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Integration of GIS-Based RUSLE Model for Land Planning and Environmental Management in Ranau Area, Sabah, Malaysia

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Soil erosion is an issue which is still under debate in the newspapers or any electronic media, especially in area like Ranau, Sabah. Triggering factor of soil erosion is often associated with agricultural, deforestation and development activities that did not consider of environmental sustainability. Ranau, Sabah have been used as experimental laboratories for Revised Universal Soil Loss Equation (RUSLE) study. The main objective of this study is to determine the annual soil loss rate (A) value by the average annual of soil loss rate (RKLSCP). There are six factors parameter maps were considered in RUSLE as rainfall erosivity factor (R), soil erodibility factor (K), slope length factor (L), slope steepness factor (S), crop and management factor (C), and conservation supporting practices factor (P). Analyses results indicate that the influence of the C and P are important in the determination of the soil erosion rate for an area. All findings showed that integration of GIS can be used for spatial analysis in a large scale. Production of A total value maps can be applied to particular development planning areas especially for housing and agriculture developments.

Keywords: revised universal soil loss equation (RUSLE); empirical model; soil erosion

I. INTRODUCTION

Soil erosion is an issue that is debated in the newspapers or any other electronic media. Triggering factor for soil erosion is often associated with agricultural activities, deforestation and development that do not preserve environmental sustainability. Mechanisms of soil erosion occur when water cannot penetrate into the ground and becomes surface runoff and transport of soil on the surface when descending slopes. Land to be impermeable due to several conditions: first when the rainfall intensity exceeds the absorptive capacity of the surface and second when the groundwater level is at a level parallel to the ground. The process of soil erosion may indirectly result in the loss of natural resources gradually and affect long-term productivity of the land. In addition, soil erosion also leads to deterioration of the quality of surface water or ground water due to the increase in turbidity due to sediment transport and may contribute to the occurrence of some event such landslide and flooding hazards.

Research topics related to soil erosion has its own history and scientific basis underlying all been researched for decades. However recently, continue to review progress and are increasingly focused on the topic in more detail about the modeling mechanisms. In general, there are three types of soil erosion models in different research that (1) Empirical model (Table 1), which represents the natural environment or that are based on statistical observations of the empirical (Nearing *et al.*, 1994). This model is often used for modeling complex process, particularly useful to identify the source of sediment (Merritt *et al.,* 2003). (2) Physical-based model (Table 1) represent the natural processes that describe each system by consolidating individual physical processes of more complex models.

The equations in the model formula are illustrated by natural processes such as stream flow or sediment transport (Merritt *et al.*, 2003). Perfection in this model can explain

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the spatial variability of its most important features found on the soil surface as topography, aspect, slope, vegetation, soil, climate and various other parameters including precipitation, temperature, and evaporation (Legesse *et al.*, 2003). (3) Conceptual model is a mixture of empirical and model-based physical model (Table 1) and its application more applicable to answer general questions related to catchment processes (Beck, 1987; Merritt *et al.*, 2003).

Table 1. The variety of research models in soil erosion rates (modified from Merritt *et al.,* 2003).

Model types	Model Methods	References
Empirical model	Musgrave Equation	Musgrave (1947)
	Pacific Southwest Interagency Committee (PSIAC) Method	Pacific Southwest Interagency Committee (1968)
	Dendy-Boltan Method Flaxman Method	Flaxman (1972)
	Equation (MUSLE) Sediment	Renfro (1975)
	Delivery Ratio Method	Dendy & Boltan (1976)
	Universal Soil Loss Equation (USLE)	Wischmeier & Smith (1978)
	Soil Loss Estimation Model for South Africa (SLEMSA)	Elwell (1978)
Physical-based model	Sediment Concentration Graph	Johnson (1943)
	Erosion Kinematic Wave Models	Hjelmfelt *et al.*(1975)
	Renard-Laursen Model	Renard & Laursen (1975)
	Quasi-Steady State	Foster. Meyer and Onstad (1977)
	Areal Non-point Source Watershed Environment Response Simulation (ANSWERS)	Beasley *et al.* (1980)
	Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS)	Knisel (1980)
	Water Erosion Prediction Project (WEPP)	Laflen *et al.* (1991)
	European Soil Erosion Model (EUROSEM)	Morgan (1998)
Conceptual model	Unit Sediment Graph	Rendon-Herrero (1978)
	Instantaneous Unit Sediment Graph	Williams (1978)
	Sediment Routing Model	Williams & Hann (1978)
	Discrete Dynamic Models	Sharma & Dickinson (1979)
	Agricultural Catchment Research Unit (ACRU)	Schulze (1995)
	Hydrologic Simulation Programme, Fortran	Walton & Hunter (1996)

