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Prediction of Soil and Nutrient Losses from the Lake Chini Watershed, Pahang, Malaysia

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Abstract: *Watersheds in tropical regions are frequently subjected to soil erosion and transportation of chemicals downstream. Any drastic change in land use and land cover would increase the process of land degradation. For this study, the Revised Universal Soil Loss Equation (RUSLE) was used to predict the average annual soil loss. The prediction of annual nutrient (phosphorus, potassium and magnesium) loss caused by soil erosion processes using RUSLE was also conducted. Soil and nutrient movements associated with several alternative methods of land use were studied. The rainfall erosivity (R), topographic factor (LS), land cover (C) and management factor (P) values were calculated from rainfall data together with the use of topographic and land-use maps. Soil was analysed to obtain the soil erodibility factor (K). Physical properties, such as particle size distribution, texture, hydraulic conductivity and organic matter (OM) content, were analysed to support the erosion rate analysis. The mean soil erodibility factors varied from 0.03 to 0.30 ton h* MJ^{-1} mm^{-1}*. The annual soil loss in the study area ranged from 0.10 to 180.49 ton* ha^{-1}*. Nutrient losses of phosphorus, potassium and magnesium were investigated in the study. Run-off and sediments were also analysed for these elements. The annual loss of phosphorus ranged from 0.003 to 3.23 kg* ha^{-1}*, potassium from 0.10 to 8.38 kg* ha^{-1} *and magnesium from 0.003 to 2.83 kg* ha^{-1} *in the study area. A small quantity of phosphorus was present in the soil, and thus, phosphorus losses were low. The findings of the present study will help in the formulation of better conservation and management options for future land-use patterns of the Lake Chini watershed.*

Keywords: Erosivity, erodibility, soil erosion, nutrient losses, Lake Chini watershed

1. INTRODUCTION

Soil erosion is considered one of the most important forms of soil degradation worldwide.[1] Soil erosion has been accepted as a serious problem arising from agricultural intensification, land degradation and possibly, global climatic changes.[2,3] Disturbance by human activities further aggravates the soil

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erosion process, especially on steep slopes. Highland watersheds, when converted for agriculture and other activities, face high risks of soil erosion and nutrient depletion. Soil erosion and loss of soil nutrients are repeatedly mentioned as a global threat to the environment and food supply.[4,5] Soil erosion and nutrient losses are accelerated by timber harvesting, changes in land-use patterns, soil type, annual rainfall and topographic conditions of the watershed. Large volumes of nutrient and suspended sediment inputs have led to the degradation of aquatic habitats due to declining water quality.[6–8]

In Malaysia, soil erosion and nutrient losses have become an important environmental problem in recent years, especially in areas where intensive use of land for development, including urbanisation 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 a tremendous impact on the communities within 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,[9] Salleh et al.,[10] Baharuddin[11] and De Neergaard et al.[12] Soil erosion affects not only the soil productivity of the upland fields but also the water quality of the streams in the watershed areas. Severe eutrophication 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.

The Lake Chini watershed has undergone a rapid economic development over the last decade. Land-use activities in the areas surrounding Lake Chini have transformed these areas from forests to agricultural and ecotourism areas, mines and settlements. These developmental activities have significantly affected the ecological, biological and hydrological functions of the lake system. Logging activities in the steep areas have also created serious environmental and ecological problems. The rates of erosion, nutrient losses and sedimentation have subsequently increased because of these changes. The chemical influx of pesticides and fertiliser 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 types of surface erosion have occurred around Lake 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 watershed over the years have resulted in erosion, nutrient losses and sedimentation of the Lake Chini watershed, thereby depleting the lake of its original aquatic and terrestrial biodiversity. Therefore, the objectives of this study were to predict the erosion rate and describe the delivery of nutrients to Lake Chini based on erosion observations, and to explain the extent of the environmental deterioration in the lake.

