Estimation of soil loss in Seremban, Malaysia using GIS and remote sensing technique

Goma B Ahmed[1,2]*, A R M Shariff[3], S K Balasundram[4] and A F B Abdullah[3]

[1]Geospatial Information Science Research Centre (GISRC), Faculty of Engineering, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
[2]Arab Center for Desert Research and Development of Desert Communities Morzok-Libya
[3] Department of Biological and Agricultural Engineering, Faculty of Engineering 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
[4] Department of Agriculture Technology, Faculty of Agriculture, Selangor Darul Ehsan, Malaysia

joma762001@gmail.com

Abstract. Runoff causes soil loss and is a continuous ecological problem in Seremban, Malaysia. It is crucial to collect data on soil loss for improved agricultural productivity and to manage natural resources effectively. This research maps the distribution and estimates the yearly mean value of soil erosion through the utilization of techniques of remote sensing and GIS by implementing the Revised Universal Soil Equation (RUSLE). To determine the variables of RUSLE's soil loss and analyze them in an integrated GIS environment, we used a scale of 1:50,000 according to criteria of topographic map, Aster Digital Elevation Model (DEM) which has a feature of spatial resolution that extends up to 20 m, a soil map which is digitally programmed with a scale of 1:250,000, and a decade of rainfall records for 12 stations. The data revealed that Seremban records an annual soil loss that ranges from no soil loss in forested areas (Lenggeng - Panti - Ampangan - Seremban) to >100 tone hectare per year in the open area (Labu - Renggam - Lenggeng). The total annual soil loss is estimated at 883 tonnes/hectare/year and is distributed across different land cover as follows: 198 tonnes from agriculture areas, 39 tonnes from forest areas, and 20.45 from rural areas, 610 tonnes from open area, 12 tonnes from urban areas, and 1.4 tonnes from inland water areas.

Keyword: soil loss, GIS, Remote sensing, Malaysia

1. Introduction

GIS and remote sensing are tools to map soil and detect the places that are under peril or encountering an alarming rate of soil erosion. It also helps measure the extent of soil loss. This data is particularly useful for policy and decision-makers to preserve the environment and engage in soil conservation measures to reduce soil loss where needed, while also enhancing safety. For this purpose, the Universal Soil Loss Equation (USLE) is considered a proficient model that enables to quantify soil erosion. It uses remote sensing techniques such as topography and land use as spatially distributed parameters, which are then converted into raster layers to be inputted into a GIS environment to produce a soil erosion risk map. Several studies of soil erosion in Malaysia have been conducted using this approach. It is common to use the GIS approach to formulate soil loss assessments. The efficacy of this approach depends on the assumption that data is error-free and that errors are not added to the outcome based on the decision rule. The problem with this assumption is that imprecise measurements mean that geographic are never completely certain and as such can hardly be considered error-free. The ways in which criteria are used to reach a decision also entails a degree of uncertainty, which further questions the efficacy of this approach. Nevertheless, the GIS approach helps determine acceptable and unacceptable risk. This is supported by Bayesian Probability Theory and Fuzzy Set Theory. This study maps soil erosion in Seremban, Malaysia, based on remotely sensed data to estimate its volume and distribution.

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2. Materials and Method

2.1. The Study area

The study area is Seremban district, an administrative unit of the state of Negeri Sembilan in Peninsula Malaysia (Figure 1). Geographically, the district lies between latitudes 3o 0' 0 N up to 2o 30' 0 N and longitudes 101o 45' 0 E up to 102o 6' 0 E, with a land mass accounting of about 951.682 kilometer. The elevation range between 0 - 1180.2 meters above mean sea level. The study area is typical tropical rainforest with average precipitation of 173 mm per annum. It is characterized with two major seasons - wet and dry season [1]. The wet season is usually between the months of May and September while the dry months includes October to March , The district comprises of eight sub- administrative units called Mukims with a total population of 536147 people according to Malaysia statistics record [2].The mukims are Lenggeng, Setul, Pantai, Labu, Seremban, Rantau, Rasah and Ampangan. The main occupation of the people is agriculture dealing in rubber farming, oil palm, coconut plant [3].

