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SOIL LOSS PREDICTION USING REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE) MODEL IN KUNDASANG, SABAH

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ABSTRACT. *Soil erosion poses a significant environmental issue in Kundasang, Sabah, which is situated in the highlands and is recognized for its soil erosion challenges. The natural forces of water gradually wear away the topsoil of fields, leading to soil erosion. This phenomenon is often exacerbated by various triggering factors such as agricultural practices, deforestation, and unsustainable development. The region is particularly noted for its temperate vegetable cultivation. This study aimed to spatially estimate potential soil loss or erosion using the Revised Universal Soil Loss Equation (RUSLE) model. The RUSLE model incorporates six parameters, all expressed quantitatively in an equation to calculate soil erosion for a specific area. These parameters include rainfall erosivity (R), soil erodibility factor (K), slope length and steepness factor (LS), cultivation and management factor (C), and conservation support practice factor (P). The analysis leverages databases of soil types, topography, land use, and precipitation. The results indicate that only 3.11% (271.92 ha) and 0.72% (62.51 ha) of the study area is categorized as having high and very high erosion potential, respectively.*

KEYWORDS: Erosion, GIS, Kundasang, Soil loss, RUSLE model

INTRODUCTION

Soil erosion is a significant global issue that warrants serious attention. In highland regions, soil erosion involves the detachment and displacement of soil material. This process results in the contamination of rivers, streams, and groundwater with pesticides, fertilizers, and other harmful agricultural pollutants (Gallaher and Hawf, 1997). Erosion can occur naturally or be accelerated by human activities. The rate of erosion varies considerably based on the area's topography and prevailing weather conditions (Hagen, 1991; Nyakatawa *et al*., 2001). It is often linked to multiple triggering factors, including unsustainable agricultural practices, deforestation, and development, which lead to the depletion of natural resources and adversely impact the long-term productivity of the land (Roslee and Sharir, 2018). Furthermore, soil erosion can lead to events such as landslides and flooding, negatively affecting the environment through issues like deteriorating water quality, road damage, land degradation, and increased sedimentation in rivers (Almouctar *et al*., 2021).

Kundasang, situated in the State of Sabah at the base of Mount Kinabalu, is a prominent region in Malaysia known for its highland vegetable farming. With an elevation exceeding 1,000 meters above sea level, Kundasang is categorized as mountainous (Gasim *et al*., 2009). The area produces a variety of vegetables, with a particular focus on five key types: carrots, spring onions, tomatoes, lettuce, and cabbage. Income pattern analyses indicate that increasing the area planted and the use of fertilizers could enhance vegetable income (Fujimoto & Miyaura, 2002). Nevertheless, large-scale vegetable cultivation and the excessive application of chemicals beyond recommended levels adversely affect downstream water resources, particularly the Liwagu River and the Labuk drainage system. These adverse effects include changes in water flow, increased sediment loads, and residues from agricultural chemicals (Sinun & Douglas, 1998; Sahibin *et al*., 2020). Erosion in vegetable fields, particularly along access tracks and on newly prepared beds, worsens these problems, especially when beds are oriented parallel to slopes, contrary to optimal agricultural practices for highland farming (Malaysian Standard, 2007).

Various erosion prediction models have been developed to calculate and estimate soil erosion rates. The Universal Soil Loss Equation (USLE) determines the average soil erosion rate by taking into account factors such as soil type, rainfall patterns, crop management techniques, and topography (Fadzilah *et al*., 2019). The Revised Universal Soil Loss Equation (RUSLE) is an improved version of the USLE, which incorporates significant modifications including adjustments to rainfall data for particular locations, improvements to the soil erodibility factor, alterations to slope length and steepness, and specific updates to the cover management factor (Renard et al., 1997). In this study, the Revised Universal Soil Loss Equation (RUSLE) model was employed to estimate the average annual spatial soil loss in Kundasang area.

