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Identification of critical erosion prone areas in Temengor Reservoir Basin using Universal Soil Loss Equation (USLE) and Geographic Information System (GIS)

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Abstract. In this study, the Geographic Information System (GIS) was integrated with the Universal Soil Loss Equation (USLE) model to identify the risk of erosion at 360,000 ha in the Temengor Reservoir Basin. GIS was utilized as a tool for generating, manipulating and spatializing data from government agencies for sediment yield modelling and offering spatial input data to the erosion model. Meanwhile, USLE was used to predict the spatial distribution of the sediment yield on the grid basis. The five main parameters used in this study were the rainfall erosivity factor (R), topographic factor (LS), soil erodibility factor (K), crop management factor (C) and practice support factor (P). The R factor was calculated based on the annual rainfall data of the study area. The soil survey data was used to generate the K value and Digital Improvement Model (DEM) of the study area was used to generate LS factor. The values of C and P factors were derived from the land use map. After generating all parameters, analysis was performed to estimate the soil erosion using USLE model with spatial information analysis approach. It was discovered that the average annual soil loss in the study area was $8 \text{ t ha}^{-1} \text{ year}^{-1}$ and only 4% of the total area was under extreme erosion risk.

1. Introduction

Soil erosion is a major environmental global concern [1,2,3] which may cause sediment accumulation that will lead to intensification of water pollution problems [4,5]. Oldeman [6] reported that roughly 1094 Mha area is affected by soil erosion due to hydrological processes. The average rates of soil loss throughout the world as stated by Biggelaar et al. [7] are approximated between 12 and $15 \text{ t ha}^{-1} \text{ year}^{-1}$, which mean, the land surface lost approximately 0.90 – 0.95 mm of soil every year [8]. Soil erosion is mostly affected by three major elements including water, wind and tillage [9]. According to the recent study, about 20 – 30 Gt of soil is being dislodged by water every year, while tillage erosion contributes 5 Gt per year [8]. Meanwhile, Lal [10] reported that there are 1094 million hectares of soil affected by soil erosion from water and 548 million hectares by wind.

The severity of soil erosion is mainly due to the variability in precipitation, soil characteristics, physiography, land use and human activities [11]. In Malaysia, soil erosion has become a major concern in recent years particularly in areas where land use is intensive for development, including urbanization and agricultural activities [12]. Invasion of development into environmentally sensitive areas has

increase the number of soil erosion occasion, water pollution, sedimentation and subsequently flooding in downstream areas which also had significant impact on the peoples in and near the affected areas [12]. The effects of timber harvesting on soil erosion and sedimentation in Malaysia have been reported by several researchers including Salleh et al. [13], Baharuddin [14] and De Neergaard et al. [15]. Soil erosion not only affects the productivity of highland farmland but also water quality within catchment areas. [12]. This situation was created by the phenomenon of runoff on the surface of the vacant slope and half exposed to the river and eventually to the lake, which will certainly reduce the depth of the lake in the long run [16]. The introduction of chemicals from pesticides and fertilizers as a result of agricultural activities has increased the concentration of excess nutrients such as nitrogen and phosphorus along with the heavy metal content in water and lake sediment [12] which subsequently lead to eutrophication problem in reservoirs [17].

There are many tools that researchers have introduced to estimate soil erosion including empirical and process-based models, for example the Water and Soil Assessment Tool (SWAT) [18], the Water Erosion Prediction Project (WEPP) [19], the Universal Soil Loss Equation (USLE) [20] and others. Process-based models, such as WEPP and SWAT typically require intensive calibration and multiple input parameters with extensive field data collection [21]. Furthermore, the variability of input parameters, leading to uncertainties, may be the main reason why process-based erosion models usually cannot produce as good an empirical model [22]. Thus, empirical models such as USLE is commonly used to estimate the soil erosion by water worldwide [23,24,3] including in Malaysia [25,26], because of its simplicity, and understandable from a functional perspective [21]. The USLE method predicts the average annual long-term erosion rate on the field by considering data from rainfall patterns, soil types, topography, crop systems and management practices [3].

The Temengor Lake catchment area has experienced rapid economic growth over the last decade. Land use activities around Temengor Lake, especially in the south, have changed from primary forest to logging area either for timber production or for agricultural purposes [27,28]. This type of developmental activities has a substantial influence on soil erosion and affect the ecological, biological and hydrological functions of the lake system. In this study, the USLE model was used to estimate the potential soil loss and develop an erosion risk maps for Temengor Reservoir catchment areas with the help of GIS that can be used to implement best management practices in future soil conservation programs.

