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Estimation of soil loss using USLE and GIS: A case of Sembrong reservoir catchment, Johor, Malaysia

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Abstract

Soil erosion stems from a combination of agricultural intensification and soil degradation. Land surface deterioration is usually severe on bare soils as a vegetative cover is lost due to human activities. These include agricultural practices, urbanisation, or industrialisation. Soil loss caused accelerated on-site soil nutrient loss from farmlands in affected reservoir catchments. It could also result in accelerated off-site sediment accumulation erosion. Sediment yield from catchment areas upstream of the Sembrong Dam, Johor, Malaysia is the main contributor of sedimentation in the Sembrong reservoir. The soil loss prediction and sediment yield from eroding sources through the channel network to a basin outlet was carried out using an erosion model and a mathematical operator. The used tools could express the sediment transport efficiency of the hillslopes and the channel network. Based on this study, the estimated soil loss of the Sembrong catchment was low to moderate, at approximately 3.93 t/ha/year. The range of soil loss was between 0-12.35 t/ha/year, and more than 90% of the catchment areas were experiencing an erosion of less than 6 t/ha/year. Sediment contribution from the three catchments accounted for about 56% of the total sediment output of the Sembrong Dam. There was nearly a 44.1% increase in the sediment output at the outlet compared to the inlets, suggesting sediment sources nearby the reservoir.

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Keywords: Erosion; Land use; Sediment yield; Universal Soil Loss Equation (USLE); Sembrong Dam; Johor.

1. Introduction

Soil erosion is a critical issue caused by a combination of intense rainstorms, agricultural intensification, and soil degradation (Amore *et al*., 2004). Soil erosion is a global environmental problem responsible for nearly 85% of land degradation and lessening crop productivity by 17% (Wijesundara *et al*., 2018). Soil erosion is the most significant cause of off-site groundwater pollution worldwide, with most of the contaminants originating in an agricultural setting (Marsh and Grossa, 1996). Sediment eroded from the hillslopes will ultimately discharge into rivers and water bodies and caused water quality deterioration. Pollution of nearby water bodies and wetlands, as well as the reduction in cropland productivity, is linked to the erosion process (Issaka and Ashraf, 2017).

Soil erosion is usually characterised by three actions, viz. soil loosening, transport, and deposition. These processes typically result in the relocation of topsoil rich in organics, nutrients, and soil life. The relocation is elsewhere 'on-site' where it builds up over time or is transported 'off-site', where it accumulates in drainage channels. It is usually severe on unprotected sloppy areas (Shi *et al*., 2012). The movement of rainwater is a primary cause of soil erosion over ploughed or unprotected land (Karamage *et al*., 2017; Zuazo and Pleguezuelo, 2008).

Soil loss in reservoir catchments is a severe environmental problem (Gelagay and Minale, 2016). Soil loss may cause accelerated on-site soil nutrient loss from farmlands in affected reservoir catchments. This phenomenon results in accelerated off-site sediment accumulation in reservoirs, with implications for a severe reduction in the water storage capacities and designed life (Wang *et al*., 2018). Soil erosion also becomes a significant contributor to off-site groundwater pollution globally, with most contaminants originating within an agricultural setting (Marsh and Grossa, 1996).

Though soil loss is a natural geological process and might result from the interplay between rainfall erosivity and soil erodibility, inappropriate human practices have significantly aggravated soil loss in reservoir catchments worldwide. Those activities include deforestation, cultivation in upslope areas without any support practices, bush burning, the extension of the urban regions, and uncontrolled and overgrazing (Mekonnen *et al*., 2017).

Erosion and sediment yield from catchment areas upstream of Sembrong Dam will contribute to sedimentation in the Sembrong reservoir. In this study, the sediment yield prediction, i.e., the volume of sediments transferred in a given time interval from eroding sources through the channel network to a basin outlet, was carried out using an erosion model and a mathematical operator. These tools could express the sediment transport efficiency of the hillslopes and the channel network (Renfro, 1975; Kirkby and Morgan, 1980; Walling, 1983).

1.1. Study area

The study was conducted at the Sembrong reservoir catchment, which is located in Peninsular Malaysia’s southern part with latitudes 3° 26’ 42” N to 3° 26’ 42” N and longitudes 102° 54’ 18” E to 102° 55’ 54” E (Figure 1). The construction of the Sembrong Dam for flood control was completed in 1984 and formed part of the Western Johore Integrated Agricultural Development Project. The fabricated reservoir was initially designated for flood mitigation but has been used for irrigation and water supply since 1997 by Syarikat Air Johor.

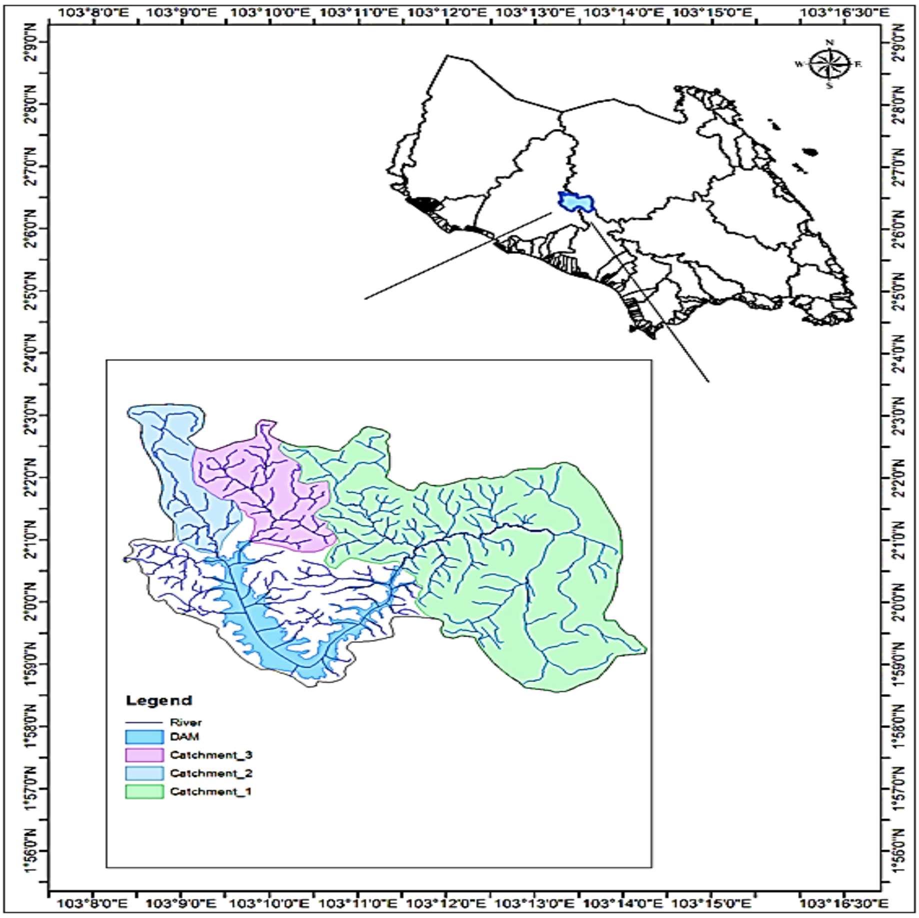

Figure 1. Sembrong reservoir catchment showing sub-catchment inlets for Sembrong reservoir. Catchment 1, 2, and 3 are the Amran river, Merpo river, and Ladang Guthrie river, respectively.

Figure 2 shows the Sembrong reservoir’s bathymetric map. The area is about 775 ha, with the storage capacity calculated at 24.845 million m^3, maximum depth of 7 m, and a mean of 3.2m. The lake floor has 4% of the average slope. The deepest part is at the southern area near the spillway, with depths ranging from 5 to 7m. Geologically, the host rock of the reservoir is a metamorphic that consists of shale, mudstone, siltstone, phyllite, and sandstone (Baharim *et al*., 2012). The water body is approximately 8.5 km^2 and surrounded by a lake basin area of roughly 130 km^2.