2. EXPERIMENTAL

2.1 The Study Area

Lake Chini is located in the south-eastern region of Pahang, Malaysia and is situated approximately 100 km from Kuantan, the capital of Pahang. The lake system lies from 3°22′30″ to 3°28′00″N and 102°52′40″ to 102°58′10″E, comprises 12 open water bodies (referred to as "laut" by the local people) and is linked to the Pahang River by the Chini River (Figure 1). A few communities of the indigenous Jakun tribe live around the lake. Lake Chini is the second largest natural fresh-water lake in Peninsula Malaysia, encompassing 202 ha of open water, as well as 700 ha of Riparian Peat and Lowland Dipterocarp forest.[13] Lake Chini is surrounded by various 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 to the south-east; (2) Bt. Tebakang (210 m) located to the north; and (3) Bt. Chini (641 m) located to the south-west.

The study area has a humid, tropical climate with two monsoon periods, the south-west and north-east monsoons, characterised by a bimodal pattern and producing an annual rainfall of between 1,488 mm and 3,071 mm. The mean annual rainfall is 2,500 mm, and the temperature range is from 21°C to 32°C. Potential evapotranspiration (PE) is between 500 mm and 1000 mm. The open water area has expanded since 1994 as a result of increased water retention after the construction of a barrage downstream of the Chini River. The lake drains north-west into the Pahang River via the Chini River, which meanders for 4.8 km before reaching the Pahang River.

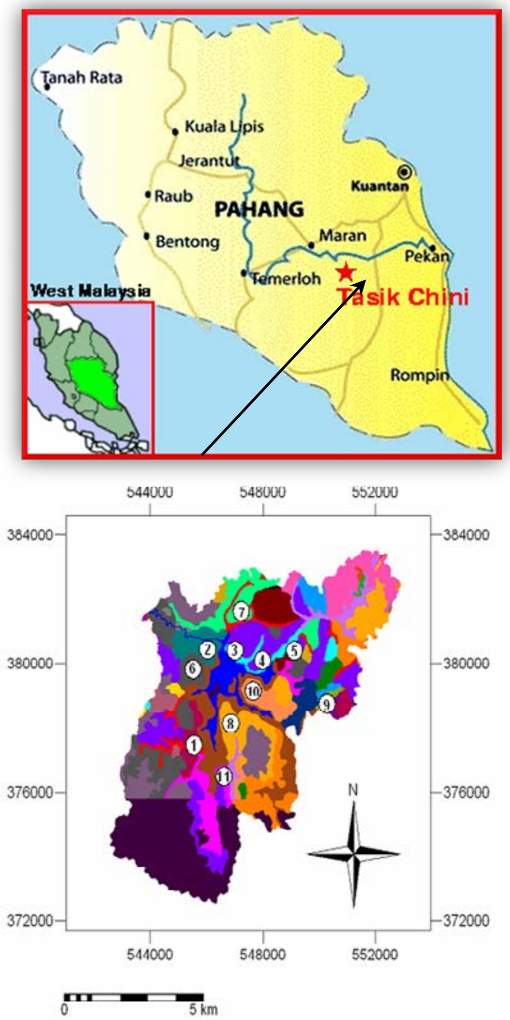

Figure 1: Location of sampling stations in and soil types in the study area, with the numbered circles indicating stations (source: Department of Agriculture, Malaysia).

2.2 Methodology

Soil sampling was carried out at selected sampling stations located around the Lake Chini watershed (Figure 1). The 2006 monthly rainfall data were obtained from the Felda Chini Dua Climatology Station, Pahang. Physical conditions such as slope, plant cover and conservation practices were considered when selecting sampling stations. Geographic information system (GIS) software was used in spatial data analysis to determine the erosion potential and spatial distribution of the study area. The study area was digitised using Ilwis 3.3 (developed and distributed by ITC Enschede International Institute for Geo-information Science and Earth Observation in the Netherlands) and topographic and land-use maps for the soil series. A soil map was obtained from the Malaysian Department of Agriculture for the measurement of the soil erodibility factor using Revised Universal Soil Loss Equation (RUSLE). Topographic and land-use maps of the study area were used as the basis for determining the LS, C and P factor values. The particle size distribution was determined by the pipette method together with dry sieving.[14] The texture of the soils was obtained by plotting the percentage ratio of sand, silt and clay using the soil texture triangle.[15] The organic matter content was determined by weight loss using the ignition technique. Nutrient (phosphorus, potassium and magnesium) losses were also measured using RUSLE. RUSLE is commonly used worldwide to predict the nutrient losses accompanying soil erosion.