DESCRIPTION OF STUDY AREA

Kundasang is situated between the latitudes of 05°52'0" N and 06°5'0" N, and the longitudes of 116°33'0" E and 116°40'0" E. The primary geological composition of the study area includes ultrabasic rocks, particularly serpentinized peridotite, which forms part of the ophiolite basement. Additionally, it features sedimentary rock formations such as the Trusmadi Formation (dating back to the Paleocene and Eocene periods) and the Crocker Formation (from the Late Eocene). A significant portion of the landscape is covered by Pinousuk Gravel, which was deposited during the Pliocene to Pleistocene epochs (Colennette, 1958). The Crocker Formation is defined by four main lithological types: slumped deposits, red and dark shales, thick-bedded sandstones, and thin-bedded sandstones. It is characterized by its monotonous rock facies, alternating layers of sandstone and shale, along with isoclinal folding and faults. Statistical evaluations of various structural features and aerial photographs have highlighted these rugged textures (Kasama *et al*., 1970; Roslee, 2020).

The Trusmadi Formation, located around the Mount Kinabalu and Ranau regions, comprises four key lithological units: thick sandstones, cataclastics, interbedded sandstone and shale (turbidites), and shale. This formation is notable for its alternating layers of dark shale and sandstone that include numerous quartz veins, with some rock units showing signs of low-grade metamorphism (Jacobson, 1970). Pinousuk Gravel is a tilloid deposit made up of granite boulders embedded in a matrix of mud and sand, transported by glacial activity from Mount Kinabalu and its vicinity (Colennette, 1958). The sedimentary rocks consist of angular to rounded clasts set within a light brown to red-brown matrix of sandy, clayey, and silty materials (Hennie *et al*., 2019; Roslee, 2020). Pinousuk Gravel is primarily found in three main locations to the south and west of Mount Kinabalu: the Pinousuk Plateau, Tohubang Valley, and near Tenompok. The outcrops along the Tawaras River, Mantaki River, Mesilau River, and Bambangan River, which flow through the Pinousuk Plateau from east to south, serve as the type section. Based on the materials' roundness, size, and sphericity, Pinousuk Gravel can be categorized into two units: the Lower Unit and the Upper Unit (Jacobson, 1970; Tjia, 1974; Liew & Gue, 2001).