II. GEOLOGY

The geology of the study area is made up of three sedimentary rock formations: the Trusmadi Formation (Palaeocene to Eocene age), the Crocker Formation (Late Eocene age) and the Pinousuk Gravel (Late Pleistocene to Holocene age).

The Trusmadi Formation consists of interbedded dark shale and sandstone. The Trusmadi Formation is exposed at the foot of the Mount Kinabalu and Ranau area. Low-grade metamorphism has occurred in some of the rocks of the Trusmadi Formation. The rock associations are highly sheared and brecciated with some cataclasites. The dark argillaceous rocks are thickly bedded or interbedded with sandstone and siltstone beds. The thickness of the argillaceous beds is about 100 feet, whereas the sandstone beds are about 120 feet at the foot of Mount Kinabalu area. Some volcanic rocks extruded through the Trusmadi Formation. Quartz veins are quite common in this Formation. The Trusmadi Formation can be divided into 4 main lithological units: shale, interbedded sandstone and shale (turbidities), cataclasites and thick sandstones.

The Crocker Formation forms the main exposure in the area where outcrops can be found along road-cuts, paths and excavations. The Crocker Formation can be divided into four main lithological units; namely thick bedded sandstone, thinly bedded sandstone and siltstone, red and dark shale and slumped deposits. Major exposures are moderately to highly weathered materials.

The Crocker Formation is characterized by monotonous rock facies, repetation of interbedded sandstone and shale strata, by isoclinal foldings and faults. The rough structure has been determined from statistical analysis of various structural elements and by the analysis of aerial photograph (Kasama *et al.,* 1970).

The Pinousuk Gravels are preserved south and west of Mount Kinabalu in three main areas: the Pinousuk Plateau, the Tohubang Valley, and near Tenompok. It is proposed to regard as the type section exposures those along Mantaki River, Mesilau River, Tawaras River and Bambangan River, flow through the Pinousuk Plateau at east - southern. The solifluction material is continuously distributed within the alluvium in which terraces have been developed along the Liwagu Valley and in the Tohubang Valley near Ranau. The angular to rounded clasts found in the Pinousuk Gravels are mainly granites and sedimentary rocks, embedded in a light brown to red brown matrix of sandy, silty and clayey materials. The Pinousok Gravels unconformable overlies the above discussed rock units and reach a maximum thickness of about 450 feet. The beds consist of poorly cemented gravel of various compositions and are considered as tilloid deposits. Division is possible into a lower unit consisting of silty to sandy gravel of angular to subangular clasts of either sedimentary or ultrabasic rocks, and an upper unit that is composed of clayey to sandy gravel of angular to rounded clasts of varied composition. The lower and upper units have been interpreted as pre-glacial solifluction deposits and as probable mudflow sediment containing reworked till, respectively (Tjia, 1974).

III. MATERIALS AND METHODS

A. *Revised Universal Soil Loss Equation (RUSLE)*

GIS applications are often used in the work of soil erosion analysis. Modeling soil erosion is often considered difficult because of the relatively complex interactions. Generally there are four factors to consider; soil, topography, land use and climate (Wischmeier & Smith 1978).

Overall approach of this paper will involve the use of models of revised universal soil loss equation (RUSLE). Although this model was found to have a lot of constraints and uncertainty, but it's very popular widely used throughout the world to date, especially in the tropics because it has the simplicity and relative robustness and uniform approach (Aniya, 1985; Balamurugan, 1991 ; Kerte'sz, 1993; Gokceoglu & Aksoy, 1996; Lenzi & Luzio, 1997; Larsen & Torres-Sanchez, 1998; Turrini & Visintainer, 1998; Guzzetti *et al.,* 1999; Sharma *et al.,* 1999; Huffman *et al.,* 2000; Jibson *et al.,* 2000; Brazier *et al.,* 2001; Millward & Mersey, 2001; Beatriz *et al.,* 2002; Bissonnais *et al.,* 2002; Martı'nez-Casasnovas, 2003; Huabin *et al.,* 2005; etc.).