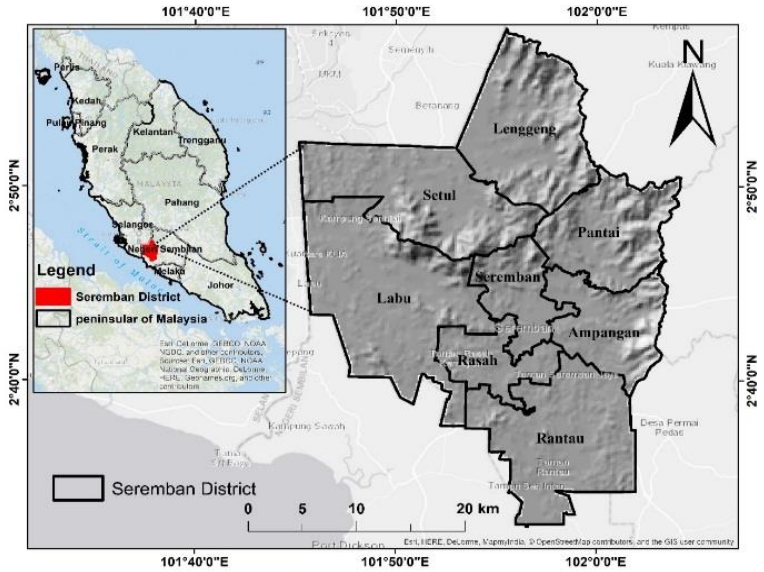

Figure 1. Location of the study area

Sources and techniques of data collection. For the purpose of preparing data that allow the spatial analysis, climatic data, geometric data and factors connected to soil data that impact soil loss. were aggregated. All these factors constitute the criterion maps estimated to a sole scale, spatial reference and resolution, boundary extent prior to their consensus to make them to a cell of the size of 300 m for UTM estimation, Table1 shows data collect from different sources for Seremban. Overall, the study was conducted in four phases (Figure 2): data collection and processing, parameter generation, process of parameter integration in GIS environment, and soil loss map production.

Table 1. List of data sets used in the study

No	Data Type	Description	Source
1	Soil chemical and physical values	Profile data for each type of soil	Department of Agriculture Kuala Lumpur (DOA)
2	Soil map	Soil semi detail, scale 1:25000	(DOA)
3	Terrain	Topographic map for each soil type	Jabatan Ukur dan Pemetaan Wilayah Persekutuan Kuala Lumpur (JUPEM, 2010)
4	Land use	Scale 1:50000	(DOA)
5	Rainfall precipitation	Monthly rainfall from 9 station for 10 years	2005-2015 (DOA)

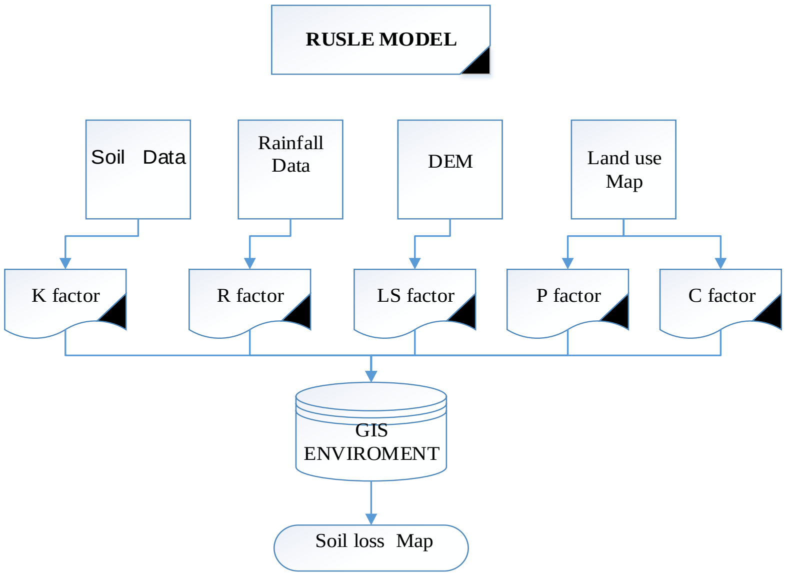

Figure 2. Framework for soil loss analysis

2.2. Soil loss estimation

This study applies the Universal Soil Loss Equation (USLE) through the implementation of remote sensing and GIS technique as well to estimate Seremban's mean annual soil loss. Wischmeier and Smith developed USLE as an empirical model to estimate soil loss from fields [4]. It was altered by the prominent Revised Universal Soil Loss Equation (RUSLE) model through the help of implementing some sophisticated tools that facilitate the computation of soil loss factors. USLE was best adapted to the condition in the United States of America (USA) where it was primarily developed [5]. RUSLE replaces the factor of rainfall runoff related to original USLE with factor of rainfall erosivity [6]. The RUSLE calculates the anticipated yearly average erosion on the slopes of field (Equation 1).