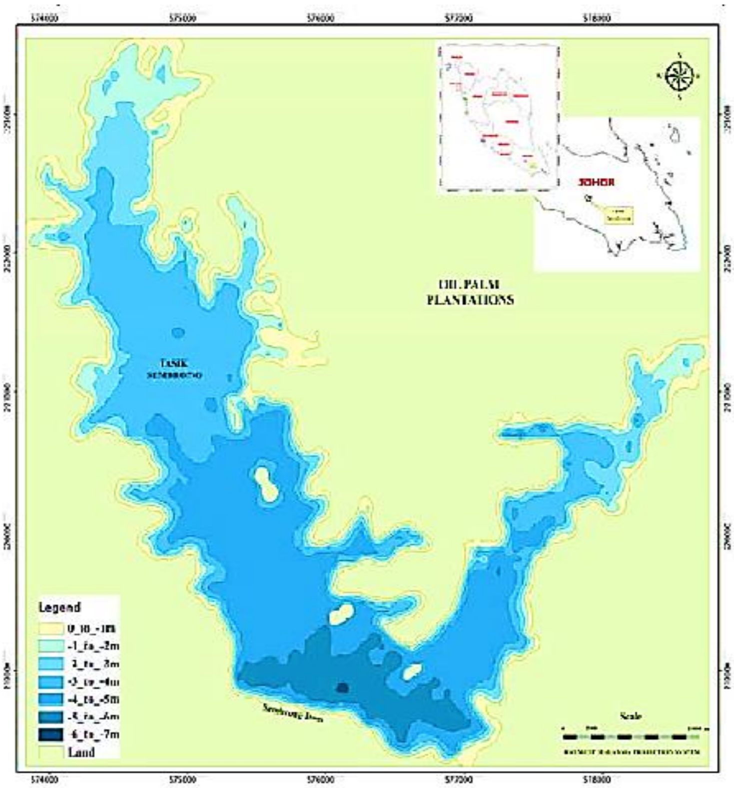

Figure 2. Bathymetry of Sembrong reservoir (Baharim *et al.*, 2012)

1.2. *Climate*

The studied area has a humid tropical climate with an annual mean temperature of 30 °C. The zone receives a mean rainfall of 1913 mm yearly. Based on long-term rainfall data at Sembrong Station, heavy rain is frequently recorded during the northeast monsoon season from November to January (Figure 3). In contrast, the southwest monsoon season between May and September brings less rainfall, with total monthly rainfall as low as 4.8 mm recorded (Baharim *et al.*, 2016).

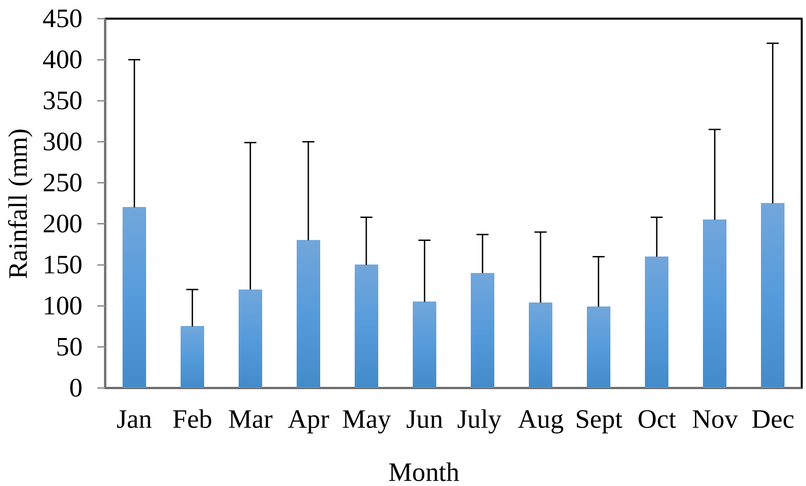

Figure 3. Mean monthly rainfall at Sembrong reservoir from 2001-2011.

1.3. *Land use*

The reservoir is also surrounded by oil palm plantation. Other minor land uses are swamp forest, modern agriculture, and husbandry (Baharim *et al.*, 2012). The recent inventory shows that the land use has changed extensively (Figure 4 and Table 1), with the increment of agricultural activities cover 8% (1984) to 82% (2010) of the catchment. Oil palm dominating the land use, covering about 72% of the basin area, followed by modern agriculture (15%), commercial and residential (5%), forest and swamp (4%), orchard (3%), and pasture (1%).

Table 1. Percentage of the land use within the catchment of the study area

No.	Landuse	Area (Hectare)	%
1	Agriculture	9, 839.79	86.96
2	Water Body	891.22	7.88
3	Residential	304.59	2.69
4	Transportation	172.92	1.53
5	Institution & Public Facilities	57.76	0.51
6	Industry	17.52	0.15
7	Open Space & Recreational	14.03	0.12
8	Commercial & Services	11.85	0.10
9	Infrastructure & Utility	5.01	0.04
	Total	11, 314.70	100.00

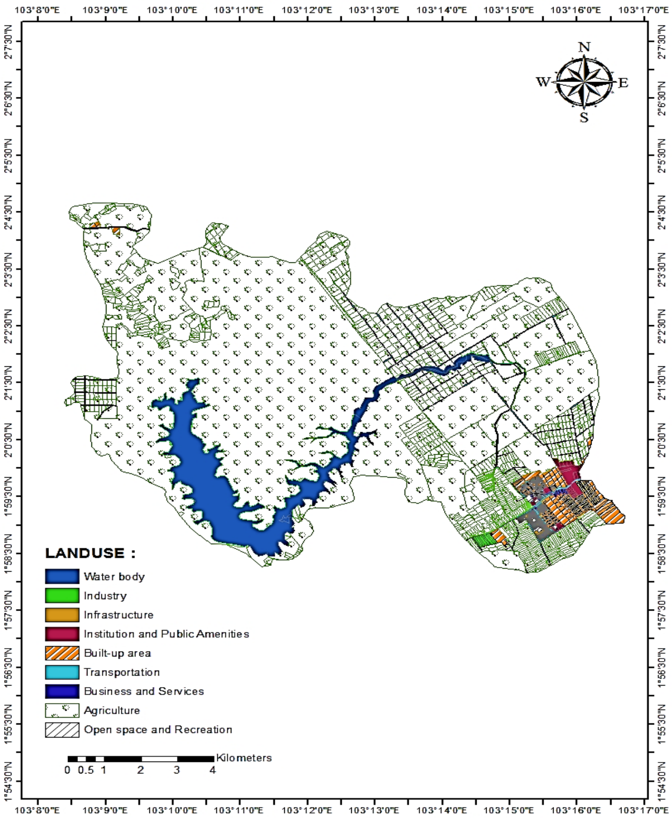

Figure 4. Distribution of the land use within the catchment of the study area

2. Material and methods

2.1. The Universal Soil Loss Equation (USLE)

The most common empirical erosion model used is USLE (Wischmeier and Smith, 1965). The model was designed by the United States Department of Agriculture (USDA) to predict long-term average interrill and rill cropland soil losses by water under various effects. The effects include land use, relief, soil, and climate. USDA is also responsible for guiding the development of conservation plans to control erosion (Wischmeier and Smith, 1978). It estimates soil erosion from an area simply as the product of empirical coefficients, which must be accurately evaluated. Meanwhile, USLE is calculated by developing natural and human-induced factors such as rainfall erosivity, soil erodibility, slope length and slope steepness, cover management, and support practice factors (Renard *et al*., 1997; Wischmeier and Smith, 1978). Original values of such coefficients were derived from field observations in different areas within the eastern part of the United States.