Precipitation, topography, soil type and land use as a database that will be used in the analysis. Each developed vector data will be converted into raster data. For raster data, the space is divided evenly into pixels in a square shape that has the same size. Value is stored for each pixel determines the type of an object or situation that is available in every location. Thus, in the approach to raster data, the space occupied by a number of uniform pixels, each of which has different values (Figure 1).

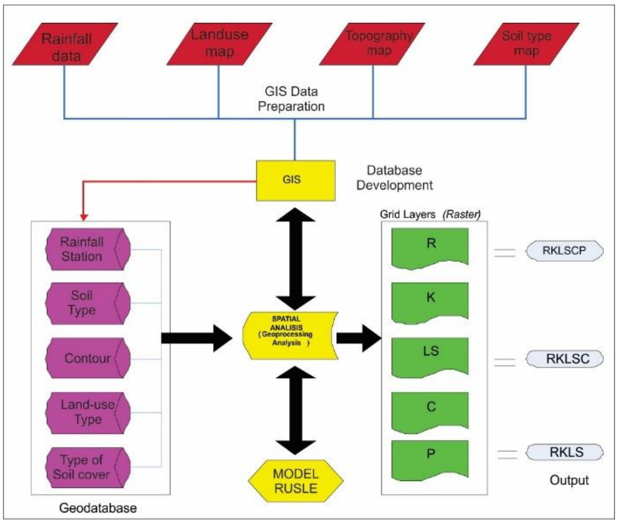

Figure 1.Research framework and methodology.

IV. RESULTS

In this study, the RUSLE is used to estimate the total value of A is expressed as mass per unit area per year (t / ha / year). RUSLE used widely as a model to predict soil loss on any field condition which involves soil erosion by water. RUSLE equation (Equation 1) was used in the GIS environment to determine the total value of A and its distribution. This equation predict the loss of land for an area based on six parameters such as rainfall erosivity factor (R), soil erodibility factor (K), slope length factor (L), slope steepness factor (S), cultivation and management factor (C) and conservation support practice factor (P) which are all evaluated numerically.

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

A. *Rain Erosivity Factor (R)*

The rate of soil erosion is associated with rain seepage strength to break the soil surface and cause surface runoff (water runoff) occurs (Morgan et *al.,* 1998). R values were calculated based on the equation that was introduced by Morgan (1974), by referring to the annual average rainfall and intensity data for 30 minutes at a maximum for each rain gauge stations in Ranau area, which obtained from the Malaysian Meteorological Department. Equation (2) by Morgan (1974) was chosen because it has been proven successful in several previous studies to tropical countries, especially in Malaysia.

R = [(9:28 * P) - 8838] * 0.075 (2)

Where,
P = annual average rainfall
I_{30} = rainfall intensity for 30 minutes (75mm)

The rain gauge stations in the study area have been registered into the GIS map format by entering the coordinate position. The average rainfall for each rainfall station will be used as input into the file attributes in the GIS (Figure 2). Based on the input, the estimated rainfall for the Ranau area is done by using the Thiessen polygon method which is a better method than the method of calculation Aritmetrik rainfall areas (Chow *et al.,* 1988).

B. Soil-Erodibility Factor (K)

K is the soil-erodibility factor which measure erodibility for a standard condition. This standard condition is the unit plot, which is an erosion plot 72.6 ft (22.13 meters) long on a 9 percent slope, tilled up and down hill periodically to control weeds and break crust that form on the surface of the soil.

Soil erodibility factor represents both susceptibility of soil to erosion and the rate of runoff, as measured under the standard unit plot condition. Soils high in clay have low K values, about 0.05 to 0.15, because they resistant to detachment. Coarse textured soils, such as sandy soils, have low K values, about 0.05 to 0.2, because of low runoff even though these soils are easily detached. Medium textured soils, such as the silt loam soils, have moderate K values, about 0.25 to 0.4, because they are moderately susceptible to detachment and they produce moderate runoff.