$$A = R * K * LS * C * P \tag{1}$$

Since A represents the calculated yearly average amount of soil loss in tons per year per acre, R represents the erosivity factor for rainfall runoff, the K is the factor that represents the soil erodibility, the L factor represents the length of the slope, the S factor represents the steepness of the slope, the C factor represents the cover management and P factor represents the conservation practice [7]. This equation includes two types of variable. Firstly, the environmental variable which includes the R, S and L determinants. These variables tend to have constant values over time. Secondly, the variable related to management that comprises the P and C factors and tend to fluctuates within a time frame of less than one year or a full year.

3. Results and Discussion

3.1. Soil lose factors

The factor (R) which represents the rainfall erosivity Equation 2 characterizes the factor of rainfall erosivity which measures the impact of the amount of rainfall and runoff which tend to be linked to precipitation The mean annual rainfall of the nearest 12 stations obtained from the Malaysian department was interpolated using the spline interpolation method to produce uninterrupted rainfall data for each grid cell [1]. Figure 3 shows the R factor derived from rainfall data Seremban.

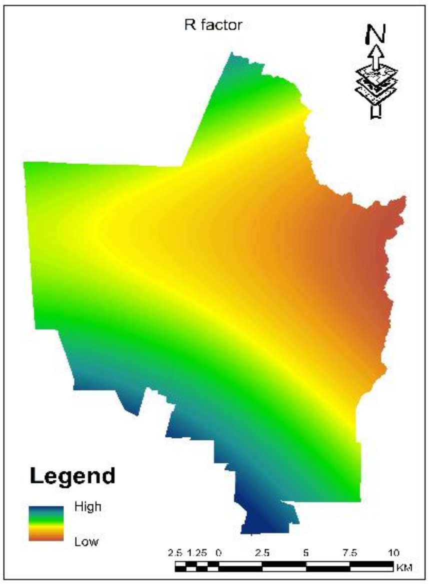

Figure 3. Map of R factor

Rainfall varies within the interval of 1846 mm up to 2240 mm and this is applicable for the 12 stations. The month of January has marked the least amount average of 84 mm whereas November received the highest amount of rainfall with approximately 300 mm.

$$R_{ann}\left[4.17 \times \sum_{i=1}^{12}\left(\frac{p2i}{p}\right)\right] \quad (2)$$

where Pi represents the average amount of rainfall (mm) for a determined month *i*, P represents the yearly averaged amount of rainfall (mm), and Rann represents the yearly averaged R at the Seremban. The factor (K) which represents Soil erodibility put an emphasis on measuring the features of soil type and its resilience to dislodging and flooding due to rainfall. Figure 4 presents the factor K extracted from diverse soil series of the region of Seremban [2].

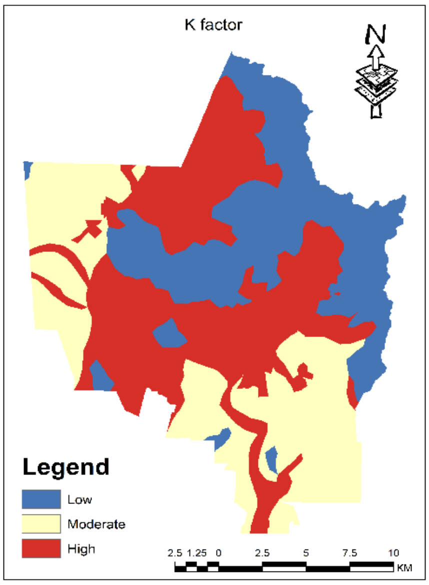

Figure 4. Map of K factor

Table number 2 displays the K value for different types of soil in Seremban. Each soil type's K factor is determined to identify its chemical and physical features, which plays a vital role in contributing to the potential of erosion. Morgan stated that the K values could be observed by the color of the soil. This serves as a sign of the soil's potential to erode and can help generate estimates of the likely volume of soil loss.