2. Materials and methods

2.1 Study area

This study was conducted in the entire area of Temengor Reservoir Basin (5°56'4.12"N, 101°34'53.55"E and 3°40'37.19"N, 101°31'13.29"E) of Gerik in the northern state of Perak (figure 1) which includes approximately 360,000 ha of tropical rainforest with elevations ranging from 130–1500 m above sea level. Temengor Reservoir (15, 734 ha) which located in the middle of the whole basin has an initial storage capacity up to 6.05×10^9 m³ with mean depth of 40 m. This reservoir is surrounded by three forest reserves namely Belum Forest Reserve (137,167 ha), Temengor Forest Reserve (148,870 ha) and Gerik Forest Reserve (37,220 ha) which serve as a water catchment area. Among them, only Belum Forest Reserve is considered a fully protected forest whereas others are still open for logging activities [27,28]. In general, the Temengor Reservoir Basin can be described as having a typical tropical monsoon climate with relatively high temperatures (24°C - 30°C) and humidity between 70-98%. It receives high rainfall in April and October each year reaching 3,000 mm per year at times while experiencing during low rainfall in February and July [29]. The major land use for this area is forestry which constitutes about 66.26% of the entire catchment area followed by road and river (21.64%) and rubber plantation (10.9%) with a projected human population of 616 by 2015 [30].

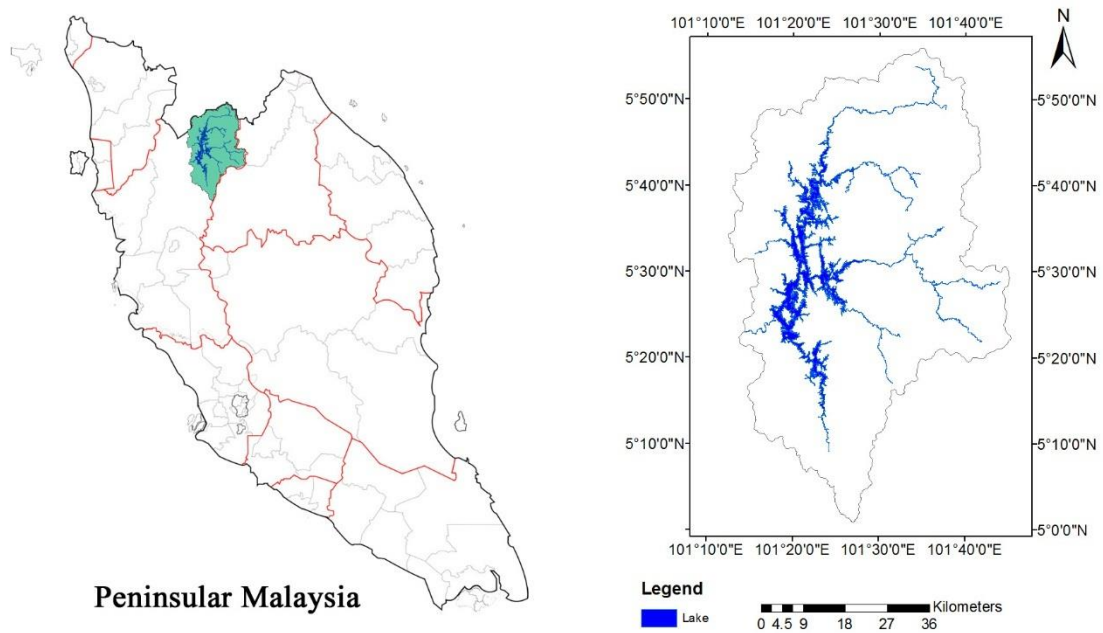


Figure 1. Study area of Temengor Reservoir, Perak

2.2 The Universal Soil Loss Equation (USLE)

In the present study, USLE was applied in the Temengor Reservoir Basin in the spatial domain using GIS. All USLE factors were obtained as raster geographic layers (grid) after processing the original data. The cell size of $100\text{m} \times 100\text{m}$ was considered as the basic operating unit for soil erosion analysis as proposed by [31]. Then, all factors were combined to calculate the final erosion risk map (figure 2). Soil erosion can be classified into five different levels as listed in table 1.