Soils having high silt content are most erodible of all soils. They are easily detached; tend to crust and produce high rates of runoff. Values of K for these soils tend to be greater than 0.4. Organic matter reduces erodibility because it reduces the susceptibility of the soil to detachment, and it increases infiltration, which reduce runoff and thus erosion. Addition or accumulation of increased organic matter through management such as incorporation of manure is represented in the C factor rather than the K factor. Extrapolation of the K factor nomograph beyond on organic matter of 4% is not recommended or allowed in RUSLE. In RUSLE, factor K considers the whole soil and factor Kf consider only the fine-earth fraction, the material of <2.00mm equivalent diameter. For most soil, Kf = K.

Soil structures affect both susceptibility to detachment and infiltration. Permeability of the soil profile affects K because it affects runoff. Although a K factor was selected to represent a soil in its natural condition, past management or misuse of a soil by intensive cropping can increase a soil's erodibility. The factor K may need to increase if the subsoil is exposed or where the organic matter has been depleted, the soil's structure destroyed or soil compaction has reduces permeability.

In this study, the K factor for each soil type data obtained from the State Department of Agriculture based on the parent material. After the entry of all data attributes carried out for each soil type in the spatial database in vector format, it was later converted into a spatial raster format using the Conversion in Arc tool Box on raster pixel size of 10 x10 square meters (Figure 2).

C. Slope Length and Steepness Factor (LS)

The LS can be used in an index (Wischmeir & Smith, 1978). Emprical equation calculating the LS was introduced by USDA Agriculture Handbook No. 537 (Offline. Wischmeier & Smith, 1978). This equation can be changed according to the suitability of an area. In this study, the formula used is based on the equations introduced by Moore & Burch (1986) (Equation 3).

LS = (flow accumulation cell size * / 22.13) ^ 0.4 * (sinslope / 0.0896) ^ 1.3 (3)

Flow accumulation was the theme of the accumulated flow grid described as the number of pixels grid, while the cell size is the length size of pixels in the grid theme. ArcGIS 9.3 application that is used to get the LS is through instruction in Hydrology tools and surface tools. To obtain the values for L and S, the digital elevation model (DEM) in advance will be generated from the topographic map contour gaps of 10 meters. The DEM is converted into raster format. To get the L, DEM data produced requires several stages of the generating process as fill DEM, flow direction and flow accumulation. While for the S, generation steepness also made by DEM data. After the process of generating the values of L and S is complete, the calculation / multiplication will then be made based on the Equation (4) by Moore & Burch (1986) using the raster calculator in Spatial Analyst extension (Figure 3). Figure 2 show the map of LS value of the study area.

LS = Pow ([Flow accumulation] * 10 / 22:13, 0.4) * Pow (Sin ([slope] * 0.01745 / 0.0896, 1.4) * 1.3 (4)

D. Cover-Management Factors (C)

The value of C is defined as the ratio of soil loss from the soil surface with a specific plant continuously until exposed (Wischmeier & Smith, 1978). Its value depends on the soil covers, management practices, and the growth and protection at any time of the rain can cause erosion. In this study, the value of C is determined based on the type of land use in the study area. After the digitization process, the process of data entry attribute and spatial format conversion from vector to raster (grid) is performed, the value of C will be matched with land use maps using reclassify as has been suggested by Wischmeier & Smith (1978) (Table 2 and Figure 2).

E. Supporting ConservationPractices Factors (P)

P values are in the range of 0 to 1 (Table 3) and depend on land management activities in the study area. In this study, the P value for each of the types of soil obtained from Hashim (2004) based on the classification of types of land use (Figure 2).