Mathematically, the equation is denoted as:

$$A\ (t/ha/year) = R \times K \times LS \times C \times P \tag{1}$$

whereby:

A = Annual soil loss (t/ha/year)
R = Rainfall and runoff erosivity factor (MJ mm/ha/hr/year)
K = Soil erodibility factor (t.ha.hr/MJ.mm)
L = Length of slope factor
S = Degree of slope factor
C = Cropping-management factor
P = Conservation practice factor

A Geographic Information System (GIS) is a preferred tool to integrate various datasets and assess any dynamic system such as soil erosion. Many soil loss studies have been conducted by different methods (Adinarayana *et al*., 1999; Lee, 2004; Millward and Mersey, 1999). One of the methods is the USLE model integrated with GIS, which could calculate soil erosion at any point in the catchment experiencing net loss. The integrated model is an easy and straightforward approach, efficient for soil loss assessment, and a universally accepted method for monitoring soil loss. Figure 5 and Figure 6 show the workflow and the methodology to estimate the soil loss.

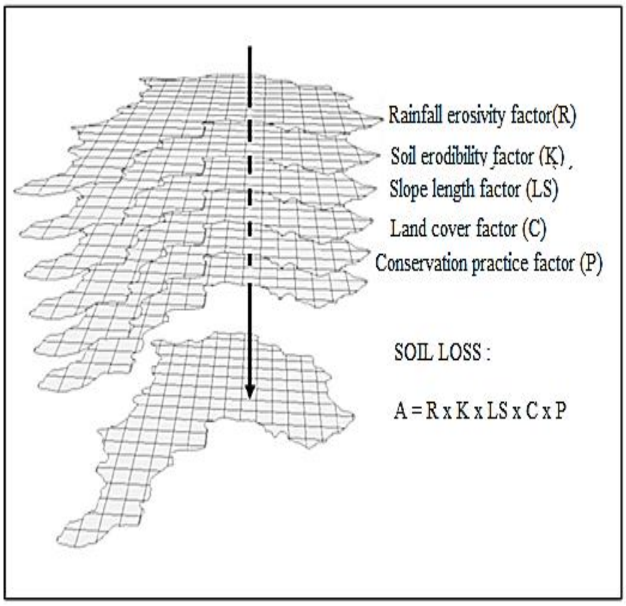

Figure 5. The layering using raster calculator

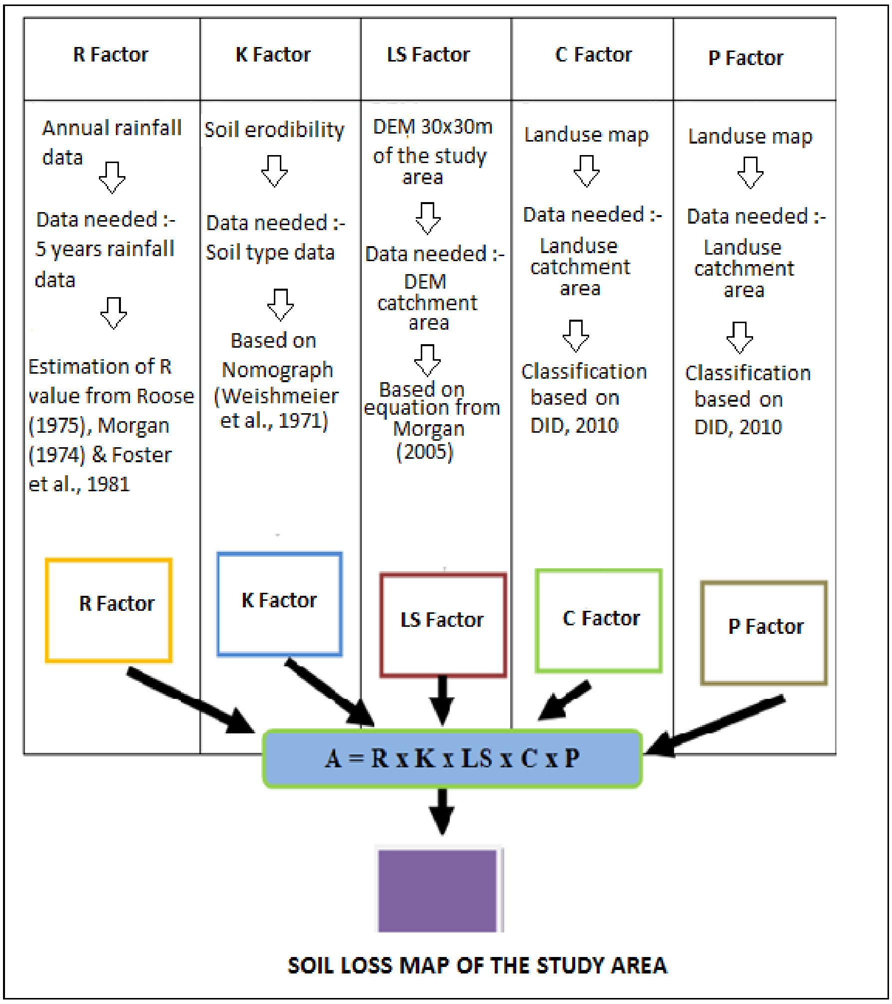

Figure 6. Workflow to determine all factors used in USLE (modified from Pillay and Rahaman, 2014). The result obtained will be multiplied by the sediment delivery ratio (SDR).

2.2. Sediment Delivery Ratio (SDR)

The gross erosion from interill, rill, gully on the hillslopes, and stream erosion, is expected delivered at the outlet of the drainage area. However, they are still temporarily deposited on the hillslopes (Ferro and Mincapilli, 1995). Thus, the basin SDR ratio is the sediment delivered to the outlet compared to the sediment deposited. SDR is a parameter that measures sediments deposition. The parameters include erosion on the hillslopes and how much is up to the mouth.

SDRs were developed after scientists observed that erosion prediction using USLE overestimates the amount of sediment delivered from hillslopes. The overestimate is because sediment deposition frequently occurs on hillslopes, and the USLE does not account for it (Kinnell, 2004). SDRs are essential 'performance' factors related to the observed or modelled amounts at the plot scale. SDR is dependent on the drainage area and other basin characteristics as described by relief, stream length, bifurcation ratio, the proximity of the sediment source to the stream, and the texture of the eroded material (Renfro, 1975; Bagarello *et al*., 1991). Sediment delivery ratios generally decrease with increasing basin size, indexed by area or stream length (Vanoni, 1975).

The relationship between the SDR and the basin size is known as the SDR curve (USDA, 1979). SDR curve that is based on the watershed size is widely used. However, there is difficulty establishing a general equation to estimate the SDR in a basin. The challenge stems from the high complexity of sediment delivery and the need to evaluate the interrelation between their intervenient factors (Walling, 1983). USDA (1979), Boyce (1975), Vanoni (1975), and Roehl (1962) had developed the SDR curve based on studies in several basins. The studies were based on the relationship between the transmission ratio of sediments and catchment areas. Table 2 presents the relationship between river basin area and SDR, as reported by Roehl (1962).

Table 2. SDR values for different catchment areas (Roehl, 1962)

Catchment area (acre)	Catchment area (km^2)	SDR value
6.4	0.025	0.65
320	1.29	0.33
3200	12.9	0.22
>6400	258	0.10

In this study, the SDR is based on Equation 2 (Vanoni, 1975) and Equation 3 (USDA NRCS[1], 1979), respectively. The studied model is more generalised to estimate SDR. The equations are as follows:

$$SDR = 0.42\ A^{-0.125} \quad (2)$$

$$SDR = 0.51\ A^{-0.11} \quad (3)$$

[1] Natural Resources Conservation Service

where, A = drainage area in square miles.