Previous studies reported that the accuracy of the soil and nutrient loss prediction models depends on the proper parameter values. RUSLE was chosen over other methods due to its easy implementation, reliance on easily available data and relatively accurate results.[16] Soil erosion and sediment yield were estimated for the year 2006 using RUSLE.[17] The formula for the RUSLE calculation is as follows:

$$A = R \times K \times LS \times C \times P$$

where

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

2.3 Soil Erosion Factor Assessment

Some factors were required to utilise RUSLE[17] for the calculation of soil loss in the study area. The factors used in RUSLE, namely, R, K, LS, C and P, are described below.

2.3.1 Rainfall erosivity index (R)

The rainfall erosivity index (R) is the erosion potential of rainstorms expected in a given locality. It is related to the kinetic energy and intensity of the rain and is occasionally used synonymously with erosivity (E). The product of E_kI_{30} reflects the potential of rain to cause erosion, where E_k = total kinetic energy of rain and I_{30} = 30 min at peak intensity. The rainfall erosivity index was calculated based on the calculation of Morgan and Roose[1] in the following study. According to Morgan,[1] 2 R-values can be present in any area; therefore, the best estimate of the erosivity index for any study area will be an average of the 2 values calculated. Wischmeier and Smith[18] recommended a maximum intensity (I_{30}) value of 75 mm hr^{-1} 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[1]	$(9.28P - 8838.15) \times 75$ in metric unit	1108.11
Roose[36]	$P \times 0.5 \times 1.73$ in metric unit	2200.99
	Best estimation	1654.55

P is the total annual rainfall and was 2544.50 mm for the Lake Chini watershed in 2006. The best-estimate value of the R factor calculated for the study area was 1,654.55 MJ mm ha^{-1} h^{-1} yr^{-1}.

2.3.2 Soil erodibility index (K)

Soil erodibility is the ability of soil to be eroded by moving water and 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.[19,20] The K value of the soil in the study area was calculated using the following equation, as given by Foster et al.[21]

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

where

OM - the percentage of organic matter
N1 - the percentage of silt + very fine sand

N2 - the percentage of silt + very fine sand + sand (0.125 – 2 mm)
S - the soil structure code[22], and
P - the soil permeability class (hydraulic conductivity)[17]

For the estimation of soil erodibility or the values of the K factor in the study area, soil samples were collected and analysed for their organic matter content, hydraulic conductivity, particle size distribution and textural classification. Based on the relative proportions of sand, silt, clay and organic matter, the soil erodibility factor was estimated in ton h MJ^{-1} mm^{-1}. The mean K factor in the study area varied from 0.03 to 0.30 ton h MJ^{-1} mm^{-1}, producing an average and standard deviation of 0.16 ton h MJ^{-1} mm^{-1} and 0.02 ton h MJ^{-1} mm^{-1}, respectively. Statistical analysis indicated that the mean K value was significantly different ($P < 0.001$) among sampling stations (soil series).

2.3.3 Topographic factor (LS)

Within the RUSLE, the LS factor reflects the effect of topography on erosion, the slope length factor (L) represents the effect of the slope length on erosion, and the slope steepness factor (S) reflects the influence of the slope gradient on erosion.[23] The slope factor (LS) is combined with the slope gradient and the length of the eroding surface into a single factor. Under RUSLE, LS refers to the actual length of the overland flow path and 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 watershed areas where the overland flow seldom exists on hill slopes.[24,25]

The subsurface storm flow is more dominant than the overland flow in forested watershed areas, and the latter only exists in limited areas near the channel margins or on shallow soil as the return flow or saturated overland flow.[25] Consequently, the overland flow path in the forested watershed 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 (Figure 2). Upon obtaining the L and S values, the topographical factor (LS) values were calculated using the formula provided by Wischmeier and Smith,[18] and Kirkby[26]:

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

where

L - the slope length (m), and
S - the slope gradient (%)

The variation in value is caused by the variation in the gradient and length of the slope.