The equation used was:

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

Where:

A is the average annual soil loss ($\text{tons ha}^{-1} \text{ year}^{-1}$),
 R is the rainfall erosivity ($\text{MJmm ha}^{-1} \text{ h year}$),
 K is the soil erodibility factor ($\text{tons ha}^{-1} \text{ R unit}^{-1}$),
 LS is the topographic factor,
 C is the cropping management factors, and
 P is the practice support factor

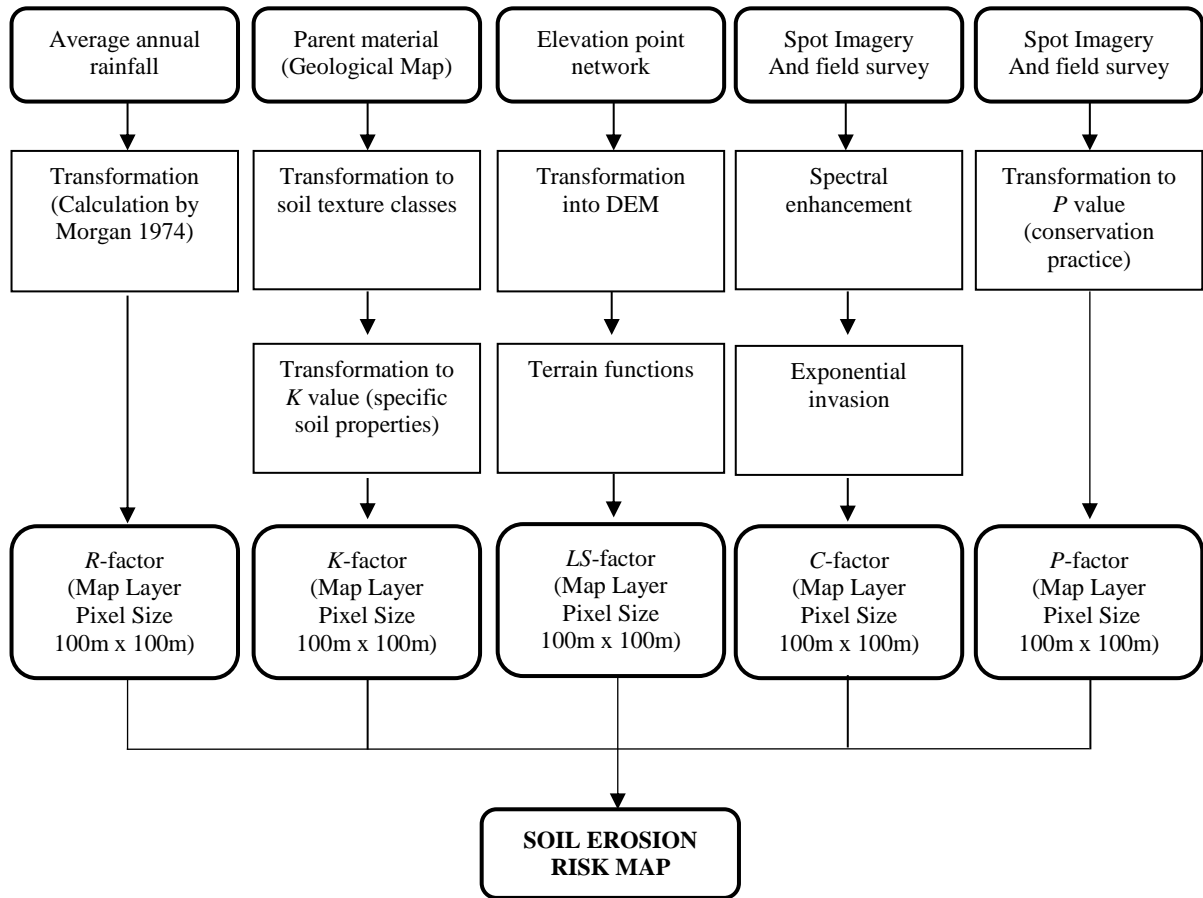


Figure 2. Procedural Flow Chart of this study

Table 1. Soil loss classification [3]

Level	Soil loss (ton ha ⁻¹ year ⁻¹)
Very low erosion	0 - 1
Low erosion	1 - 5
Medium erosion	5- 10
High erosion	10 - 50
Extreme erosion	> 50

2.2.1 Rainfall erosivity factor (*R*). Rainfall erosivity factor (*R*) plays the most vital factor in USLE compared to the other input parameters [32]. Rainfall erosivity (*R*) was defined as the product of the total kinetic energy multiplied by a maximum intensity of 30 minutes of rain [33]. Many methods have been introduced by researchers to calculate the annual rainfall erosivity factor [35,1]. For Peninsular Malaysia, Morgan [36] developed an equation to calculate the *R* factor based on annual precipitation by analysing the rainfall data obtained from the Department of Irrigation and Drainage of Malaysia (DID) and Tenaga Nasional Berhad (TNB) from 2007 to 2017.

