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ORIGINAL ARTICLE

Flux of nutrients and heavy metals from the Melai River sub-catchment into Lake Chini, Pekan, Pahang, Malaysia

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Abstract This study was carried out to determine the flux of nutrients and heavy metals from the Melai sub-catchment into Lake Chini through the process of erosion. Melai River is one of the seven feeder rivers that contributed to the present water level of Lake Chini. Three properties of soils, such as particle size, organic matter content, and soil hydraulic conductivity and three chemical soil properties, such as available nutrients, dissolved nutrients, and heavy metals, were analyzed and interpreted. Potential soil loss was estimated using the revised universal soil loss equation model. The results show that the soil textures in the study area consist of clay, silty clay, clay loam, and sandy silt loam. The organic matter content ranges from 3.40 to 9.92 %, while the hydraulic conductivity ranges from 5.2 to 25.3 cm/h. Mean values of available P, K, and Mg amount was 8.5 ± 3.7 µg/g, 24.5 ± 3.4 µg/g, and 20.7 ± 18.6 µg/g, respectively. The highest concentration of soluble nutrients was SO_4^{-2} (815.8 ± 624.1 µg/g), followed by NO_3^{-}-N (295.5 ± 372.7 µg/g), NH_4^{+}-N (24.5 ± 22.1 µg/g) and PO_4^{3-} (2.0 ± 0.8 µg/g). The rainfall erosivity value was 1658.7 MJ mm/ha/h/year. The soil erodibility and slope factor ranges from 0.06 to 0.26 ton h/MJ/mm and 7.63 to 18.33, respectively. The rate of soil loss from the Melai sub-catchment in the present condition is very low (0.0028 ton/ha/year) to low (18.93 ton/ha/year), and low level flow of nutrients and heavy metals, indicating that the Melai River was not the contaminant source of sediments, nutrients, and heavy metals to the lake.

Keywords Heavy metals · Melai river sub-catchment · Nutrient · Soil erosion · Soil loss

Introduction

Without vegetation cover, the soil surface can be severely eroded by heavy rain or rainstorms (Batie 1983). Because vegetation offers natural protection from the direct impact of rainfall, it can markedly reduce the amount of material eroded from the soil surface. The degree of soil erosion is relatively higher in dipterocarp hill forests compared with lowland areas (Baharuddin 1988) or other land uses (Lopez et al. 1998). Bower (2010) highlighted the processes between natural resources, urbanization and their impact to the environment. Karageorgis et al. (2012) studied the degree of contamination of the sediments, major and minor elements from deltaic plain of the Messolonghi lagoon complex, Greece. Yang et al. (2003) added that the potential for soil erosion varies with different land uses and climates. Numerous studies have been performed on soil erosion; for example, Mohd Ekhwan et al. (2009) compared the processes and effects of infiltration, runoff, and erosion on the soil loss of irrigated land. Srivastava et al. (2010) carried out a study on six different experimental plots with the intention to conserve water and soil erosion along the riparian zone at their study area. Bhattarai and Dutta (2007) and Xu et al. (2008) adopted the revised universal soil loss equation (RUSLE) and GIS model approaches for their analysis of soil loss. Finally, Foster et al. (1981) conducted a study in

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which they converted the RUSLE equation units into meters, while Lee and Lee (2006) used the remotely sensed geospatial technic to estimate soil loss.

Lake Chini consists of seven feeder rivers, among which is the Melai River sub-catchment (Muhammad et al. 2009). The Melai River is located to the south of the lake, and it drains directly into the Lake Chini. According to Sujaul (2009), the Melai River sub-catchment covers approximately 395.72 ha. Through field investigation, the major land uses in this sub-catchment can be categorized into rubber plantation, forest, mining, oil palm plantation, and the settlement of indigenous people. The rubber plantation consists of mature trees, and the forest is a secondary forest. The oil palm plantation and the settlements of the indigenous people are located in the former rubber plantation area. A study by De Neergaard et al. (2008) showed that the management of oil palm plantations involves the use of chemicals such as fertilizers and pesticides, which contribute to the increase of heavy metal flux into open water. Illegal mining activities were prominent during the study period. These activities contributed significantly to the decline of water quality in Lake Chini due to the presence of nutrients and heavy metals. Thus, the main aim of this study is to quantify the amount of nutrients and heavy metals flowing into Lake Chini through the soil erosion of the Melai River sub-catchment. The objectives of this study are (1) to determine the physical and heavy metal properties of the soil, (2) to calculate the amount of soil loss, and (3) to identify the concentration of nutrients and the flow of heavy metals.

