times (L/22.13)^{0.5}$$

where L is slope length in m and S is slope gradient in percent. The variation in value was caused by variation in gradient and length of slope.

Vegetation Cover Factor (C)

The vegetation covers factor (C) represents the ratio of soil loss under a given vegetation cover as opposed to that bare soil. 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 the root growth. The vegetation cover intercepts raindrops and dissipates its kinetic energy before it reaches the ground surface. In the current study, the C values (Table 5) were extracted from the Morgan (2005) estimates and assigned to the corresponding land cover based in the 2002 land use map of the Malaysian Department of Agriculture (2006) (Figure 4).

Conservation Factor (P)

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 this study, it was assumed that contour terracing practice on slopes was carried out for both rubber and oil palm plantation. In the current study, the value of P was assigned by overlaying the slope map and land use map. The rubber and oil palm plantation 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.

Rate of Soil Erosion

The calculation of the soil erosion based on the USLE model showed that Tebok, Lating, Bungor, Kekura and Gong Chenak Series had low rates of soil loss, ranging from 0.26 to 1.43 ton/ha/year or an average of 0.65 ton/ha/year, 0.06 to 0.17 ton/ha/year, with an average of 0.10 ton/ha/year, 0.66 to 2.65 ton/ha/year, with an average of 1.61 ton/ha/year, 1.27 to 9.57 ton/ha/year, with an average of 4.23 ton/ha/year and 0.17 to 0.90 ton/ha/year, with an average of 0.53 ton/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. Relatively low steep areas were located in the eastern and southern parts of the study area. Tebok, Lating, Bungor, Gong Chenak and Kekura soil series were located in the forested area 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 (Department of Environment, 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 ton/ha/year, averaging 47.41 ton/ha/year and 1.11 to 102.05 ton/ha/year, averaging 42.62 ton/ha/year. These soil series were located in the oil palm, rubber and forested areas; hence the value of 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 ton/ha/year, averaging 57.16 ton/ha/year and 3.35 to 100.46 ton/ha/year, averaging 57.93 ton/ha/year. The Kuala Brang and Rasau soil series were located under oil palm plantation, 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 ton/ha/year, or an average of 130.26 ton/ha/year. On the basis of the land use map, the Malacca series was covered with the oil palm plantation, scrub, mining and forest vegetation. Most of the Malacca soil series were covered with the 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 ton/ha/year, or an average of 180.49 ton/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 lowest in forest areas.

CONCLUSION

The USLE/GIS approach was used to predict potential soil erosion in the Tasik Chini catchment. Soil erosion within catchment varied spatially and temporally. In general, soil erosion increases with annual rainfall, slope and land use with open canopies. With the use of the USLE/GIS methodology spatial distribution of different erosion prone areas were identified in the catchment to successfully take erosion control measures in the severely affected areas. The rate of potential soil loss in the area studied was very severe, especially at station 5, 8 and 9. The results showed that soil erosion in the Tasik Chini catchment was higher than that classified by the Department of Agriculture as areas with severe soil loss. This was due to the high soil erodibility potential and the lack of conservation practices on open surfaces. Station 3, 4 and 5 were located in the

Table 3: Hydraulic conductivity classification for the K value (after Mustafa Kamal Baharuddin, 1984).

Hydraulic Conductivity (cm/hr)	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

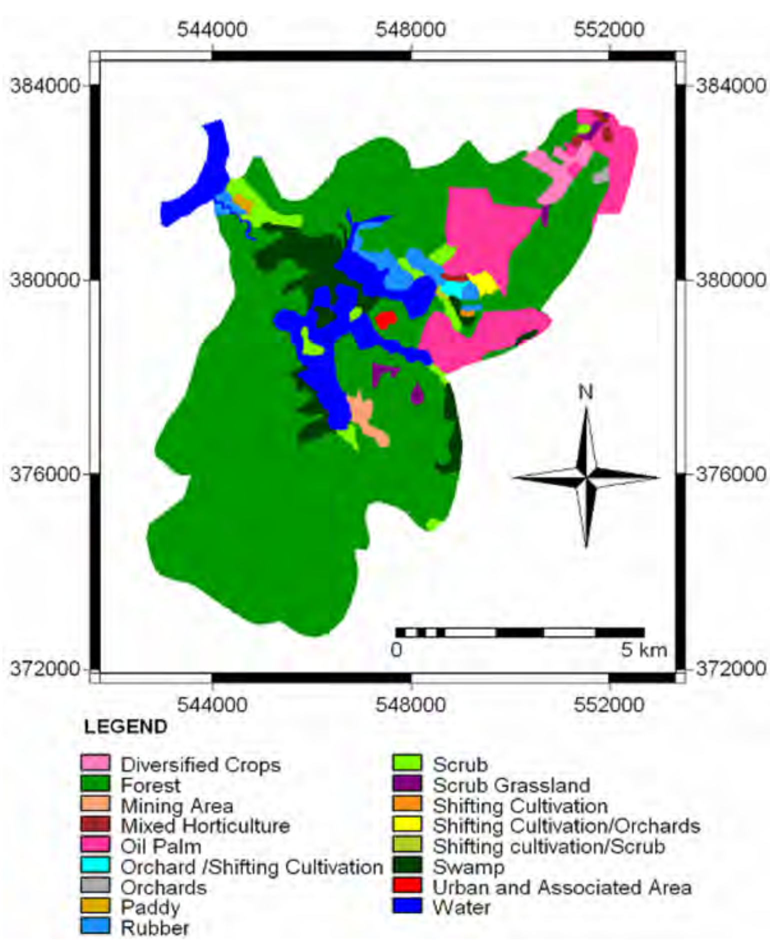

Figure 4: Land use map (year 2002) of the study area (Source: Department of Agriculture, 2006)

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

		Average of Five Replications				
		Map Distant	Contour	L Distant	S	LS
Station	Soil Series	cm	Difference m	m	%	
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

Table 5: Crop practice and vegetation management factors for the studied catchment (after Wischmeier and Smith, 1978, Roose, 1977, Singh *et al*., 1981, El-Swaify *et al*., 1982, Hurni, 1987 and Hashim & Wong, 1988).

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

Table 6: P values with corresponding slope steepness for the Tasik Chini catchment. * 50% of the value for contour bunds or if contour strip cropping was applied. (after Wischmeier and Smith, 1978, Roose, 1977 and Chan, 1981).

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

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

			Average of Five Replications				
Station	Soil Series	R	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 from erosion risk map of Malaysia (Department of Environment, 2003).

Soil Erosion Class	Potential Soil Loss (ton/ha/year)
Very Low	<10
Low	10 - 50
Moderate High	50 - 100
High	100 - 150
Very High	>150

area prone to moderate soil loss. Stations 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. 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.

Human activities were the greatest threat to the environment. An effective way to control the negative impacts to the environment due to human interruption is through controlling human's activities. A comprehensive approach of planning and management programme is needed for the development of Tasik Chini in order to reduce the occurrence of potential disaster such as soil erosion, sedimentation and flash flood.

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