The equation used was:

$$R = \frac{(9.28P - 8838.15)}{100}$$

Where P is the mean annual rainfall (mm)

2.2.2 Soil erodibility factor (K). The soil erodibility factor (K) defines the resistance of the soil to both detachment and transport [35]. This factor illustrates the impact of soil properties and soil profile characteristics on soil loss. All equations for measuring K factor are associated to soil texture, soil organic matter, and percentage of sand, silt, and clay in soil [37]. In Malaysia, K factor value was already determined by Department of Irrigation and Drainage of Malaysia (DID) according to the type of soil. In this study, the main soil type for the whole catchment area is ‘Steepland’ with a clay soil structure.

2.2.3 Topographic factor (LS). Topographic factor (LS) is the slope length gradient factor consisting of slope length (L), and slope steepness (S) [38]. The rate of soil erosion by water is greatly influenced by both slope length and slope steepness based on its gradient and slope percentage [35]. The LS factor can be calculated using the methodology proposed by Wischmeier [39]:

$$LS = \left(\frac{\lambda}{\psi}\right)^m \times (0.065 + 0.046S + 0.0065S^2)$$

Where:

λ	= sheet flow path length (m)
Ψ	= 22.13 for SI Units and 72.6 for English Units (BU)
S	= average slope gradient (%)
m	= 0.2 for $s < 1$, = 0.3 for $1 \leq s < 3$, = 0.4 for $3 \leq s < 5$, = 0.5 for $5 \leq s < 12$ and = 0.6 for $s \geq 12\%$

Currently, GIS is considered an important tool for the study of environmental management. Therefore, almost all researchers use Digital Elevation Model (DEM) and GIS tools to measure LS in soil erosion studies [38,40]. In the present study, the LS factor was calculated using ArcGIS and DEM model obtained from a 10-meter interval contour with a 1:50,000 scale based on topographic maps from the Department of National Mapping, Malaysia (JUPEM).

2.2.4 Cropping management factor (C). The value of C factor ranges between 1 and 0. C equals to 1 indicating no cover exist and surface is considered to be barren soil, while C approaching zero shows very strong protective effects [3]. The C factor can be calculated based on current land use and crop management in the area [41]. In the present study, the C factor was determined using a land use map provided by the Department of Agriculture of Malaysia (DOA). The Department of Irrigation and Drainage of Malaysia (DID) summarizes the list of C factor values for several crops and conditions available in Malaysia; for agricultural and urbanization areas (table 2) and for unaffected and undisturbed land (table 3).

2.2.5 Support practice index (P). P factor is defined as the effect of land use or agricultural system on soil erosion. The P factor can affect the potential erosion of water runoff by applying contour effects,

crop rotation, and terraced contour farming [42,43]. If no erosion control solution exists, then the value of P is 1. In this study, due to the lack of data distributed spatially for the P factor, it was set to 1 for the entire study area, assuming that no protection measures were taken [23,44].

Table 2. Cropping management factor (C) for agricultural and urbanized areas [24]

Erosion control treatment	C factor
Mining areas	1.00
Agricultural areas	
Agricultural crop	0.38
Horticulture	0.25
Cocoa	0.20
Coconut	0.20
Oil palm	0.20
Rubber	0.20
Paddy (with water)	0.01
Urbanized areas	
Residential	
Low density (50% green area)	0.25
Medium density (25% green area)	0.15
High density (5% green area)	0.05
Commercial, Educational and Industrial	
Low density (50% green area)	0.25
Medium density (25% green area)	0.15
High density (5% green area)	0.05
Impervious (Parking lot, road, etc.)	0.01

Note: average runoff condition

Table 3. Cropping management factor (C) for forested and undisturbed lands [24]

Erosion control treatment	C factor
Rangeland	0.23
Forest/Tree	
25% cover	0.42
50% cover	0.39
75% cover	0.36
100% cover	0.03
Bushes/Scrub	
25% cover	0.40
50% cover	0.35
75% cover	0.30
100% cover	0.03
Grassland (100% coverage)	0.03
Swamps/mangrove	0.01
Water body	0.01