Materials and methods

The study is in the Chini territory under Pekan district of the Pahang state, Malaysia. It is the cover catchment of the Melai River, which is at the southern part of Lake Chini (Fig. 1). The Melai River is one of the seven feeder rivers that drains directly into Lake Chini, which is approximately 53 m above sea level. There are logging, iron ore mining, and oil palm activities carried out by local residents at the Melai Village upstream of the catchment. Previously, mining was carried out by an appointed mining company, but abandoned once the Government terminated their contract. Selection of sampling stations is based on topography, contour gradient, and type of land use. Soil samples were collected from four sampling locations within this catchment area, five replicates from each station bearing a total of 20 soil samples, which were taken to the lab for further analysis. In situ parameters were observed and noted in the field based on the coordinates of the sampling stations, their canopy cover and the natural conservation practices. The potential soil loss through erosion was calculated for this area using the RUSLE model.

The particle size distribution, organic matter content, hydraulic conductivity, heavy metal, and nutrient contents were determined for the soil samples. Particle size was determined using the pipette method with slight modification (Abdulla 1966). The organic matter content was determined using the gravimetric method (Avery and Bascomb 1982), and the hydraulic conductivity was determined using the falling head method described by Kirkby (1980). The heavy metals were extracted using the wet digestion method with nitric acid with perchloric acid at 3:1 ratio. The available nutrients in the soil were extracted using the double acid extraction method with a mixture of ammonium acetate and acetic acid. The heavy metals in the solution extract were determined using the atomic adsorption spectrophotometry flame technique (AAS) using a 3300 PERKIN ELMER 1967 instrument. The concentration of NO_3-N was determined by the cadmium reduction method (APHA 1989). The prediction of soil losses was based on rainfall intensities in agricultural areas (Wischmeier and Smith 1965; Wischmeier et al. 1971) and on orthophosphate using the molybdenum blue method developed by Murphy and Riley (1962).

Results and discussions

Soil organic matter

As a binding agent, organic matter is important in the formation of soil aggregates. Organic matter binds to the clay component, producing an even stronger soil structural stability. Organic matter decomposition produces humic chemicals that interact with clay, thus increasing the binding strength of particles. The formation of good and strong soil aggregates enhances water infiltration through the soil profile, thus reducing surface water flow, which causes erosion. The organic matter content data shown in Table 1 ranges from 3.40 to 9.92 %, indicating a higher content at Station 4 followed by Stations 1, 3, and 2. Stations 1 and 4 each have high clay contents, which can produce strong binding with the organic matter. Station 2, which has the lowest content of organic matter, was a rubber tree plantation where the trees were widely spaced when planted, thus producing low canopy cover. According to Morgan (2005), soil with less than 3.5 % organic matter content is considered weakly aggregated and is easily eroded. Variance analysis indicates a significant difference in organic matter content at the 5 % level among the stations.