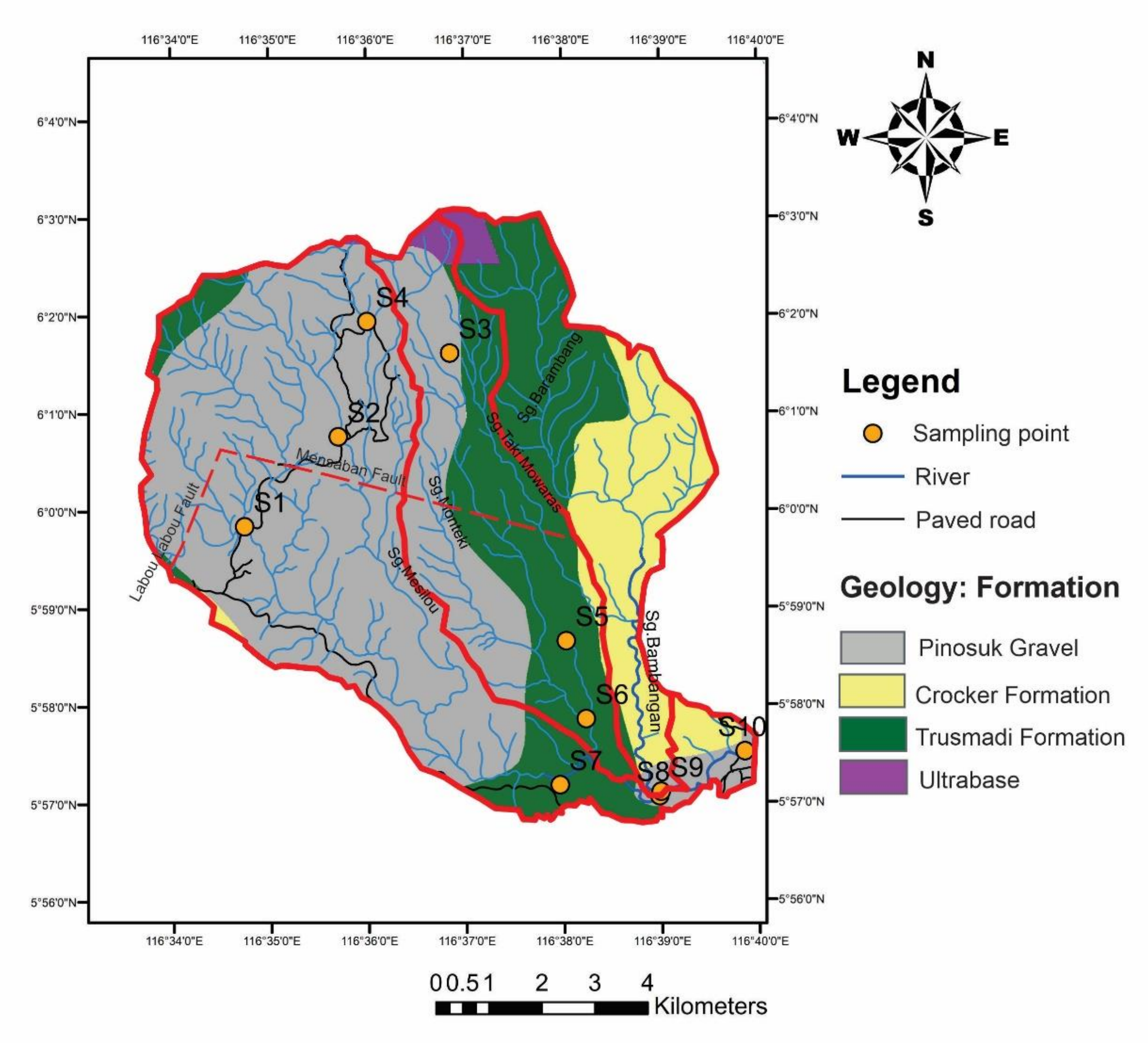


Figure 1. General geological map of the study area

MATERIALS AND METHODS

In the analysis of soil erosion, ArcGIS 10.8 software is utilized to enhance the study's accuracy. This research integrates Geographic Information System (GIS) applications with the Revised Universal Soil Loss Equation (RUSLE) model to estimate soil loss in specific locations (Yusof *et al*., 2019). The model considers five critical factors: the Rainfall Erosivity factor (R), the Soil Erodibility factor

(K), the Slope Length and Steepness factor (LS), the Cultivation and Management factor (C), and the Conservation Support Practice factor (P). These factors are combined to formulate an equation for predicting soil loss, which is presented in Equation 1 below:

$$A = R \times K \times LS \times C \times P \qquad (1)$$

Where A is the mean annual soil loss per unit area (ton ha^{-1} yr^{-1}); R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}); K is the soil erodibility factor (ton h^{-1} MJ^{-1} mm^{-1}); slope length and steepness produce LS factor; C is cultivation and management factor; and P is the conservation support practices factor.

The preliminary assessment suggests that Road 1 is the most preferred choice, followed by Road 3, while Road 2 is the least preferred option. It is important to highlight that the score differences between Road 1 and Road 3 are relatively minor. The scoring provides a broad evaluation of the unmitigated environmental impacts of each alignment in relation to site-specific conditions. Consequently, any alternative can be chosen, provided that the proposed mitigation measures are considered and put into practice. These measures are designed to reduce the project's impacts and support sustainable development objectives.