Note: average runoff condition

3. Results and discussion

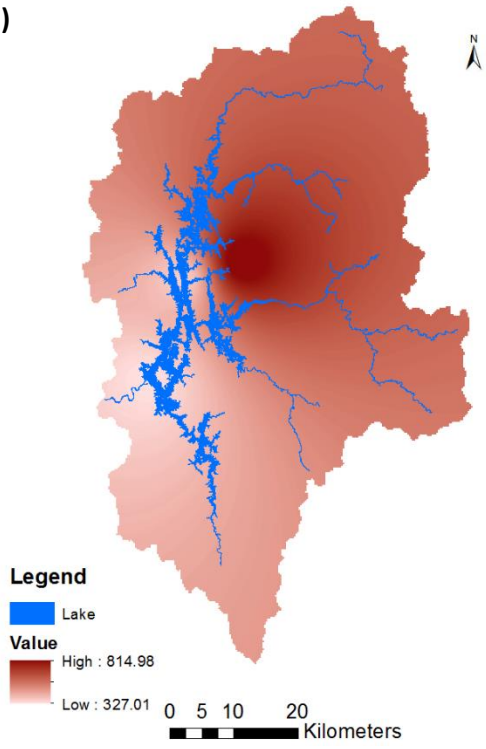
The average annual rainfall from 2007 to 2017 was used to determine the R factor for the whole catchment area using the equation described in section 2.2.1. The mean annual rainfall ranged from 1606 to 2219 mm resulting in rainfall erosivity of 327 to 815 mm, with the highest R factor recorded in the middle of the Temengor catchment area (figure 3a). As mentioned earlier, the equation for measuring K

factor were related to soil texture, soil organic matter, and percentage of clay, sand and mud in the soil [37]. Therefore, K is one of the most arduous factors, which requires considerable time, cost and resources for field observations and analysis. In Malaysia, the value of K factor has been determined by the Department of Irrigation and Drainage Malaysia (DID) by type of soil. Based on the data obtained from the DID, the main soil type for the entire catchment area was 'Steepland' with clay structure and the K value for soil type and structure was 0.06 (figure 3b). Slope length and slope steepness play a vital role in the rate of soil erosion by water in terms of its gradient and slope percentage [35]. However, longer slopes do not necessarily correspond to higher soil loss irrespective of the three-dimensional complexity of the terrain [3]. Thus, many researchers come to agreement that the rate of soil lost hinge on the three-dimensional distribution of the area [45,46]. In this study, the combined spatial distribution of LS factor was obtained from the DEM of the study area. The LS factor in the Temengor Reservoir Basin ranging from 0 to 67.3 (figure 3c) with LS value less than 5 was 72.6 % (265,146 ha) while LS value exceeding 5 was 27.4% (100,069 ha). The potential for erosion is higher in areas with high LS values due to the increased slope angle and the slope length [45]. Areas with LS value of more than 5 are more likely to experience soil erosion than areas with slopes of less than 5 [47]. High LS values will lead to very strong rainfall rates and makes the soil erosion worse. The C factor in the study area was in between 0.01 to 0.45 with the highest value of C focused in the southern Temengor River Basin where most of the logging and rubber plantation activities were located (Figure 3d). The P factor was set to 1 for the whole study area (figure 3e) due to the lack of data distributed spatially which means no protection measures were taken [23,44].