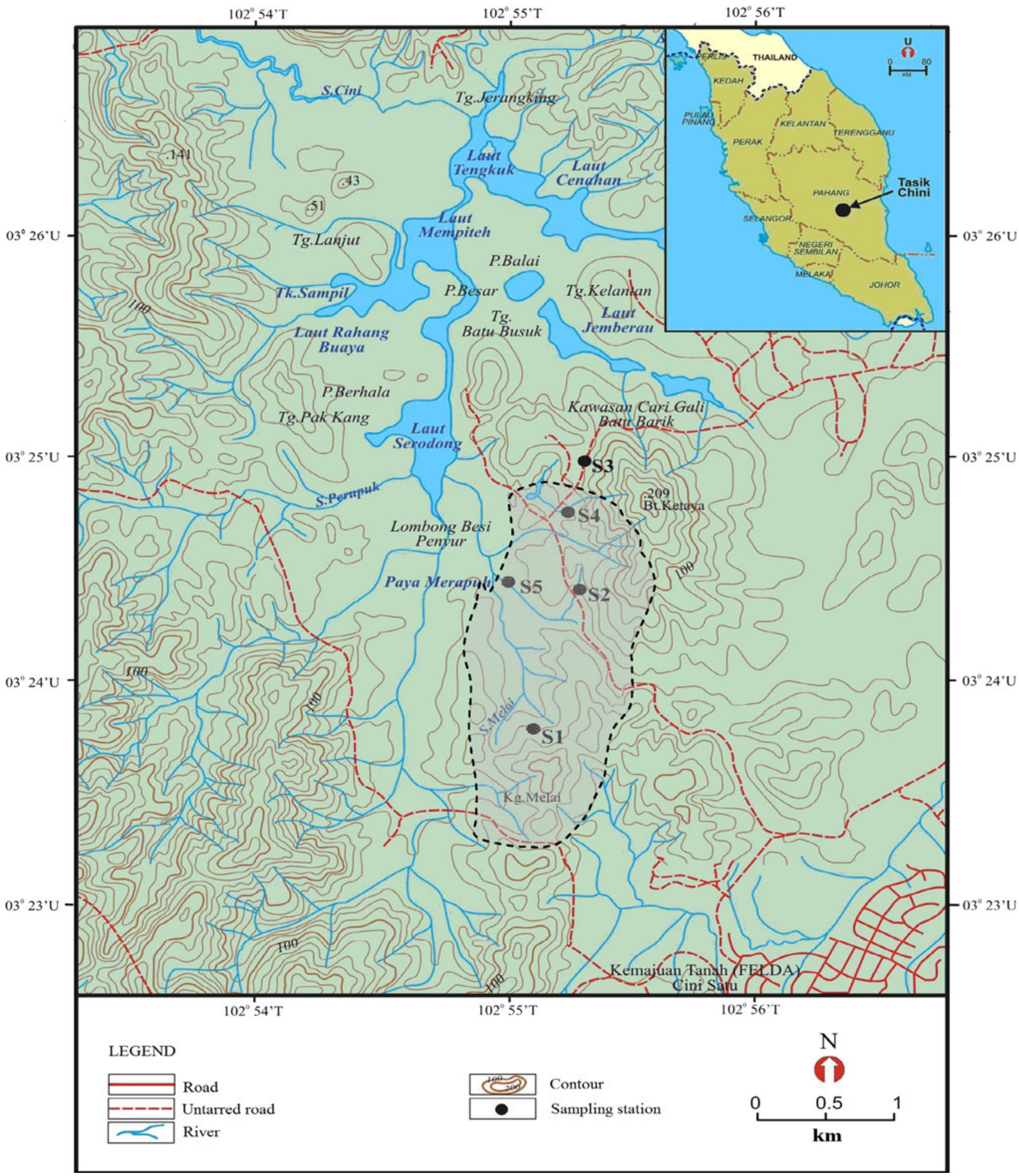

Fig. 1 Map showing the sub-catchment of Melai River and sampling stations

Soil texture

In Table 1, the soil particle size is dominated by the clay fraction at Stations 1 and 4 but is dominated by the silt fraction in Stations 2 and 3. Station 1 recorded the highest clay content, followed by Stations 4, 2, and 3. The silt fractions are approximately the same at Stations 2, 3, and 4 but are lower than at Station 1. The dominant soil texture is clay, followed by clay loam, silty loam, silty clay, and sandy silt loam.