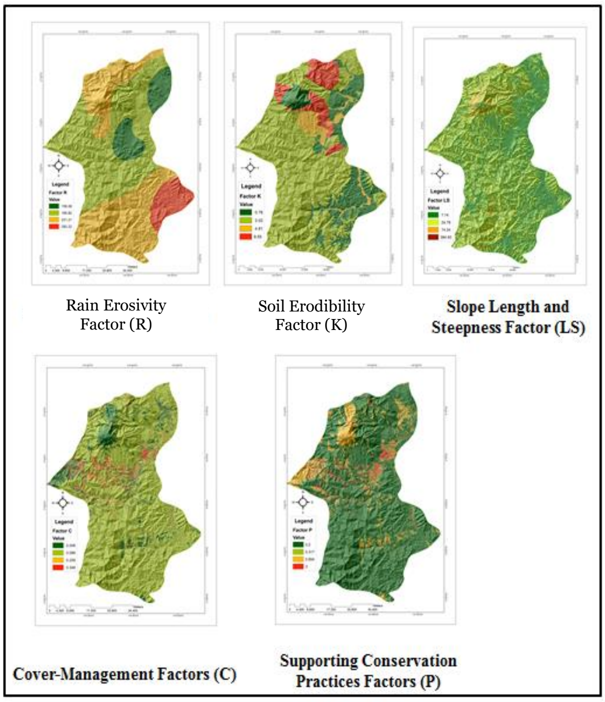

Figure 2. USLE factors using in Annual Soil Loss Value Analysis determination

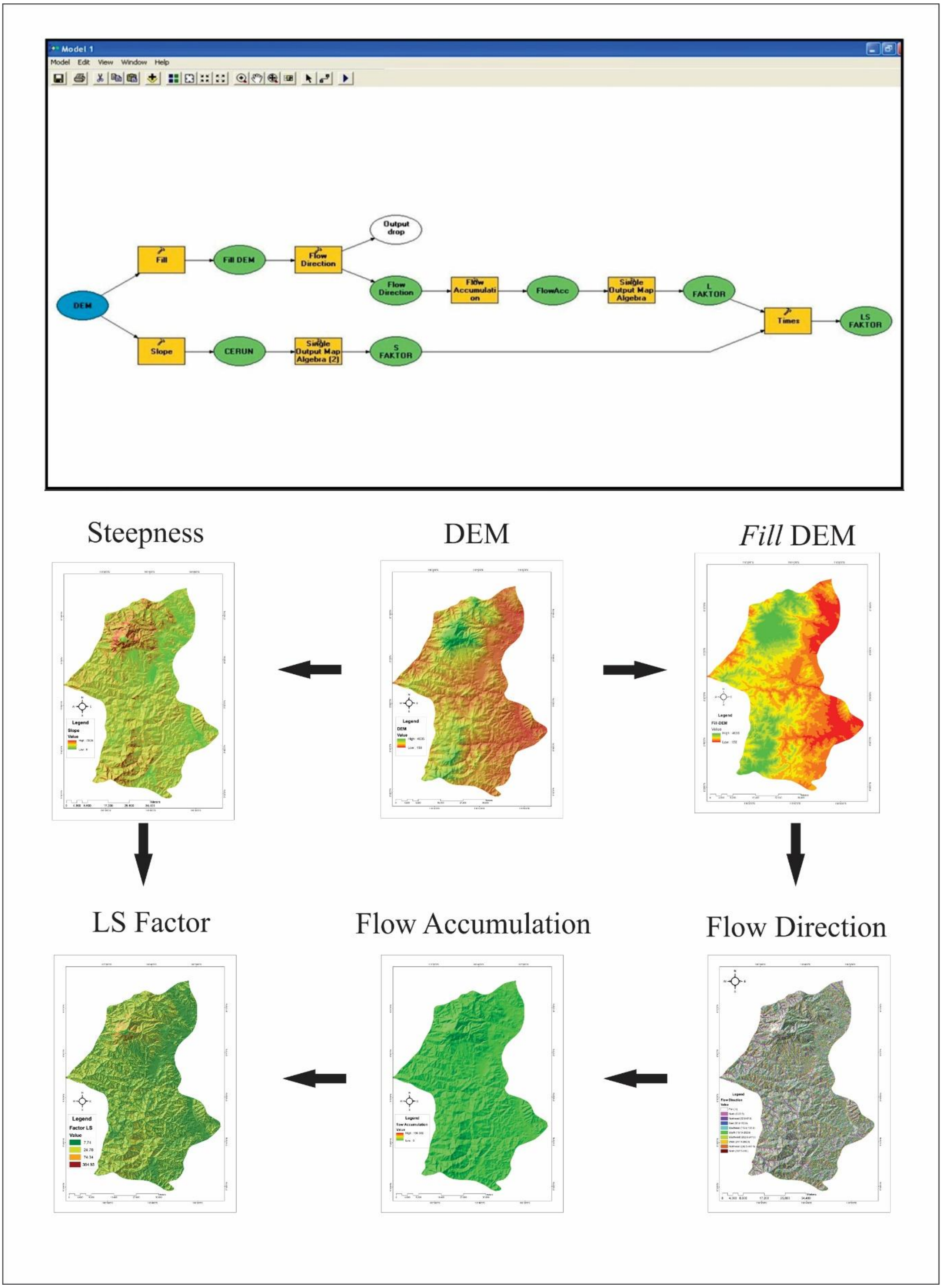

Figure 3. Geoprocessing approach by using the ModelBuilder™ to produse new maps for LS factor.

Table 2.Class of land-use types used to determine C value for the study area (after Hashim, 2004).

Land Use Code	Land Use Types	P Value
1U	City	1
1X*	Mine and quarry	1
2H*	Varied Horticulture	0.25
2M*	Market Cultivation	0.25
3GM	Mature Rubber	0.25
3GS	Aged Rubber	0.25
3H*	Fish Pond and Yam	0.1
3X*	Orchard	0.5
4P*	Paddy Area	0.25
6*	Grass	1
7F*	Forest	0
7S*	Bushy Area	1
8*	Morass Area	1
9	Neglected Area	1
W*	Water	0

Table 3.Class of land-use types used to determine P value for the study area (after Hashim, 2004).

Land Use Code	Type of Land Use	C Value
1U	City	0.005
1X*	Mine and quarry	1
2H*	Varied Horticulture	0.2
2M*	Market Cultivation	0.2
3GM	Mature Rubber	0.2
3GS	Aged Rubber	0.2
3H*	Fish Pond and Yam	0.1
3X*	Orchard	0.2
4P*	Paddy Area	0.1
6*	Grass, Unutilized land	0.001
7F*	Forest	0.001
7S*	Bushy Area	0.01
8*	Morass Area	0.001
9	Neglected Area	1
W*	Water	0

F. *Average Annual Soil Loss Value Analysis (A)*

To obtain the final output raster calculator, multiplication process between layers of thematic maps in USLE model will be done. To get the total value of A, all six parameters map USLE factors (R, K, LS, C and P) will be multiplied based on the equation (1) refers to the Model Builder ™ frame layout which was designed (Figure 3).

V. DISCUSSION

A. *Average Annual Rate of Land Loss (RKLSCP)*

Calculation of the total value of A was carried out based on the risk classification of soil erosion (Table 4). This classification is determined by using reclassify techniques and for the purpose of statistical analysis, it uses the zonal attributes. For the purpose of conversion of land into acres, each number of pixels (count) will be multiplied by 100 (10 * 10 square meters) and then divided by 10,000. In terms of soil erosion risk classification (Figure 4), the calculation of the RKLSCP (total value of A) for the study area suggests that 24.38% (12.26 hectares) as Very Low Risk, 32.41% (16.30 hectares) as Low Risk, 27.81% (13.99 hectares) as Medium Risk, 5.75% (2.89 hectares) as High Risk and 9.66% (4.86 hectares) as Very High Risk (Table 5). In general, the risk was "very low" to "low" refers to the slope of the horizontal (<15°) or moderately steep (16° - 25°). Conversely, areas with "high" to "very high" represent segments steep slopes (> 25°), upland areas and the banks of the creek. As a result of this decision emphasizes the importance of the potential impacts of soil erosion in the study area, which can be considered to represent a large part of Ranau area.

Table 4. Classification of average soil loss risk.