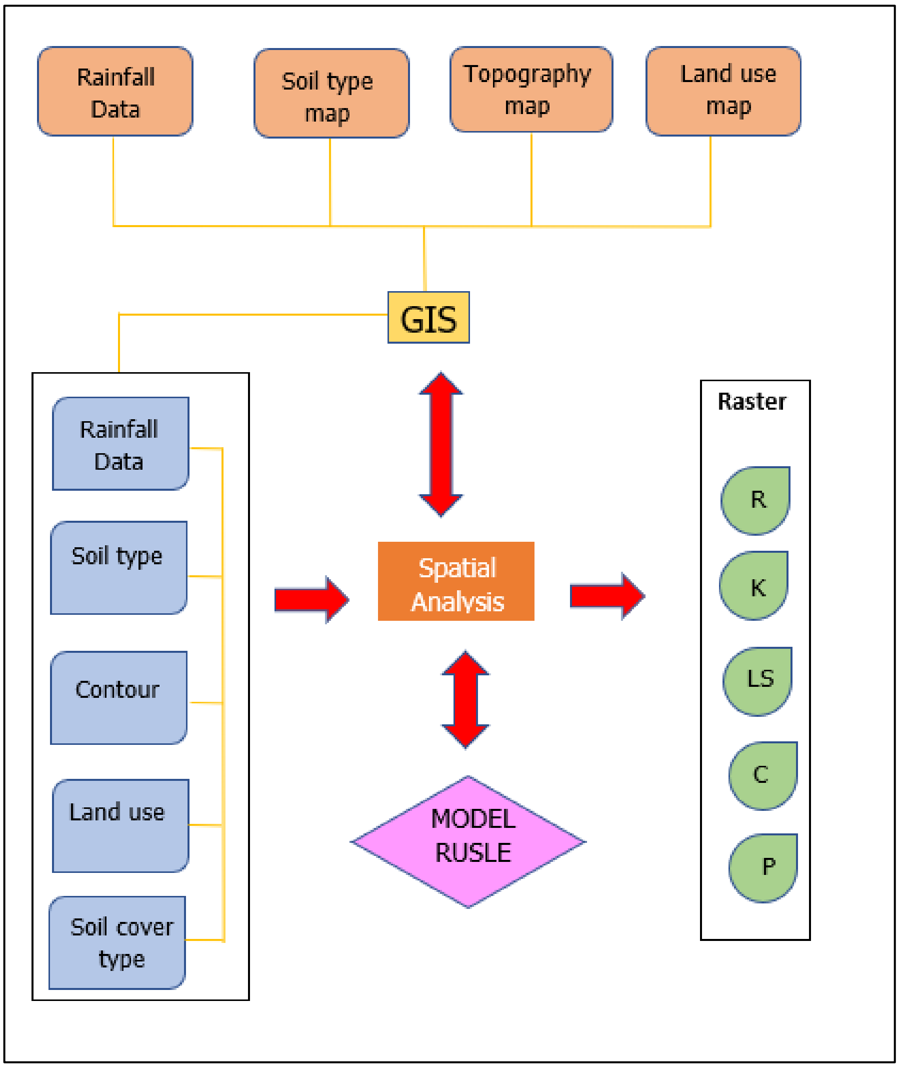


Figure 2. Flow chart for modelling soil erosion (Modified from Roslee *et al.*, 2017)

i. Rainfall Erosivity Factor (R)

Erosivity, which gauges the capability of rainfall to detach soil particles, is a crucial factor in evaluating soil erosion. It influences how rainwater penetrates the soil surface and subsequently generates surface runoff, which in turn affects the rate of soil erosion (Morgan *et al*., 1998; Rasooli, 2022). The erosivity factor is dependent on both the intensity and amount of rainfall. To assess this factor, precipitation data is utilized. Monthly rainfall data (in mm) from 2010 to 2019 was acquired from the Malaysian Meteorological Department in Sabah. The Equations 2 and 3 proposed by Roose (1977) and Morgan (2005) were employed, with the best estimates (Equation 4) taken as the final results.

$$R_M = \frac{[(9.28P - 8838.15)\times(75)]}{100} \tag{2}$$

$$R_R = 0.5\ P \times 17.3 \tag{3}$$

$$\text{Best estimation, } R_{MR} = \frac{(\text{Morgan} + \text{Roose})}{2} \tag{4}$$