Table 1 Organic matter contents, size distributions and texture of soils

Station	Organic matter (%)	Mean (%)	Sand (%)	Silt (%)	Clay (%)	Texture
1	7.05	7.59 ± 0.58	20	33	47	Clay
Forest	7.51		10	25	64	Clay
	8.20		10	22	68	Clay
2	2.59		17	46	37	Silty clay
Rubber	4.20	3.40 ± 0.81	24	42	34	Clay loam
	3.42		23	43	34	Clay loam
3	7.03		43	43	15	Sandy silt loam
Former mine rubber	7.67	7.17 ± 0.45	18	76	7	Silty loam
	6.81		18	31	51	Clay
4	9.23		23	37	40	Clay
Forest	13.83	9.92 ± 3.6	19	40	41	Clay
	6.70		21	38	42	Clay

Hydraulic conductivity

Hydraulic conductivity is a measurement of the ease of water infiltration downward during rainfall. A higher soil hydraulic conductivity is essential for reducing the surface water movement that causes erosion. The hydraulic conductivity in the study area ranges from 5.2 to 25.3 cm/h. Due to the higher sand content, high hydraulic conductivity was recorded at Station 3 (Fig. 2). Hydraulic conductivity is influenced by soil texture, clay minerals, and bulk density. Coarsely textured soils, such as sand and loamy sand, have open pore spaces and are able to drain water faster and more readily (Bocco 1991). Organic matter content is another factor that contributed to the high hydraulic conductivity of Station 3, which had slightly higher concentrations than the other stations.

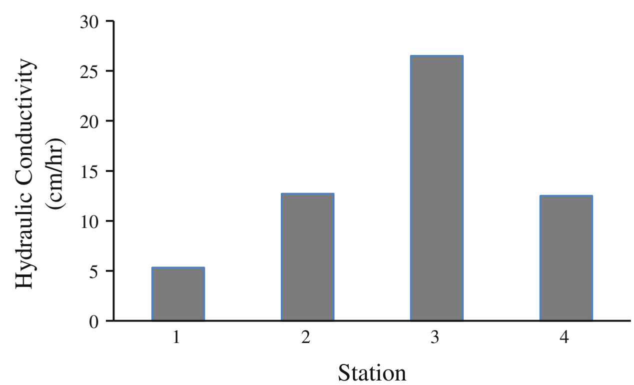

Fig. 2 Hydraulic conductivity of the soil in the study area

Available nutrients

Available nutrient content represents the amount of nutrients in the soil that can be utilized for plant growth. Available nutrients are essential and are normally supplemented through plant fertilization. The fertilizers commonly used include nutrients such as N, P, K, Ca, and Mg. Only the available P, K, and Mg were measured in this analysis. In Fig. 3, the mean concentration of K is the highest (24.5 ± 3.4 μg/g), followed by Mg (20.7 ± 18.6 μg/g), and P (8.5 ± 3.7 μg/g).

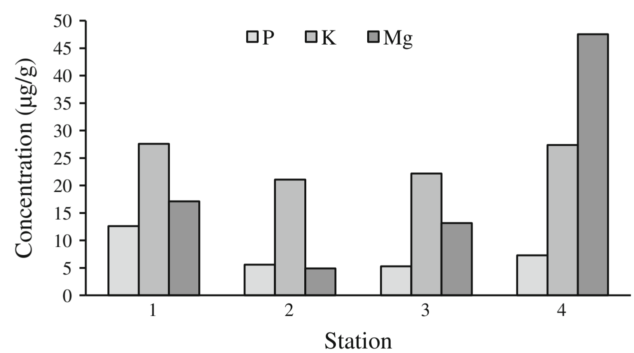

Fig. 3 Available nutrient contents in soil

The potassium content in the soil is relatively constant for all four sampling stations, as indicated by the low SD values. The variance test shows that there are no significant differences among the stations. High amounts of K can be contributed to soils by the weathering of minerals that contain K, such as feldspar and mica. The element is then absorbed and held by organic matter at their exchange base (Fortescue 1979) and is released as an available nutrient. There is a wide variation in the mean concentrations of Mg, as indicated by its SD, which was significantly different among the stations at the 1 % level. The highest mean concentration is found at Station 4, followed by Station 1; the soils of both stations are under forested land use. The magnesium content in the sedimentary rocks is naturally high, with an average content of approximately 0.5 % (Sujaul 2009).