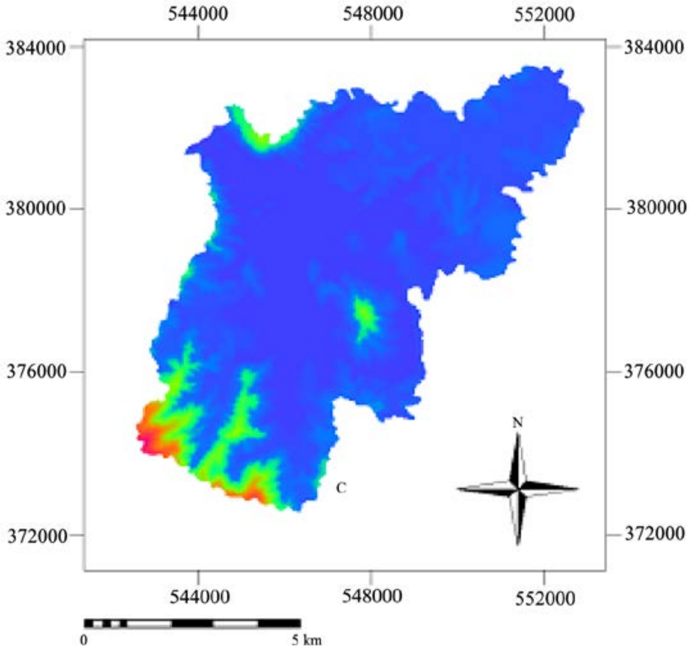

Figure 2: Digital elevation model (DEM) of the study area, where majority of the area lies within 20 and 108 m elevation, while a portion on the south western area falls within the 108–460 m range (source: Department of Agriculture, Malaysia).

2.3.4 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 forested regions.[17] The effectiveness of a plant cover for reducing erosion depends on the height and continuity of the tree canopy and the density of the ground cover and root growth. The vegetation cover intercepts raindrops and dissipates their kinetic energy before they reach the ground surface. The relative impact of management options can be easily compared by making changes in the C factor, which vary from near zero for well-protected land cover to one for barren areas.[27] The C values (Table 2) were extracted from the Morgan[1] estimates and assigned to the corresponding land cover based on the 2002 land-use map of the Malaysian Department of Agriculture (Figure 3).

Table 2: Crop practice and vegetation management factors for the studied watershed.