P denotes the average annual precipitation for the study area. The mean annual rainfall recorded at each rainfall station is documented in the GIS file attributes. Subsequently, to create continuous raster rainfall data for the study area (Figure 3), the mean annual rainfall was computed using the interpolated rainfall data through the Inverse Distance Weighting (IDW) method.

ii. Soil Erodibility Factor (K)

The soil erodibility factor, K, represents both the amount and rate at which soil influences runoff, as well as its inherent susceptibility and resistance to erosion. Factors such as organic content, permeability, soil structure, and soil texture are utilized to determine the K factor. Soil maps for the study area were sourced from the Sabah Department of Agriculture. All data were documented in spatial vector format within attribute tables and subsequently converted to spatial raster format using conversion tools. The K factor was calculated in SI units using the Equation 5 below (Tew, 1999):

$$K = \frac{[1.0 \times 10^{-4}\ (12 - \%\text{OM})(\text{M})^{1.14} + 4.5\ (\text{S} - 3) + 8.0\ (\text{P} - 2)]}{100} \tag{5}$$

In this equation, K represents the soil erodibility factor (to convert it to SI units, this equation is divided by 7.59); OM denotes the percentage of organic matter; M indicates the product of the primary particle size fractions [(% modified silt or the 0.002-0.1 mm size fraction) multiplied by (% silt + % sand)]; S refers to the soil structure; and P signifies hydraulic conductivity. The calculated K factor values are presented in Table 1.

Table 1. Soil series with soil erodibility factor

Soil series	**Lithology (Geological Formation)**	**K value (ton h^{-1} MJ^{-1} mm^{-1})**
Bidu-Bidu	Ultrabasic Rock	0.019
Pinosuk	Pinousuk Gravel	0.006
Crocker	Crocker Formation	0.013
Trusmadi	Trusmadi Formation	0.032
Labau	Alluvium	0.021

(Source: Sabah Department of Agriculture, 2021)

iii. Slope Length and Steepness Factor (LS)

The contour topographical map of the Sg Liwagu basin, along with the digital elevation model (DEM) derived from a USGS satellite image at a resolution of 30 meters, is utilized to calculate the slope length and steepness, also known as the LS factor, for the study area. L represents the distance from the point where surface flow initiates to the location where runoff converges into a channel or where the slope gradient decreases, leading to the deposition of eroded sediments. S is evaluated using both percentage and angle measurements (Coote, 2002). The calculation for the LS factor is outlined in Equation 6, where L represents the slope length (in meters) and S denotes the slope angle (in percentage).

$$\mathrm{LS} = (0.065 + 0.046S + 0.065S^2) \times \sqrt{\mathrm{L}/22.13} \quad (6)$$

iv. Cultivation and Management Factor ©

The Cultivation and Management Factor © serves as an indicator of the effectiveness of soil and crop management practices in preventing or reducing soil erosion (Shelton, 2002). Known as the soil loss ratio, the C factor quantifies the amount of soil erosion from the surface caused by a specific plant over a continuous duration until the soil becomes exposed. This ratio directly correlates with land use type and its effects on the rate of soil erosion (Wischmeier & Smith, 1978). The C value is affected by management practices, the presence of soil cover, and protective growth during rainfall, all of which can contribute to erosion (Roslee & Sharir, 2019). The land use map was sourced from the Sabah Department of Agriculture. The C value is assessed based on the land use types within the study area, and C factors were assigned to each land use class according to recommendations from the Department of Irrigation and Drainage (DID, 2010). After the digitizing process, all data were converted from vector to raster format.

V. Conservation and Support Practices Factor (P)

The P factor measures the effectiveness of erosion control practices and is affected by the cover management factor (Vliet, 2002). It reflects the management strategies implemented in the study area. Depending on the land management activities in the region, P values range from 0 to 1. These P values are established based on the updated land use types and the variables suggested by the Department of Irrigation and Drainage (DID, 2010).