Soluble nutrients

Some fractions of the soil nutrients are present in the soluble form. Soluble nutrients are easily transported and are therefore a potential contaminator of bodies of water. As shown in Table 2, SO_4^{-2} is the most soluble nutrient, with a mean and SD of 815.8 ± 624.1 μg/g. SO_4^{-2} is followed by NO_3^--N, with a mean and SD of 295.5 ± 372.7 μg/g; NH_4^+-N, with a mean and SD of 24.5 ± 22.1 μg/g; and PO_4^{3-}, with the lowest mean and SD of 2.0 ± 0.8 μg/g. Station 1 recorded the highest concentration of all of the soluble nutrients; however, the SD is too high, indicating the presence of an anomaly in the sampling substation. It is, however, valid to include any possible variation at a sampling station. Due to the high SD, there are no significant differences in the particular nutrient concentrations among the stations, with P values of 0.133, 0.107, 0.124, and 0.091 ($p > 0.05$) at Stations 1–4, respectively. The higher N than P concentration indicates the importance of the N component in organic matter, which is more readily leached from the soil than P.

Soluble PO_4^{3-} presents the lowest concentrations at the sampling stations, which can be attributed to its low solubility in the soil. The solubility of soil is influenced by soil pH. PO_4^{3-} is more soluble in soil with a pH between 5.5 and 7, and its solubility decreases when the pH falls below 5.5 or exceeds pH 7. At low pH, PO_4^{3-} reacts with Fe and aluminum to form a complex that fixes the PO_4^{3-} (Tisdale and Nelson 1975).

Heavy metals content

Table 3 shows that Mn represents the highest heavy metal concentration in the soil, followed by Pb, Cr, Cu, Co, and Cd. The highest concentration of Mn is found at Station 3, with a mean and SD of 932.93 ± 65.39 μg/g, and the lowest level is at Station 2, with a mean and SD of 18.05 ± 2.40 μg/g. A high Mn concentration is normally associated with the formation of secondary iron ore in the form of goethite nodules. High Pb concentrations are also recorded at Station 3, with a mean and SD of 259.71 ± 76.89 μg/g, while the lowest is found at Station 4, with a mean and SD of 30.0 ± 5.86 μg/g. The mean at Station 3 is already within the range of the critical concentration proposed by Kabata-Pendias and Pendias (2001), at 100–400 mg/kg. Station 3 is a former iron mining area, where rock blasting and crushing were conducted to separate the iron from its ore. According to Sahibin et al. (2009), the blasting and crushing of rocks containing ore will produce heavy metals such as Mn, Pb, Cu, and Cd in the form of dust. This dust is eventually deposited on the surface of water bodies and soil, leading to the risk contamination.

The heavy metals Cr, Cu, Co, and Cd were found to be within the normal concentrations in soils (Kabata-Pendias and Pendias 2001). The copper and Co concentrations are high at Station 3. These high values are associated with the former iron mining activities. These metals probably precipitated together with Fe and Mn during the formation of the iron concretion.

Soil loss prediction (RUSLE)

Soil loss prediction for the study area was carried out with the widely used RUSLE soil erosion model. With this model, the amount of soil loss (A) can be obtained by measuring five key factors: rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), plant cover (C) and conservation practice (P). The RUSLE equation model is as follows: $A = R.\ K.\ \mathrm{LS}.\ C.\ P.$

Erosivity factor (R)

Rainfall data collected from the FELDA Chini 2 rainfall station were used to calculate rainfall erosivity for the

Table 2 Soluble nutrient content in soil of the study area (μg/g)

Station	PO_4^{-3}	SO_4^{-2}	NO_3^-	NH_4^+–N
1				
Mean	1.65	1743.33	850.00	57.67
SD	0.64	1220.22	795.32	42.02
2				
Mean	1.51	590.00	149.00	14.20
SD	0.22	75.50	55.51	4.07
3				
Mean	1.60	540.00	44.00	11.80
SD	0.28	353.69	10.54	11.10
4				
Mean	3.23	390.00	139.00	14.40
SD	1.14	180.00	54.44	2.95