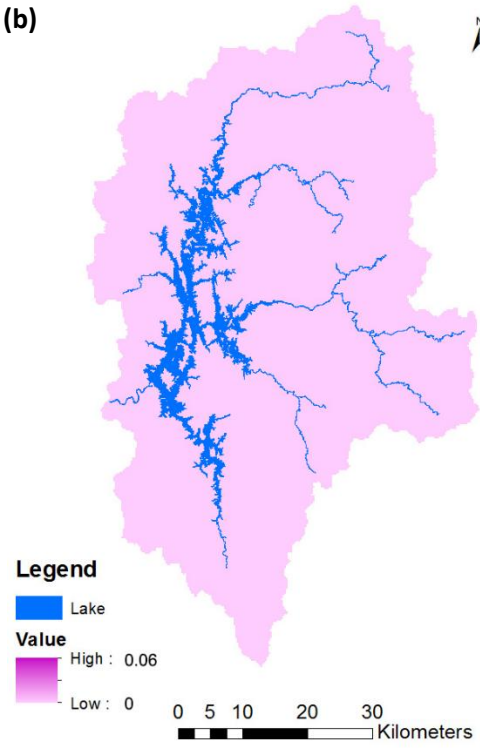
Average annual soil erosion (A) was calculated by multiplying the raster data generated from each of the USLE factors as described in section 2.2. The average forecasts of soil loss in the study area ranged from "very low erosion" to "extreme erosion" (table 4; figure 3f). The data shows that throughout the whole Temengor Reservoir Basin, the area where the erosion is high, occupies 28.8% of the total area especially at high elevations zone. The "extreme erosion" area accounted for 4.0% of the study area mostly recorded in the southeastern Temengor Reservoir Basin where logging activity was located. The north-east and south-western basins have less erosion rates than other areas.

In this study, the level of erosion in the Temengor Lake basin, largely influenced by the combined effects of R , LS and C factors. LS and C factors were also giving a huge impact on soil erosion on Siruvani River Basin as noted by Thomas & Thirivikramji [11]. Meanwhile, Magesh and Chandrasekar [48] identified R and LS factors as the leading factors affecting the soil erosion in the sub-basin of the Tamiraparani River. Many studies [49,50,51] have discovered that soil loss rates in catchment areas are more sensitive to water runoff (R factor). From the R factor map (figure 3a), the lowest value of R was recorded in the southwestern Temengor Reservoir Basin where low erosion was detected. Various researchers [11, 48] indicated that LS factor plays a significant role in soil loss rate and is the most challenging factor in the USLE model [24]. Similar result was shown in this study where the soil erosion was high, occupying 28.8% of the total area, mostly occurred at high elevations area. The C factor was closely linked to land use in the area. Most researches have concluded that land use influenced both results and characteristics of soil loss [52,53,54]. Different land uses will give a different levels of soil erosion. Pham [55] proposes that plantation forests will erode the most. In studies conducted by several researchers [56,57,58], it was found that land use for agricultural land resulted in the worst erosion. In this study, the agricultural land together with logging areas were severely eroded. When natural plants are cleared for agricultural activities, exposed soil layers are often blown away by wind or washed away by rain compared to forests filled with vegetation canopy [2].

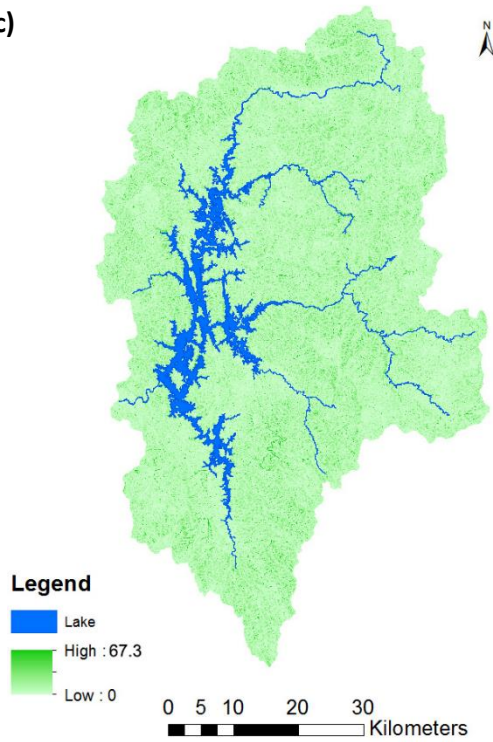
(a)



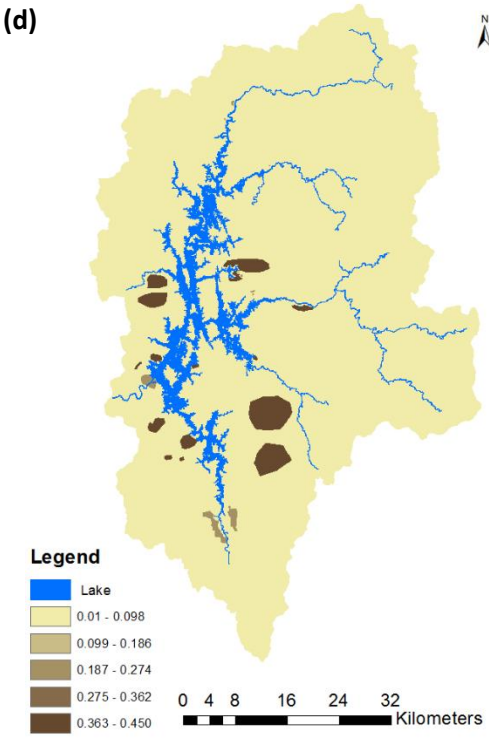
(b)