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

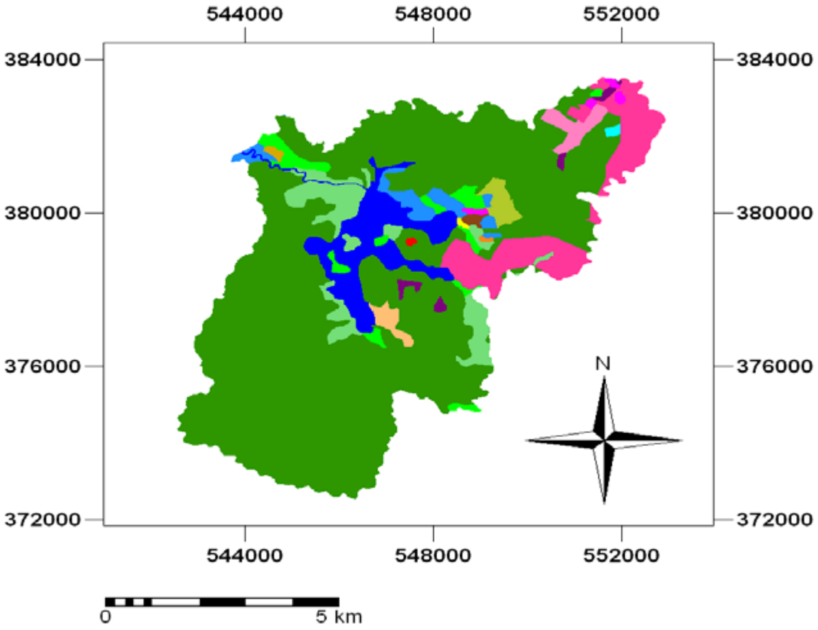

Figure 3: Land use map (2002) of the study area consisting of various uses including: diversified crops, forest, mining area, mixed horticulture, oil palm, orchards, shifting cultivation, paddy, rubber, scrub, scrub grassland, swamps and wetland forests, water, and urban and associated area (source: Department of Agriculture, Malaysia).

2.3.5 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.[17] Wischmeier and Smith[18] 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 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. The most common conservation practice in Malaysia is contour terracing in rubber and oil palm plantations. It was assumed that the contour terracing practice on slopes was carried out for both rubber and oil palm plantations in the present 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 3, while other agricultural activities were given a value of 1, assuming no conservation practices were adopted.

Table 3: P values with corresponding slope steepness for the Lake Chini watershed.

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

*Note: * means 50% of the value for contour bunds or if contour strip cropping was applied.*[18,36]

2.4 Sediment Collection and Nutrient Analysis

Surface runoff and soil loss were collected from the 11 installed erosion plots in the study area. Soil loss, suspended solids, phosphorus, potassium and magnesium in sediment were analysed in the laboratory. Runoff and sediment yield volumes were determined during the entire 2006 runoff season for the surrounding area of the lake. The soil samples were air dried, passed through a 2 mm sieve and, together with runoff, analysed for phosphorus, potassium and magnesium.[28] Phosphorus, potassium and magnesium were extracted by an ammonium acetate-acetic acid extractant and determined using Flame Atomic Absorption Spectrophotometer (FAAS).[29] Phosphorus was determined using an Ultra Violet Spectrophotometer (Helios Gamma 9423 UVG 1702E).

2.5 Statistical Analysis

The differences in nutrient losses at different stations were analysed using the analysis of variance (ANOVA). Data analyses were carried out using the SPSS (Version 15.0) statistical package. An independent t-test was used to compare the means of different variables.

3. RESULTS AND DISCUSSION

3.1 Rate of Soil Erosion

The calculation of soil erosion based on the RUSLE model showed that stations 1, 2, 6, 7 and 11 had low rates of soil loss, ranging from 0.10 to 4.23 ton ha^{-1} year^{-1}, with an average of 1.42 ton ha^{-1} year^{-1} (Table 4). Forested areas were mostly in the western and northern parts of the Lake Chini watershed, and human activities were localised in the eastern and southern regions. The steepest slopes were in the western and northern parts of the watershed. Relatively few steep areas were located in the eastern and southern parts of the study area. Stations 1, 2, 6, 7 and 11 were located in the forested areas with low C values (0.001) and very low erosion yields (< 10 ton ha^{-1} year^{-1}).

Shallow[30] also reported similar results for areas under natural forests in Malaysia, showing that most of the forested areas of the Lake Chini watershed were under the very low erosion risk category (71.54%) and were located in the western and southern parts of the study area. The soil loss tolerance rates[31] were prepared for standard evaluation of soil loss in the study area (Table 5). Stations 3 and 10 showed low rates of soil loss, ranging from 0.56 to 144.90 ton ha^{-1} year^{-1}, averaging 45.02 ton ha^{-1} year^{-1}. These stations were located in the rubber, settlement and forested areas; the value of the erosion yield was low.

Approximately 2.94% of the watershed was under low erosion risk (10–50 ton ha^{-1} year^{-1}), and this was mostly found in the eastern and southern regions of the watershed. Stations 4 and 9 had moderately high rates of soil loss, ranging from 1.25 to 100.46 ton ha^{-1} year^{-1}, averaging 57.55 ton ha^{-1} year^{-1}.

Table 4: Predicted average soil loss (ton ha^{-1} year^{-1}) from different land-use patterns using RUSLE (for the Lake Chini watershed).