Table 3 Heavy metals content in soils (μg/g)

Station	Mn	Pb	Cr	Cu	Co	Cd
1						
Mean	108.23	36.04	27.95	12.74	9.82	1.51
SD	31.90	18.23	5.82	3.80	7.17	0.26
2						
Mean	18.05	30.16	3.61	2.59	9.02	0.91
SD	2.40	8.68	0.88	1.08	1.43	0.28
3						
Mean	932.93	259.71	18.94	50.25	13.99	1.32
SD	65.39	76.89	1.89	9.43	2.41	0.32
4						
Mean	185.19	30.00	6.08	2.16	9.62	1.16
SD	172.96	5.86	0.35	1.05	1.85	0.71

Tasik Chini area. The mean annual rainfall calculated from 1997 to 2006 is 2125.7 mm. The formula used for this calculation is from Morgan (2005) and Roose (1977), the details of which are shown in Table 4. The value of mean rainfall (P) was inserted into the formula, and the best estimated value of rainfall erosivity was obtained, which is 1327.9 MJ mm/ha/h/year.

Table 4 Rainfall erosivity calculated for Tasik Chini

Method	Formula (in metric unit)	R value (MJ mm/ha/h/year)
Morgan (2005)	$\frac{(9.28P-8838)\times 75}{1000}$	816.6
Roose (1977)	$0.5P \times 1.73$	1838.7
Best estimate		1327.9

Rainfall mean (P) = 2125.7 mm

Source: FELDA Chini 2 rainfall data for observation period from 1997 to 2006

Erodibility factor (K)

The erodibility factor is calculated using the nomograph formula given below. The erosivity values were produced using this formula (Table 5). The soil erodibility factor ranges from 0.01 to 0.19/MJ/mm. The highest erodibility factor is found at Station 2, followed by Stations 3, 4, and 1. The high erodibility factor at Station 2 can be attributed to the combined effect of the soil texture with a low percentage of organic matter.

$$K = \frac{\left(2.1\times 10^{-4}(12-\mathrm{OM}\%)(N_1\times N_2)^{1.14}+3.25(\mathrm{S}-2)+2.5(P-3)\right)}{100}$$

Slope length and steepness factor (LS)

The sampling station sites are in areas with different topographies. Station 1 is on a 36.4 % slope with a length of approximately 70 m; Station 2 is at 25.5 %, with a slope length of 100 m; Station 3 is at 18.2 %, with a slope length of 140 m; and Station 4 is at 28.3 %, with a slope length of 90 m. The slope lengths and steepness factors (LS), calculated using the formula as shown below, are 18.3 for Station 1, 11.5 for Station 2, 7.6 for Station 3, and 13.2 for Station 4 (Table 6). It is obvious that the high LS factor for Station 1 is due to the degree of steepness.

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

Land canopy cover (C)

The field observations indicate closed canopy coverage in the forested areas at Stations 1 and 4. The ground is covered by a litter layer together with undergrowth. Stations 2 and 3 are both matured rubber plantations; however, they have no closed canopy cover. In addition, there is lesser litter layer on the ground at Stations 2 and 3 compared with 1 and 4. The assigned CP value for Stations 1 and 4, which have a closed canopy cover of forested area, based on

Table 5 Erodibility factor of soil (*K*)

	N_1		N_2				
Station	Z + VFS (%)	CS (%)	Z + VFS + CS (%)	OM (%)	(S)	HC (cm/h)	K_{erod} t h (MJ mm)$^{-1}$
1	31.46	13.58	45.04	7.59	2	4	0.06
2	51.54	21.10	72.65	3.40	2	2	0.19
3	53.48	26.29	79.78	7.17	2	1	0.09
4	44.93	20.99	65.92	9.92	2	2	0.01

Z silt, *CS* coarse sand, *VFS* very fine sand, *OM* organic matter, *HC* or *P* hydraulic conductivity, K_{erod} erodibility rate, *S* soil structure

Table 6 Slope length and steepness (LS) factor of the study area

Station	Slope length (L) (m)	Steepness (S) (%)	LS
1	70	36.4	18.3
2	100	25.5	11.5
3	140	18.2	7.6
4	90	28.3	13.2

Source: Morgan (2005)

Roslan and Tew (1997), is 0.010. For Stations 2 and 3, the *C* value for rubber plantations, based on Morgan (2005), is 0.2. The individual *C* factor for forested areas is 0.001–0.002 (Morgan 2005).