2.3. Rainfall-runoff erosive factor (R)

Rainfall data were obtained from the weather stations from the Department of Irrigation and Drainage, Malaysia. This study used data from four rainfall stations surrounding the Sembrong Dam to calculate areal rainfall (Table 3). Meanwhile, the annual aerial precipitation, P(mm), was calculated using the Thiessen polygon average method (Thiessen and Alter, 1911) (Figure 7). Average or mean total rainfall for all stations in the catchment were calculated using the following formula:

$$P = \frac{p1}{TA} \times rainfall\,1 + \frac{p2}{TA} \times rainfall\,2 + \frac{p3}{TA} \times rainfall\,3 \quad (4)$$

where:

P1 = Area of polygon

TA = Total Area

Table 3. Mean annual rainfall data of the study area

Station number	Rainfall station	Year	Rainfall (mm) Mean ± S.D.
2033152	Mengkibol Estate at Kluang, Johor	2010 – 2015	1725.6 ± 494.7
1931003	Sembrong Dam, Johor	2010 – 2015	1764.9 ± 346.4
2032071	Kian Hoe Estate at Kluang, Johor	2010 - 2015	1871.9 ± 432.6
2031069	Yong Peng Estate at Batu Pahat, Johor	2010 - 2015	1881.5 ± 498.9

Source: Drainage and Irrigation Department, Johor

Wischmeier and Smith (1978) suggested that a maximum intensity (I_{30}) value of 75 mm/h for tropical regions has decreased the raindrops erosive size as the intensity exceeds the threshold value. For Kluang station, the I_{30} was 100 mm once in five years. Among the methods that could be used to obtain rain index are based on Equations 5 (Morgan, 1995), 6 (Foster *et al*., 1981), and 7 (Roose, 1975), whereby P is the average annual precipitation (mm), and I_{30} is the intensity of the rain for 30 minutes. Meanwhile, Table 4 computes the R-value based on data and methods used in this study.

$$\text{R-value} = 9.28 \times P - 8838 \text{ (metric units)} \quad (5)$$

$$\text{R-value} = 0.276 \times P \times I_{30} \text{ (metric units)} \quad (6)$$

$$\text{R-value} = 0.5 \times P \times 1.75 \text{ (metric units)} \quad (7)$$

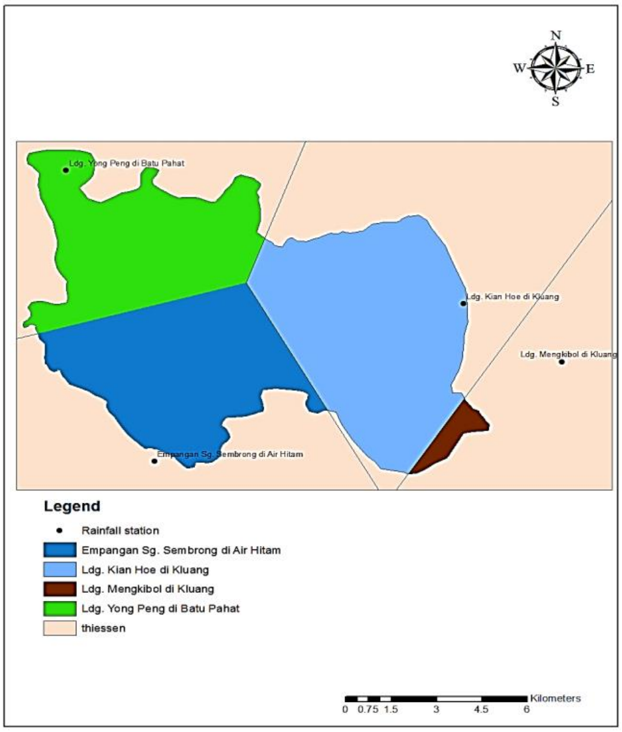

Figure 7. Thiessen Polygon for Sembrong Lake catchment area, Johor

Table 4. The data and methods used for the computation of R-value

Method	Annual aerial precipitation, P (mm)	Equation for R	Erosivity, R (MJ mm.ha/h/yr)
Morgan (1995)	1840	R = (9.28 × P - 8838) × 100/1000	823.7
Roose (1975)	1840	R = (0.50 × P × 1.75) × 100/1000	161.0
Average			492.4

The erosivity factor, R, was calculated using the annual aerial precipitation of 1840 mm using Morgan (1975) and Roose (1975). The average value of the R factor (492.4 MJ mm.ha/h/yr) was then used in the calculation of soil loss from the catchment.

2.4. *Soil erodibility factor (K)*

Soil erodibility is a soil resistance against the disassembly process and transport of soil. It is a significant index to measure the tendency of soil to water erosion and a vital parameter to predict soil erosion (Renard *et al*., 1997). Soil factor (K) shows the effect of the soil, the nature, and the characteristics of the soil profile as soil texture, stability aggregate, shear stress, infiltration capacity, organic and chemical content in soil loss. An attempt to formulate index soil erodibility was also based on the properties of soils as determined in the laboratory or the field and the reaction of soil against rain (Wischmeier *et al*., 1971;

Wischmeier and Smith, 1978; Tew, 1999; Shirazi and Boersma, 1984; Singh and Phadke, 2006, Helden, 1987).

Table 5 shows the differences in K factor at various soil series in Sembrong lake catchments, while Figure 8 shows the soil series in the Sembrong reservoir catchment. Equation 8 and nomograph in Figure 9 (Tew, 1999) estimate the K factor for soil series in Malaysia. Figure 10 shows the K factor map for Sembrong reservoir catchments. Therefore, the K factor calculation in the Guidelines for Erosion and Sediment Control in Malaysia is recommended (DID, 2010). The equation for the K is:

$$K = [1.0\times10^{-4} (12 - OM) \times M^{1.14} + 4.5 \times (s - 3) + 8.0 \times (P - 2)] / 100 \quad (8)$$

where:

K = Soil erodibility factor (t/ha) (ha. hr/MJ.mm)

M = (% silt + % very fine sand) × (100 – % clay)

OM = % of organic matter

S = soil structure code

P = permeability code

Table 5. K factor for different soil series in Sembrong Lake catchment

Soil series	K factor
Organic Clay and Muck	0.057
Kulai Yong Peng	0.022
Gajah Mati Munchong Malacca	0.041
Holyrood Lunas	0.025
Rengam Jerangau	0.013
Water	0
Telemong Akob Local Alluvium	0.012
Batu Anam Malaca Tavy	0.037
Durian Malacca Tavy	0.076
Steepland	0.075