Station	Soil series	Land-use pattern	Soil loss
1	Tebok	Secondary forest	0.65
2	Lating	Secondary forest	0.10
3	Serdang	Rubber plantation and forest	47.41
4	Kuala Brang	Rubber plantation and forest	57.16
5	Kedah	Rubber, oil palm and shifting cultivation	180.49
6	Bungor	Secondary forest	1.61
7	Kekura	Secondary forest	4.23
8	Malacca	Mining, oil palm and forest	130.26
9	Rasau	Oil palm plantation	57.93
10	Prang	Settlement and forest areas	42.62
11	Gong Chenak	Secondary forest	0.53

Table 5: Soil loss tolerance rates (erosion risk map of Malaysia).

Soil erosion class	Potential soil loss (ton ha^{-1} yr^{-1})
Very low	< 10
Low	10–50
Moderate high	50–100
High	100–150
Very high	> 150

Stations 4 and 9 were located under oil palm, rubber and forests, but the LS factor values for station 4 and the K values for station 9 were found to be higher than those of the other stations. Rubber plantations occupied 3.38% of the study area. Areas subjected to the human activities of the indigenous people were under the moderately high erosion risk class (50–100 ton ha^{-1} year^{-1}), and these were located nearest to the lake. Station 8 had a high rate of soil loss, ranging from 21.44 to 348.75 ton ha^{-1} year^{-1}, with an average of 130.26 ton ha^{-1} year^{-1}. Station 8 was located under oil palm, scrub, mining and forested areas based on the land-use map. Most of the Malacca soil series (station 8) were under oil palm plantations and had high erosion yield (100–150 ton ha^{-1} year^{-1}).

With regard to soil loss based on land-use types, high erosion risk (1.45% of the study area) was observed in the oil palm plantations and agricultural areas. These areas were located in the north-southern part of the study area. The worst-case scenario was observed for station 5, which had a very high erosion yield ranging from 79.99 to 319.75 ton ha^{-1} year^{-1}, with an average of 180.49 ton ha^{-1} year^{-1}. The C value for station 5 was considered very high (0.20) because it was located under rubber, oil palm and shifting cultivation areas. Soil analysis of the dominant patterns of land use and land cover areas showed that the very high soil loss (> 150 ton ha^{-1} year^{-1}) occurred in oil palm plantations, logging areas and reactivated mining areas located in the northern and eastern parts of the Lake Chini watershed (13.25%). Lopez et al.[32] mentioned that soil erosion varied with the land-use pattern, with the highest values occurring in areas of bare soil and the lowest in forested areas.

3.2 Nutrient Losses

Only phosphorus, potassium and magnesium losses were investigated in the current study. The predicted losses of the nutrients (as shown in Table 6) were studied to understand the deposition of nutrients into Lake Chini. The predicted value of phosphorus loss ranged from 0.003 to 3.23 kg ha^{-1} year^{-1}, with an average of 0.73 kg ha^{-1} year^{-1}. The highest and lowest values of phosphorus loss were recorded at stations 5 and 2, respectively. The results showed that phosphorus losses were significantly higher ($p < 0.001$) at certain stations.

Table 6: Estimated annual nutrient losses (kg ha^{-1}) at the study area.

Station	Land use	Soil texture	Phosphorus loss	Potassium loss	Magnesium loss
1	Forest	Clay	0.03	0.04	0.01
2	Forest	Clay	0.003	0.01	0.003
3	Rubber and forest	Clay loam	2.05	2.09	0.5
4	Rubber and forest	Clay	1.24	3.05	1.06
5	Rubber, oil palm and shifting cultivation	Clay loam	3.23	8.38	1.31
6	Forest	Clay loam	0.02	0.1	0.11
7	Forest	Sandy loam	0.04	0.16	0.06
8	Mining and oil palm	Clay	0.7	4.3	2.83
9	Oil palm	Sandy loam	0.38	2.84	1.41
10	Settlement and forest	Clay	0.25	1.82	1.03
11	Forest	Clay	0.01	0.03	0.02