Conservation practice (P)

Natural conservation practices in forested areas that aim for erosion control greatly depend on the existing environmental conditions. Examples of these conditions are the litter layer, which acts as a cover protecting the soil from the impact of direct rainfall; the rooting system, which helps to bind the soil; and canopy cover and undergrowth, which reduce the surface movement of particulates. In forested areas, the conservation factor is $P = C \times 0.15$, where *C* is the plant canopy value. In rubber plantations, certain mechanical soil conservation measures are practiced, including contouring multiplied by 0.6, contour stripping multiplied by 0.35, and terracing multiplied by 0.15 (Morgan et al. 1982). The rubber trees in the study area were planted according to the contour stripping method. The *P* value assigned for this practice is $P = C \times 0.35$.

Predicted soil loss

The amount of predicted soil loss (Table 7) within the catchment of Melai River is considered low to very low according to the Malaysian soil loss tolerance guidelines. The range of soil loss in the study area is 0.00003–40.62 t/ha/year. The higher soil loss at Station 2 is due to the combined effect of high soil erodibility and a lack of canopy and ground cover. This station is located on the dumping ground of a former mining area. Station 2 has the highest predicted soil loss, followed by Stations 3, 1, and 4.

Available nutrient flow

The concentration of available nutrients (Table 8) in the sampled soils is low; therefore, the amount of nutrient flow from the Melai sub-catchment into Lake Chini is expected to be low. The P and K concentrations are fairly consistent, but there is a wide variation in Mg among the stations. The highest amount of nutrient flow into Lake Chini is from Station 2, followed by Stations 3, 1, and 4. The total amount of P, K, and Mg flow from this sub-catchment is 81.8 g/ha/year, 1140.0 g/ha/year, and 367.2 g/ha/year, respectively.

Soluble nutrient flow

The total soluble nutrient flow into the lake is high at Stations 2 and 3, but relatively low at Stations 1 and 4. In terms of individual nutrients, SO_4^{2-} is the highest, followed by NO_3^--N, NH_4^+-N, and P, with values of 30860.0 g/ha/year, 6614.3 g/ha/year, 727.5 g/ha/year, and

Table 7 Predicted soil loss (*A*) within the catchment of Melai River (t/ha/year)

Station	*R*	*K*	LS	*C*	*P*	*A*
1	1327.9	0.06	18.33	0.001	0.00015	0.0002
2	1327.9	0.19	11.53	0.20	0.07	40.62
3	1327.9	0.09	7.63	0.20	0.07	12.77
4	1327.9	0.01	13.19	0.001	0.00015	0.00003
Mean	1327.9	0.09	12.67	0.10	0.04	13.35

Table 8 Available nutrient flow from Melai sub-catchment to Lake Chini

Station	Nutrient in soil (μg/g)			Erosion rate (ton/ha/year)	Total nutrient flow (g/ha/year)		
	P	K	Mg		P	K	Mg
1	1.65	27.58	17.12	0.0002	0.0004	0.006	0.004
2	1.51	21.09	4.90	40.62	61.34	856.68	199.04
3	1.60	22.19	13.17	12.77	20.43	283.28	168.13
4	3.23	27.37	47.54	0.00003	0.0001	0.001	0.001
Total	8.0	98.2	82.7	53.4	81.8	1140.0	367.2