Table 2. Soil types in the study area

Soil series (types)	*K* factor
Durian-Malaka	0.003
Serdang	0.002
Renggam	0.001
Telemong	0.005
Steep land	0.003
Renggam	0.005
Alluvium	0.002
Urban land	0.006

The original vector format soil map was converted into grid (raster) format which was then reclassified based on the K factor value for each soil class. Slope Length-Steepness (LS) factor. The factor of LS determines the impact exerted by local topography on soil erosion rate, cumulating impacts of the length of slope (L) and the steepness of the slope (S) as a function of the assumed soil loss ratio for each unit area. Figure 5 presents the factor of LS extracted from the selected slope [8].

Figure 5. Map of LS factor

The L and S parameters were derived from the 20m resolution. USLE commonly combines the gradient of the slope (S) and the length of slope (L) within a sole factor.

$$LS = \left(\frac{As}{22.13}\right) 0.6 \left(\frac{\sin B}{0.0896}\right) 1.3 \tag{3}$$

where LS represents the upslope related to the contributing area, A depicts the aggregated power theory for unit stream's movement that put an emphasis on water and sediments, as depicted in Equation number 3, and P represents the slope measured in degrees. Conservation practice factor (P) The P factor seeks to control erosion by determining the ratio of soil loss [9].

This factor considers the control practices which reduce the eroding strength of runoff and rainfall through their effect on the patterns of drainage, the concentration of runoff and its speed. Table 3 presents the P-factor map generated to understand the conservation practices observed in the sample area. Figure 6 comprises diverse sorts of practices of agricultural management such as contouring, strip cropping and terracing [10]. The map related to P-factor was extracted the map of land cover and land use, the P value was allocated to every land cover and land use slope and sort.

Table 3. P factor in the study area

Land use	*P* factor	Land use	*P* factor
agricultural stations	0.40	orchards	0.40
Coconut	0.50	Mining area	1.00
Diversified crops	0.45	Paddy	0.50
estate buildings areas	0.40	recreational area	0.60
Fish and hyacinth ponds	0.50	rubber	0.40
Forest	0.10	Scrub	0.20
Mixed horticulture	0.40	Swamps	0.50
newly cleared land	0.70	Urban area	1.00
lowland forest	0.10	Water	0.50

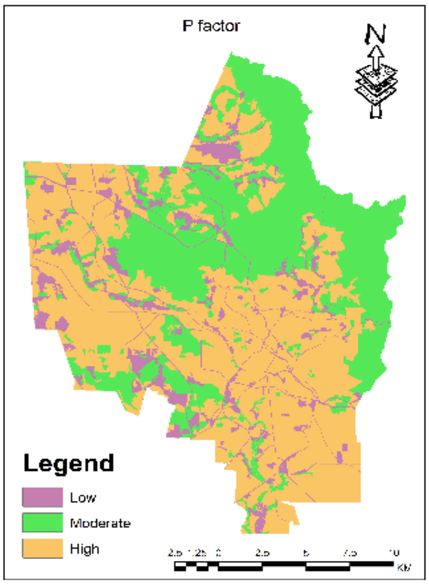

Figure 6. Map of P factor

The (C) factor represents Cover and management this factor indicates the rate of soil erosion of land with some unique vegetation relative to soil erosion It is the single factor that is most easily changed and is often considered in conservation planning. The major types of land use and land cover were determined based on unsupervised classification [11]. The data were then converted to vector format. The literature was reviewed to obtain the corresponding management factor value from which the raster map of the C-factor was produced (Figure 7). All the grid factor maps have been covered to result in soil loss map (Figure 8). Table 4 is the quantitative result of the soil erosion (tone hectare per year) indicating the severity of erosion potential.