RESULTS AND DISCUSSION

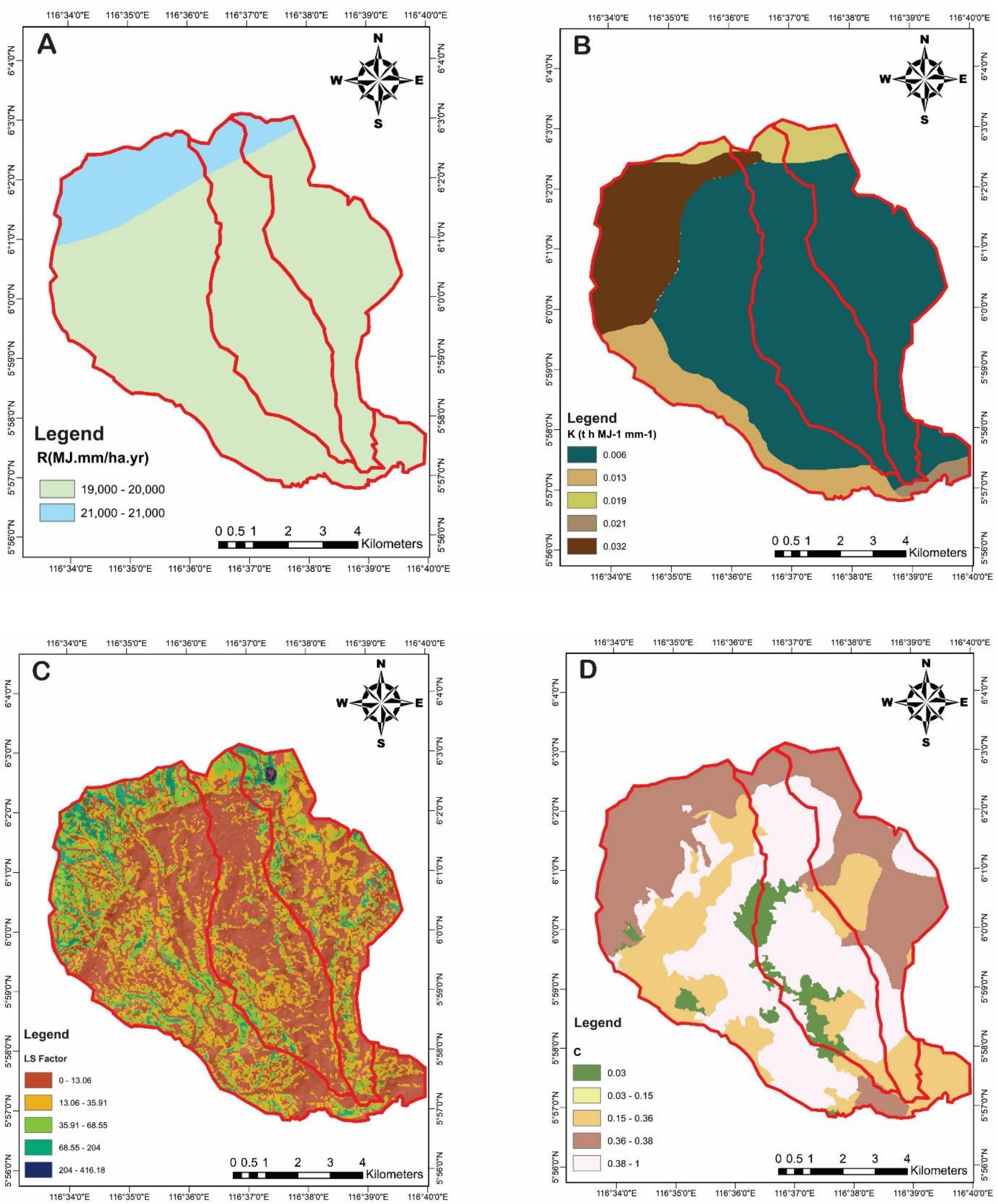
The soil erosion rate in the Liwagu River basin was assessed by integrating the erosion factors from the Revised Universal Soil Loss Equation (RUSLE) model into Geographic Information System (GIS) software. The calculated R value for the Liwagu River basin falls between 19,000 and 21,000 $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$. It was found that the northwest region of the study area exhibits the highest rainfall erosivity (21,000 $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$), indicating this area receives significantly more rainfall compared to other regions in the basin.