(c)



(d)



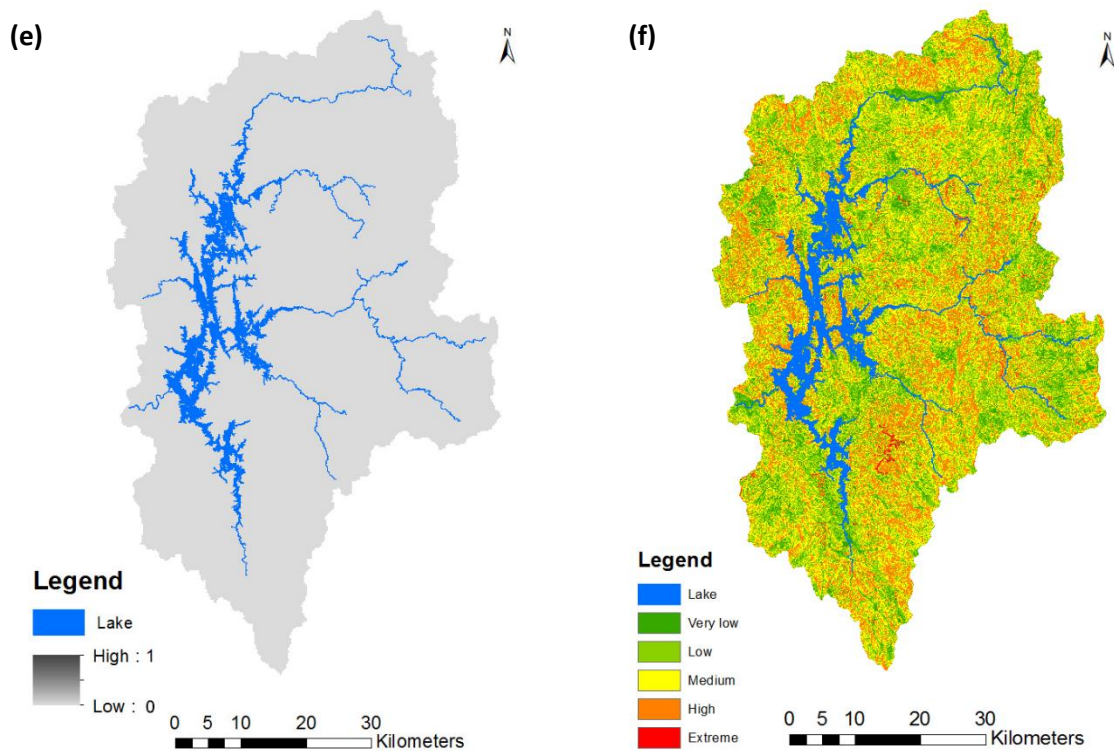


Figure 3. a. Rainfall erosivity factor (R), b. Soil erodibility factor (K), c. Topographic factor (LS), d. Cropping management factor (C) and e. Support practices factor (P), f. Soil erosion

Table 4. Soil erosion rate in Temengor Reservoir Basin

Erosion level	Soil loss (tons ha ⁻¹ year ⁻¹)	Area (ha)	Percentage of total area (%)
Very low	0 - 1	34,330	9.4
Low	1 - 5	41,635	11.4
Medium	5- 10	153,756	42.1
High	10 - 50	105,182	28.8
Extreme	> 50	14,609	4.0
Water		15,703	4.3
Total		365,215	100

4. Conclusion

The average soil loss rate in the Temengor Reservoir Basin was around 8 tons ha⁻¹ year⁻¹. 42.1% of the Temengor Reservoir Basin area represents moderate erosion risk while high erosion risk (28.8%) was located in the southeast which includes timber and some agricultural areas. The effects of parameters affecting soil loss in the USLE model indicate that the rainfall erosivity factor (R), topographic factor (LS) and crop management factor (C) have the greatest impact on soil loss in the study area. This study also demonstrates that the USLE soil erosion model combined with GIS is an efficient tool for handling large volumes of data needed for soil loss studies in the catchment area.

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