Table 9 Total of soluble nutrient flow to the lake

Station	Nutrient in soil (μg/g)				Soil loss (ton/ha/year)	Total nutrient flow (g/ha/year)			
	PO_4^{3-}	SO_4^{2-}	NO_3^--N	NH_4^+-N		PO_4^{3-}	SO_4^{2-}	NO_3^--N	NH_4^+-N
1	12.60	1743.33	850.00	57.67	0.0002	0.003	0.38	0.19	0.01
2	5.60	590.00	149.00	14.20	40.62	227.47	23965.9	6052.40	576.81
3	5.30	540.00	44.00	11.80	12.77	67.66	6893.7	561.71	150.64
4	7.30	390.00	139.00	14.40	0.00003	0.0002	0.010	0.004	0.0004
Total	30.8	3263.3	1182.0	98.1	53.4	295.1	30860.0	6614.3	727.5

Table 10 Heavy metals flow from Melai sub-catchment area to Lake Chini

Station	Heavy metals in soil (μg/g)						Erosion rate (ton/ha/year)	Total heavy metals flow (g/ha/year)					
	Mn	Pb	Cr	Cu	Co	Cd		Mn	Pb	Cr	Cu	Co	Cd
1	108.23	36.04	27.95	12.74	9.82	1.51	0.0002	0.024	0.008	0.006	0.003	0.002	0.0003
2	18.05	30.16	3.61	2.59	9.02	0.91	40.62	733.19	1225.10	146.64	105.21	366.39	36.96
3	932.93	259.71	18.94	50.25	13.99	1.32	12.77	11909.85	3315.48	241.79	641.49	178.60	16.85
4	185.19	30.00	6.08	2.16	9.62	1.16	0.00003	0.0049	0.0008	0.0002	0.0001	0.0003	0.00003
Total	1244.4	355.9	56.6	67.7	42.5	4.9	53.4	12643.1	4540.6	388.4	746.7	545.0	53.8

295.1 g/ha/year, respectively. Based on Table 9, the PO_4^{3-} flow into the lake is the highest from Station 2 and the lowest from Station 4, with values of 227.47 g/ha/year and 0.003 g/ha/year, respectively. The SO_4^{2-} flow is the lowest from Station 4, at 0.010 g/ha/year, and the highest at Station 2, at 23,965.9 g/ha/year. Station 2 has the highest total flow of NO_3^- into the lake, which is at 6,052.40 g/ha/year, while Station 4 has the lowest, at 0.004 g/ha/year. The flow of NH_4^+-N followed the same trend as NO_3^--N, where Station 2 had the highest, at 576.81 g/ha/year and Station 4 had the lowest, at 0.0004 g/ha/year. In general, the total nutrient flow into the lake is influenced by the rate of soil loss from the sub-catchment.

Heavy metals flow

The heavy metals content in the soil is shown in Table 10. Mn has the highest concentration in the soil, followed by Pb, Cu, Cr, Co, and Cd. Station 3 shows a high concentration of all studied heavy metals. Stations 3 and 2 show a higher amount of nutrient flow into Lake Chini compared with Stations 1 and 4. In terms of individual heavy metals, the highest concentration of nutrient to flow into the lake is Mn, followed by Pb, Cu, Cr, Co, and Cd. The high concentration of Mn is due to its naturally high content in the parent material in addition to its coprecipitation with Fe in weathered soils, which increases its concentration during the formation of oxide and oxyhydroxide. Higher rates of soil loss also contribute to higher amounts of heavy metal flow into the lake.

Conclusions

The estimated soil loss (*A*) in the Melai sub-catchment is generally low due to low human activity; most the study area is covered by forested land use and most of the soil texture consists of clayey soil. Station 1 recorded the highest soluble nutrients in the soil, while Station 3 was the highest heavy metals. As an order the highest soil loss was from Station 2, rubber plantation, followed by Station 3, rubber and former mine, and the lowest was at Stations 1 and 4, forest cover areas.

Overall, total flow of nutrients and heavy metals from the Melai sub-catchment into Lake Chini is expected low due to the low rate of soil loss. Low discharge of soluble nutrients and heavy metals due to minor land use activity in the study area showed that Melai River is considered as a stable sub-catchment for the present time.

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