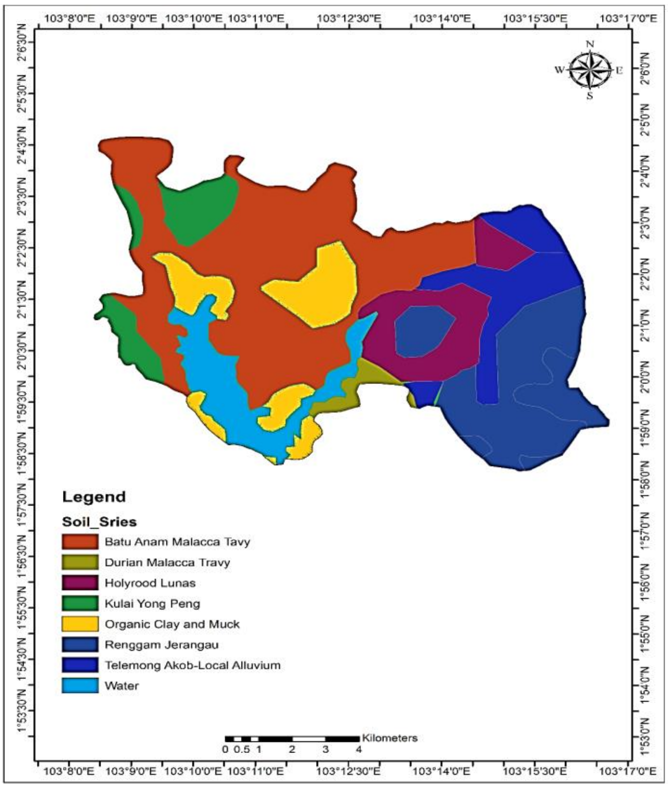

Figure 8. Soil series of Sembrong reservoir catchment

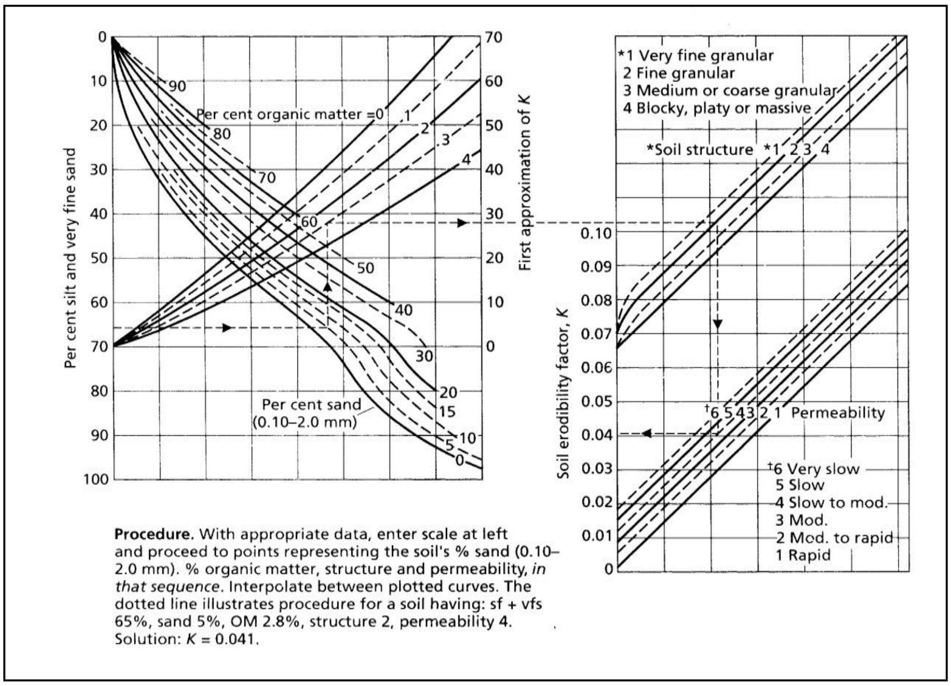

Figure 9**.** Nomographs to calculate soil erodibility (K) (t/ac.) x (100 ft.t. in/ac.hr) for Malaysia (Tew, 1999).

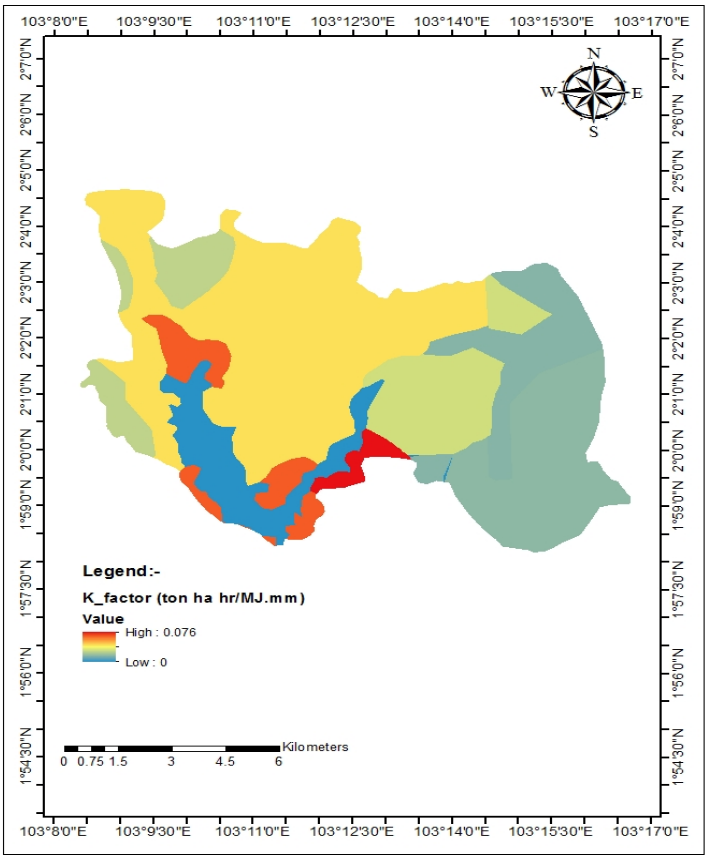

Figure 10. K factor map for Sembrong reservoir catchment

2.5. *Length of the slope factor (LS)*

The topography effect on soil erosion is translated by the LS factor, which combines the impact of a slope length factor (L) and a slope steepness factor (S). Wishmeier and Smith (1978) defined slope length as the distance between the point of origin of overland flow and the end at which the slope begins to decline, and deposition begins; or the point at which runoff becomes concentrated in a defined channel. Slope steepness reflects the influence of slope gradient on soil erosion (Wischmeier and Smith, 1965). It is known that the volume of runoff increases due to the continuous accumulation down the slope. The velocity of runoff is directly proportional to L as S increases. The development of a triangular irregular network (TIN) (30 m × 30 m resolution) using ESRI ArcGIS software (Figure 12), and the topographic factors (i.e., L and S factor values), were then derived from the TIN and combined to a single LS factor. Workflow for LS factor processes shown in Figure 11. The LS factor was calculated based on the equation from Wischmeier and Smith (1978) (Equations 9 and 10).

$$S = 0.065 + 0.045S + 0.0065S^2 \quad (9)$$

$$LS = (0.065 + 0.045S + 0.0065S^2) \times \sqrt{L}/22.13 \quad (10)$$

where:

L = Slope length in metre; S = Slope angle in %.

While gradient, m, will be

$m = 0.2$ if $S < 1\%$,

$m = 0.3$ if $1 \leq S < 3\%$,

$m = 0.4$ if $3 \leq S < 5\%$,

$m = 0.5$ if $5 \leq S < 12\%$

$m = 0.6$ if $S \geq 12\%$

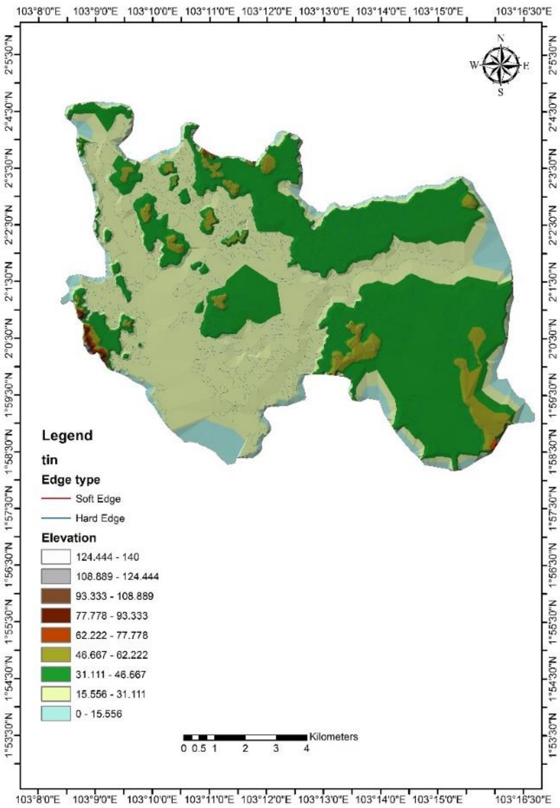

Figure 12. A Triangulated Irregular Network map (TIN)