Due to the small quantity of phosphorus in these soils, phosphorus losses were also low across all the stations. The study showed that high losses of nutrients occurred at stations 3 and 5, and this loss would in turn reduce the quality of surface water due to high phosphorus concentrations, which would stimulate the growth of algae and other aquatic weeds. The value of potassium losses ranged from 0.01 to 8.38 kg ha^{-1} year^{-1}, with an average of 2.08 kg ha^{-1} year^{-1}. The potassium losses were significantly higher ($p < 0.001$) at certain stations. The levels of potassium losses were also found to be high at station 5 and low at station 2. Higher potassium losses were recorded at stations 4 and 5 due to different land-use activities. The value of magnesium losses ranged from 0.003 to 2.83 kg ha^{-1} year^{-1}, with an average of 0.76 kg ha^{-1} year^{-1}. The loss of magnesium was the highest at station 8 and the lowest at station 2. The magnesium losses were significantly higher ($p < 0.001$) at certain stations. The results indicated that nutrient losses were related to land-use patterns and the fertility status of the studied soils.

The amount of nutrients lost is also dependent on the fertility status of the soil and the abundance of a particular nutrient in the soil. Soils with a higher fertility status lose more nutrients, as the nutrient concentration in the soil is higher.[33] The elements occurring most abundantly in the studied soils were potassium followed by magnesium, while phosphorus occurred in the lowest content and thus showed the least loss. Yusop et al.[34] determined that the annual normal loss rates of potassium, magnesium and phosphorus for the natural forested tropical soil at Bukit Tarek in Selangor, Malaysia ranged from 2.63 to 7.52 kg ha^{-1}, 1.61 to 3.35 kg ha^{-1} and 0.03 to 0.08 kg ha^{-1}, respectively. The accelerated soil erosion in the Lake Chini watershed was associated with an accelerated loss of considerable nutrients from the topsoil. It is apparent from the study that mining, human settlement and agricultural activities resulted in very high nutrient losses. A previous investigation at Cameron Highlands, Malaysia reported that nutrient losses were directly influenced by land-use practices and erosion rate.[35]

4. CONCLUSION

The RUSLE/GIS methodology was used to predict potential soil and nutrient losses in the Lake Chini watershed. Soil erosion and nutrient losses within the watershed varied spatially. The spatial distributions of different erosion-prone areas were identified in the watershed using the RUSLE method to successfully undertake erosion control measures in the severely affected areas. The rate of potential soil loss was very severe, especially in the mining, shifting cultivation and agricultural areas. In these areas, the soil erosion was higher than that listed by the Department of Environment (Malaysia) under the classification of severe soil loss, which was due to the high soil erodibility potential and the lack of conservation practices at the open surfaces. Human activities are the greatest threat to the Lake Chini environment. Fortunately, the environmental problems of erosion and sedimentation in the study area have already been recognised widely.

A major portion of the study area has been categorised under the low and very low erosion-prone class, and this includes a significant portion covered with forests and vegetation. Comparisons of watershed-scale erosion under different land-use configurations have also indicated that reforestation is one of the most effective ways to reduce soil erosion in this watershed. The amount of phosphorus, potassium and magnesium lost was significantly higher within the mining, settlement and agricultural areas than that within the forested areas. The amount of nutrients exported was higher during storms than when the flows were low.

Soil erosion and nutrient loss in the study area are expected to occur at a higher rate when illegal logging, removal of palm and rubber trees and replanting of new trees damage the forested area. Improper management practices in the study area have resulted in high erosion and high losses of important plant nutrients both inherent and applied. The productivity of the soils has thus been reduced, and production costs have increased as plant nutrient inputs have to be added as replacements. Furthermore, the lost nutrients have been channelled into rivers, dams and lakes, reducing the quality of the water. Therefore, precautionary measures should be taken with the key focus on soil and water conservation to control further soil and nutrient losses from the Lake Chini watershed. This study also indicates that relevant management practices and strategies should be adopted to control nutrient loss by soil erosion.

5. ACKNOWLEDGEMENT

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