Table 4. Actual soil erosion (t/ha/year)

class	Actual soil erosion (soil loss per t/ha/year)	Erosion potential
1	Very low	0 – 1
2	low	1 – 5
3	Moderate	5 -10
4	High	10 – 20
5	Very high	20 – 50
6	Extreme	< 50

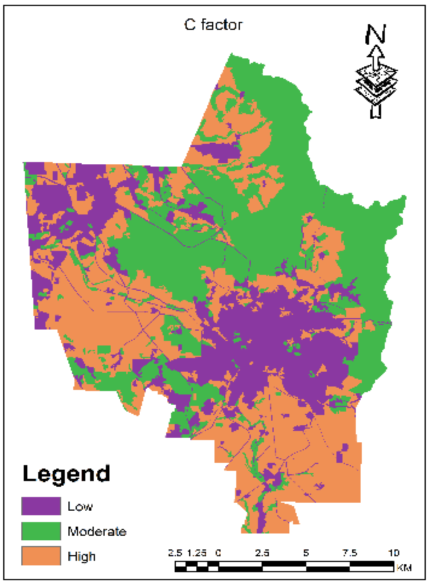

Figure 7. Map of C factor

3.2. Soil erosion outcome

The extent of erosion corresponds directly to the different land cover (LC) classes. This study found that this relationship has an indirect relationship with urban regions and direct relationship with the remaining regions. Open regions (bare land) are most susceptible to agricultural land that preceded soil erodibility due to its loose soil[12]. Erosion in urban areas decreased possibly due to the growth of settlements with significant impervious surfaces. In the urban areas, the C and P factors render the soil more resilient to erosion. Seremban's recorded an annual soil erosion of 883 tonnes/hectares/year. The majority of soil loss occurred in open spaces with 610.11tonnes/hectares/year, 198.44 tonnes/hectares/year in agricultural areas, 39.81 tonnes/hectares/year in forests, 20.45 tonnes/hectares/year in rural areas, 12.8 tonnes/hectares/year Urban and 1.39 tonnes/hectares/year for water bodies (Table 5).

Table 5. Distribution of soil erosion classes (ton/ha/year) in different types of land cover in the study area

Land-cover class	Area (km2)	Mean annual soil loss (ton/ha/year)
agriculture	592.5198	198.44
Forest	266.2632	39.81
Rural area	33.6891	20.45
open space	10.9470	610.11
Urban	45.4537	12.80
Water body	3.0011	1.39
total-Area	951.8739	883.00

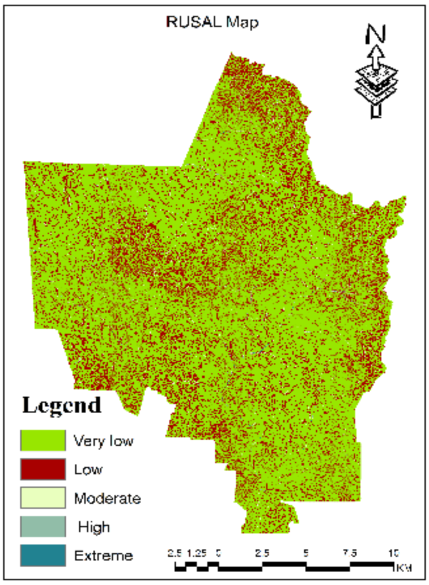

Figure 8. RUSAL Map

The rise in erosion could stem from deforestation and the increasing oil palm and sectors related to agriculture that have played key role in augmenting the erosion of the surface. The districts of Lenggeng, Panti, Setul, and Ampangan recorded less soil erosion while Seremban and Rasah recorded moderate soil erosion, and Pantai and Rentau had the highest levels of soil loss in that region.

4. Conclusion

By applying the USLE model, we noticed that the current soil erosion for every hectare per annum and the soil loss yearly average are 610, 198 and 39 tons for every hectare per year respectively. This results from the combined effects of deforestation and an expanding oil palm and agriculture sectors which increased surface runoff. Most of the basin areas (located mainly in forest areas) recorded low level of soil loss that ranges between 0 up to 1 ton for every hectare on an annual basis) Extreme levels of erosion (above 100 tonnes/hectare/year) can be easily perceived mainly in open areas, oil palm and agriculture as well. The skyrocketing rate of deforestation and random land clearing that the region of Seremban has witnessed urban expansion and infrastructural severe soil erosion is the aftermath of development. Besides, soil erosion has become rampant and prevalent and is by far a serious issue As such, further study is required for more effective policy and mitigation efforts.

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