Meanwhile, the calculations for the LS using map calculator in a raster analysis is based on Equation 11:

$$\text{Pow}\,(((\text{FlowAcc}) \times 30/22.1,\ 0.6) \times \text{Pow}\,(\text{Sin}\,[\text{Slope}]) \times 0.01745/0.09,\ 1.3) \tag{11}$$

where:

30 = resolution

0.6 = m factor

0.09 = 9% or 5.16 slope gradient according to standard plot USLE

1.3 = n factor

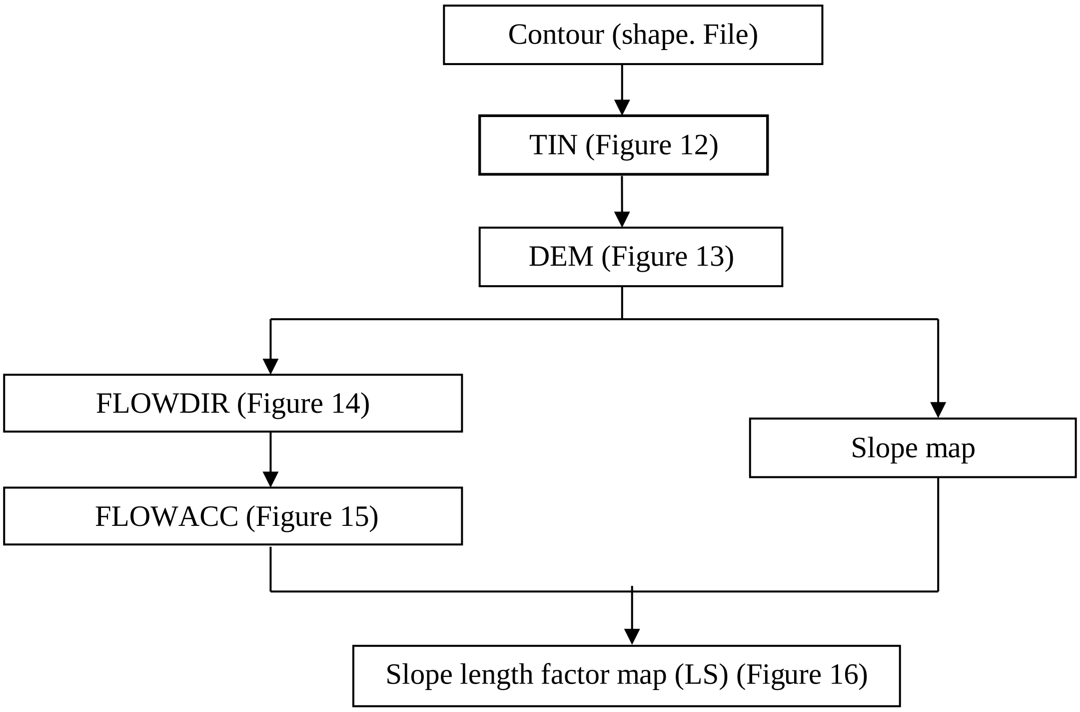

Figure 11. The process of obtaining the slope length (LS) factor

FlowAcc map (Figure 15) is a key output in hydrological and terrain analysis. The input to generate a flow accumulation map (FLOWACC) is the DEM (Figure 13) and the flow direction (FLOWDIR) map (Figure 14). The FLOWDIR map shows the direction of water that would flow from each cell to the neighbouring cell following the steepest descent. For each cell, the FLOWACC map calculates the number of upstream cells that contribute to the total flow to it. It represents the accumulation of surface water flow across a landscape by showing how much water (or a number of contributing cells) flows into each cell of a raster grid. The flow accumulation map further imposed on the slope map will produce the slope length (LS) factor map (Figure 16).

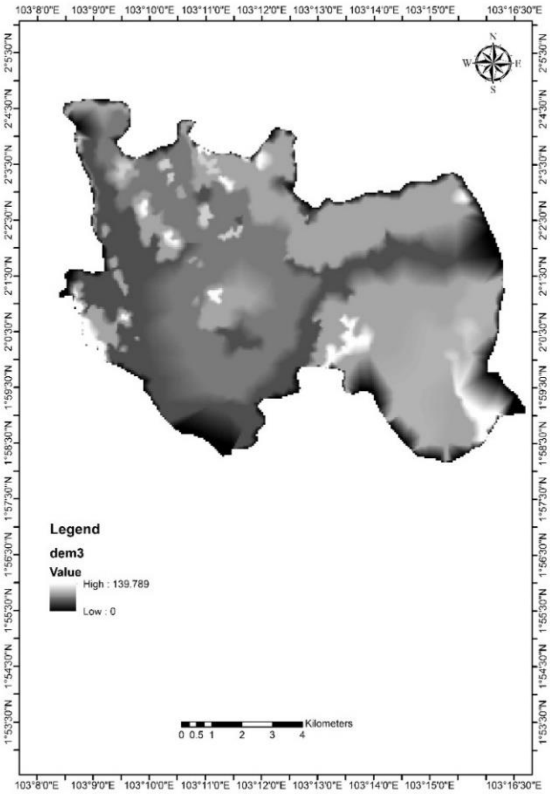

Figure 13. A digital elevation model map (DEM)

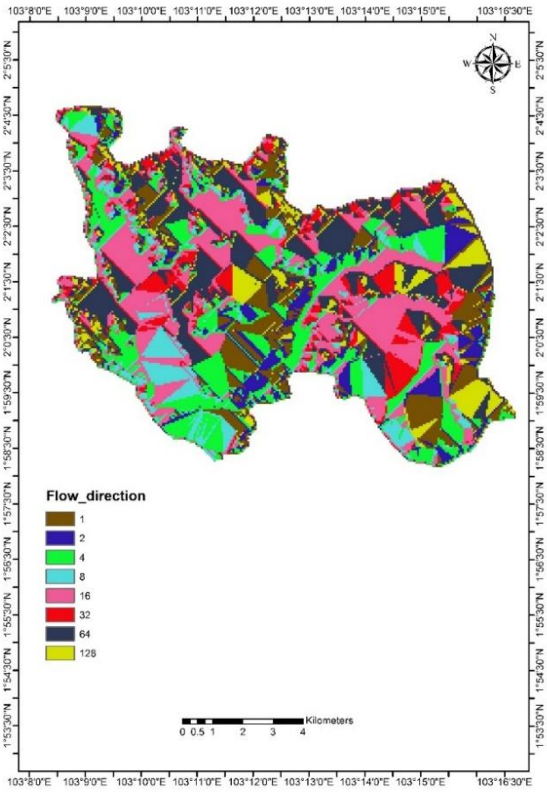

Figure 14. A Flow direction map (FLOWDIR)

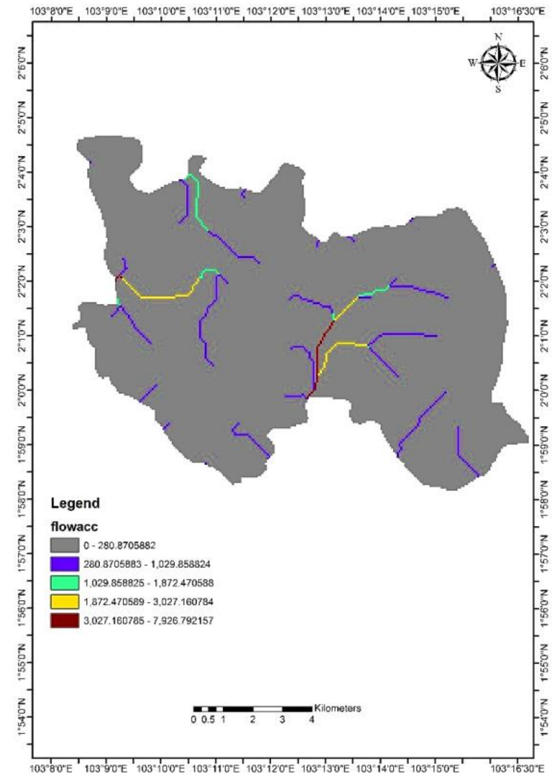

Figure 15. Flow accumulation map (FLOWACC)