Total soil loss erosion (tons/ha/year)	Risk Level
<10	Very Low
11- 50	Low
50-100	Moderate
101-150	High
>150	Very High

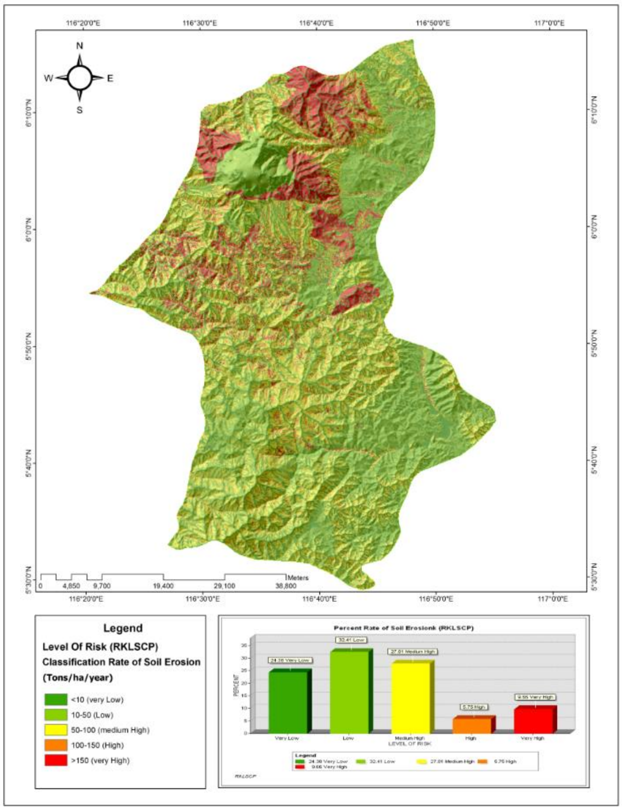

Figure 4.Map of average annual soil loss (RKLSCP) of the study area.

Table 5. Average annual soil loss rate (RKLSCP).

Class Of Average Soil Loss Risk	Total soil loss erosion (tons/ha/year)	Area Wide (Meter^2)	Area Wide (Hectare)	(%) Soil Loss
Very Low	<10	122,592	12.26	24.38
Low	11- 50	162,978	16.30	32.41
Moderate	50-100	139,869	13.99	27.81
High	101-150	28,913	2.89	5.75
Very high	>150	48,582	4.86	9.66
Total		**502,934**	**50.3**	**100**

VI. RELATIONSHIP BETWEEN CLIMATE CHANGE AND EROSION

Few problems are more fundamental to the study of geomorphology than the relationship between climate and erosion. The role of climate as a driver for erosion and sediment transport is important to surface processes that act over timescales ranging from individual storms to millions of years. Consequently, the research questions pursued here have direct implications for problems of immediate societal relevance including climatic impacts on reservoir

sedimentation rates, natural hazards, and rates of soil erosion. Not surprisingly, climate's role in surface processes is equally central to fundamental problems in allied fields like geochemistry, sedimentology, tectonics, and geodynamics. In geochemistry, there is a great deal of interest in how climate controls silicate weathering rates, a key feedback in the carbon cycle: silicate weathering extracts atmospheric carbon dioxide and thus acts to cool the planet. Recent data shows chemical weathering rates can be strongly modulated by physical erosion rates (Sidle & Ochiai 2006; Tobe & Chigira 2006). As such, the question of how strongly climate controls physical erosion rates becomes directly relevant to the carbon cycle and global climate.

In sedimentology, geologists studying the sedimentary record have long faced a difficult challenge in isolating climatic from tectonic controls on detrital and chemical fluxes into depositional basins. At its core, this requires at least an accurate qualitative (preferably quantitative) understanding of the degree to which climate influences erosion rates. And lastly, in tectonics and geodynamics, there is vigorous inquiry into the potential for dynamic two-way interactions between climate and tectonics on million-year timescales. The expected, but unproven, link between climate and erosion rate is the cornerstone of this extensive literature.

VII. CONCLUSION

The total value of A shows that the result of the RKLSCP is estimated as 46.33% of soil loss (1074.1 hectares). In terms of average soil erosion risk classification, for the class of very low to medium, the results for the total RKLSCP showed the highest value of 24.38%, 32.41% and 27.81% respectively with an area of approximately 42.55 hectares. The findings prove that integration of GIS spatial analysis is able to scale the region. The maps of total value of A produced can be used as a reference for development planning area, particularly agricultural and residential development.

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