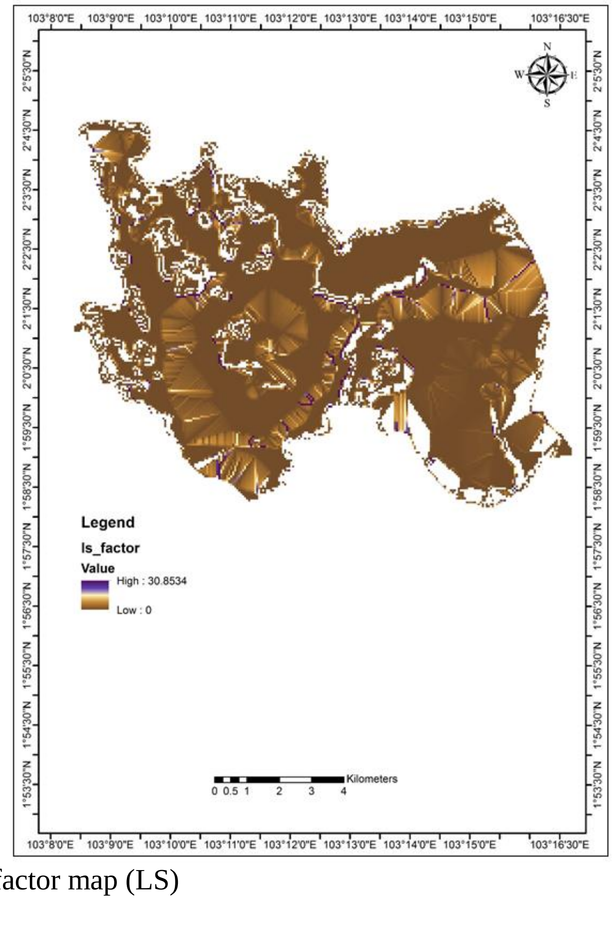

Figure 16. Slope length factor map (LS)

2.6. Cropping-management factor (C)

The crop management factor (C) represents the expected soil loss ratio under a given vegetation cover compared to the bare soil under the same rainfall conditions. The plant cover effectiveness in reducing erosion depends on the height and continuity of the tree canopy, the ground cover density, and its root growth. The vegetation cover intercepts raindrops and dissipates its kinetic energy before it reaches the ground surface. In the current study, C values for land use in the study area attribute for each basin (Table 6). The map generated is shown in Figure 17.

Table 6. C factor values for the land use classes in the study area (DID, 2010; Rizeei *et al*., 2016)

Land use	C factor
Forest	0.03
Built-up area	0.15
Agriculture	0.38
Rubber	0.25
Oil palm	0.20
Bare land	1.0
Waterbody	0.01

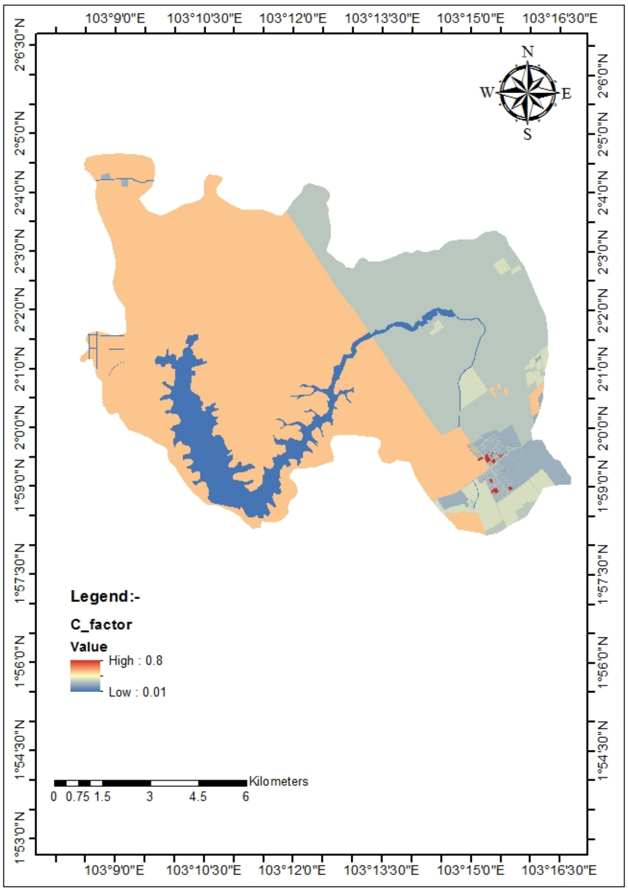

Figure 17. Crop management factor map (C)

2.7. Conservation practice factor (P)

Conservation practice factor (P) is the ratio of soil loss with a specific support practice to the corresponding loss with up and downslope cultivation. P 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 (DID, 2010). In this study, the P-value is 1, assuming no conservation practices were adopted. Thus, applying all the selected values in the calculation, the P factor map is generated, as shown in Figure 18.

2.8. Soil loss estimation

The calculation of soil loss (A) is carried out using the formula:

$$[A] = [R] \times [K] \times [LS] \times [C] \times [P] \times \text{resolution} \times \text{SDR (Equations 2 and 3)} \qquad (12)$$

The formula (Equations 2 and 3) were added to the 30 m resolution DEM that was converted into pixel units of 30 × 30/10000 km^2 = 0.09 (t/ha). Once the soil loss calculated, zonal statistical analysis was performed to determine the overall amount of soil loss representing each pixel. USLE calculation was carried out using the formula in the raster calculator (Figure 19), and Figure 20 illustrates the soil loss map. The unit of annual soil loss (A) is t/ha/year.

Figure 18. Conservation practice factor map (P)

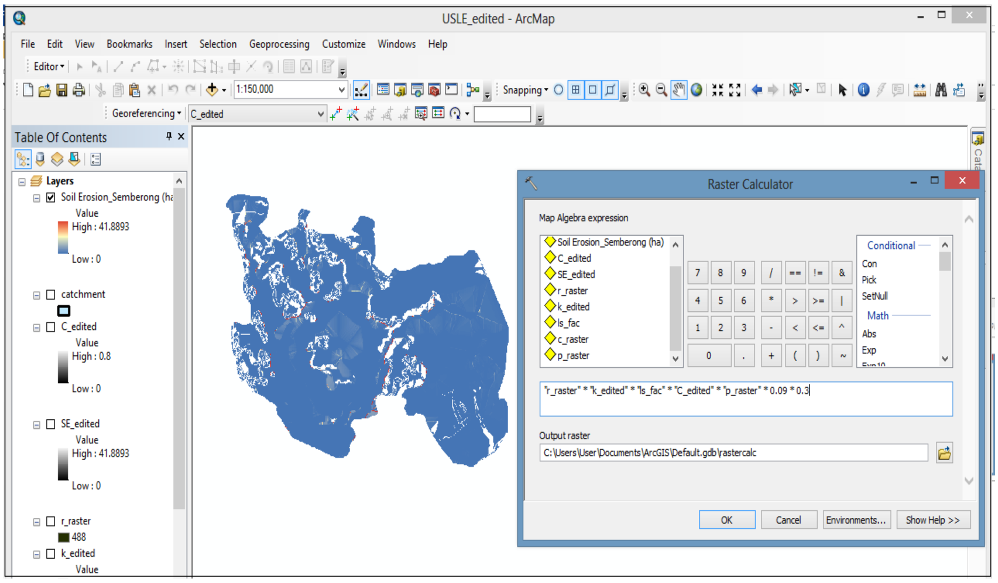

Figure 19. USLE calculation using raster calculator

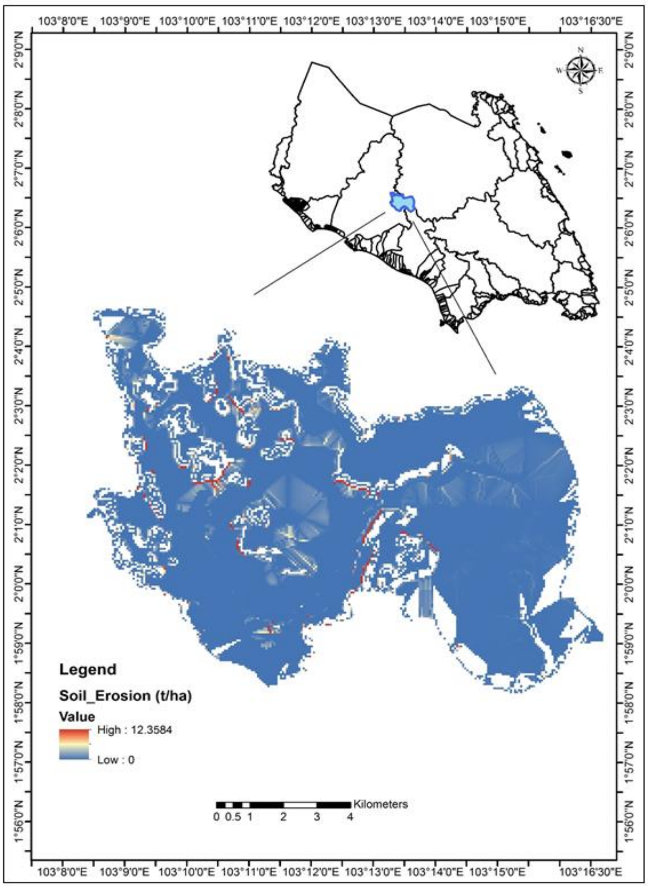

Figure 20. Soil erosion map of Sembrong dam catchment area (A)

3. Results and Discussion

The soil erosion calculation based on the USLE model showed that Sembrong Dam catchment had a relatively low to moderate rates of soil loss. The range of soil loss in Figure 20 is between 0-12.35 t/ha/year while in Table 7 the total soil loss was estimated at 3.92

t/ha/year. This is considered as a low to moderate soil tolerable limit. In this study, the rate of erosion or soil loss in the Sembrong catchment is considered low to moderate as suggested by The Organisation for Economic Co-operation and Development (OECD) (European Environment Agency, 1998). However, the high end of the range is 12.35 t/ha/year which is more than the maximum soil loss tolerable limit of 11.5 t/ha/year (Bagarello *et al*., 2015; Di Stefano and Ferro, 2016). According to European Environment Assessment (European Environment Agency, 1998), the tolerable soil loss varies between different soil depths, types and agro-climatic conditions, but typically ranges from 1 t/ha/year on shallow sandy soils to 5 t/ha/year on deeper well-developed soil (Di Stefano and Ferro, 2016).

Further analysis of the soil loss for three primary sub-catchments input to the lake (Table7) showed that the highest contribution came from the right flank of the lake, i.e., from the Amran river, as the total sediment input was 1.392 t/ha/year. While the left side of the lake received 0.802 t/ha/year; which came Guthrie Plantation river sub-catchment (0.526 t/ha/year) and 0.276 t/ha/year from Merpo river sub-catchment.

The sediment contribution from the three catchments accounted for 2.19 t/ha/year or 55.9% of the whole Sembrong catchment. There was an increase of the sediment output of 1.734 t/ha/year or 44.1 % of sediment production compared to the input.

Table 7. Soil loss from three sub-catchments input as compared to the whole catchment area

Catchment	Area (km^2)	Soil Loss (t/ha/yr)	Percentage of total catchment soil loss (%)
1 Amran river	59.49	1.392	35.44
2 Merpo river	9.55	0.276	7.02
3 Ladang Guthrie river	12.37	0.526	13.39
Total Input	81.41	2.193	55.9
Total Output from Sembrong catchment	113.15	3.927	100
Input – Output*	31.74	-1.734	-44.1

*Note: Negative value indicates sediment production from the lake area

The sediment could also come from areas not delineated in the calculation, including those between the three main catchments (inter-basin) accounted for about 31.74 km^2 (Table 7). The area near the lake periphery could contribute more sediment, and this sediment could be captured and deposited in the lake.

Agricultural activities in the lake basin areas, especially in close vicinity to the lake, could contribute to significant sources of pollution, both point and non-point source, especially sediment and nutrients. Meanwhile, high loading of phosphate and nitrate may induce eutrophication (Boeykens *et al*., 2017). Also, the existing aquaculture industry may further aggravate the water quality problem in the lake (Zhou *et al*., 2011).

Moreover, recent studies indicated that sediment becomes a vital contributor to non-point sources of pollution. The non-point nutrient contaminants, heavy metals, and chemicals are also transported with soil particles, causing higher sediment levels, which eventually lead to water eutrophication and disturbance of delicate aquatic ecosystems (Bing *et al*., 2013). The roles of sediment as a carrier of pathogens (Niewolak and Opieka, 2000), nutrients and heavy metals (Varol and Sen, 2012), radioisotopes (Rose *et al*., 2013), and organic matter (Marengo *et al*., 2006) in an ecosystem have been identified to pose threats on water resources.

Another common challenge in managing a reservoir in humid tropical areas is high rainfall intensity that leads to accelerated erosion rates. The erosion rate from oil palm plantation and the modern agricultural area is high, and over the long term, may affect the dam storage. The reservoir is currently experiencing a critical low water level, especially during the dry months of February and March. However, good plantation and farming practices for controlling erosion, such as buffer strip is not strictly enforced.

Due to the several lands use activities in the catchment areas, the erosion and sediment issue in the Sembrong catchment is considered high, primarily related to agricultural practices. The main erosion problem is related to the modern agricultural land, which needed buffer zones and silt trap to reduce sediment from the ground into the lake. Higher sediment sources were coming from the Amran river catchment (35.44%), Ladang Guthrie river catchment (13.39%), and the least was from the Merpo river (7%), which accounted for almost 56% of the total sediment from the Sembrong catchment.

There was an additional sediment production of up to 44.1% that did not originate from the three catchments mentioned above. Most of the sediment was from the vicinity of the lake that is dumped or deposited in it. Besides the buffer zone, a sediment trap should be installed to trap the sediment from agricultural runoff water entering the lake directly. This study also predicted that other pollutants around the lake might be contributed by the agro-tourism resort, Pusat Latihan Khidmat Negara camping ground, and animal husbandry.

Conclusion

The rate of erosion or soil loss in the Sembrong catchment is relatively moderate, amounting to a total of 3.927 t/ha/year. The range of soil loss in the catchment was from 0 -12.35 t/ha/year, and more than 90% of the catchment areas are experiencing erosion of less than 6 t/ha/year. Individual sub-catchment analysis showed that the highest input came from the right flank of the lake, i.e., from the Amran river, whereby the total sediment input was 1.39 t/ha/year. The left side of the lake only received an overall amount of 0.802 t/ha/year. The sediment contribution from the three catchments accounted for about 55.9% of the total Sembrong catchment. There was an increase in the sediment output, i.e., 44.1% of the sediment production compared to the input. The sediment could have come from inter-basin land, and areas not delineated in the calculation. Those near the lake periphery could contribute more sediment, and it could be collected and deposited in the lake. Also, sedimentation pond could be employed along the water route. A comprehensive planning and management programme is deemed necessary to develop a Sembrong reservoir catchment to reduce environmental degradation due to erosion and sediment related phenomena.

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