The basin contains five distinct soil types: Bidu – Bidu (Ultrabasic Rock), Labau (Alluvium), Crocker (Crocker Formation), Trusmadi (Trusmadi Formation), and Pinousuk (Pinousuk Gravel), each with varying K factor values (Table 1). Pinousuk soil is the most prevalent, covering 67.77% (6,218.06 ha) of the total area, followed by Trusmadi at 14.61% (1,340.41 ha), Crocker at 9.49% (870.62 ha), Bidu-Bidu at 6.79% (622.82 ha), and Labau at only 1.35% (123.83 ha). The K factor values in the area range from 0.006 to 0.032 $ton.ha^{-1}.h^{-1}.MJ^{-1}.mm^{-1}$, with an average K factor of 0.018 $ton.ha^{-1}.h^{-1}.MJ^{-1}.mm^{-1}$.

The sand content in the soil varies from 26% to 67%, clay ranges from 23% to 64%, and silt is between 3% and 51%. The soil structure codes in this area range from 3 to 4, and permeability scales vary from 3 to 4. Sandy soil, due to its high infiltration rate, is less prone to transport; in contrast, silt loam soil is more easily eroded, while clay soil tends to remain cohesive (Anees *et al*., 2018). Clay soils demonstrate resistance to detachment because they form stronger structures (Roslee, 2019), resulting in lower K values that range from 0.05 to 0.15. Likewise, coarse-textured soils, like sandy soils, generally have low K values between 0.05 and 0.2. The low K values for sandy soils are attributed to the reduced surface runoff expected when good infiltration conditions exist, despite their susceptible nature. Soils with high silt content are the most erodible due to their weak structure, making them easily detached and prone to collapse, which can obstruct surface soil pore spaces and lead to surface runoff. Specifically, soil with over 40% silt is highly vulnerable to erosion, while clay soils exceeding 30% clay content show significant resistance to erosion (Morgan, 2005; Roslee, 2019). Among the four soil types, Trusmadi has the highest K value at 0.032 $ton.ha^{-1}.h^{-1}.MJ^{-1}.mm^{-1}$, while Pinousuk, with its high sand content, presents a low K value of 0.006 $ton.ha^{-1}.h^{-1}.MJ^{-1}.mm^{-1}$ (Table 1).

Overall, an increase in both slope length and steepness contributes to a higher rate of soil erosion. Consequently, the LS factor is crucial as it measures the impact of topography and terrain on erosion occurrences. The LS map (Figure 3C) demonstrates that as slope steepness decreases, the potential for soil loss diminishes. In the study area, slopes tend to increase with elevation. LS values in this region range from 0 to 416.18, with the majority falling between 0 and 12, indicating that the slopes are slightly to moderately sloped. The influence of the LS factor in the study area is evident, as a significant portion shows a low potential for soil loss. Asmamaw and Mohammed (2019) found that on steeper slopes, the velocity and volume of surface runoff increase, significantly elevating the risk of soil erosion.

The land cover factor C and the erosion management practice P are interconnected. The C factor represents the land cover in the area, while P reflects the specific erosion management strategies employed. Factors influencing the C value include management practices, soil cover, and protective growth. The study area comprises six distinct land cover categories: urban area, scrubland, agricultural land, grassland, cleared land, and forest. Forests, which account for approximately 44% of the Liwagu River Basin, exhibit low C and P values, indicating minimal susceptibility to erosion. The dense canopy in forested areas reduces the risk of erosion, thereby protecting the soil from rapid loss. The P values depend on the land management practices within the study area and range from 0 to 1. The C and P factors were estimated following the guidelines of Morgan (2005) and the Department of Irrigation and Drainage (DID, 2010) (Table 2), with a C value of 0.39 for forests and 0.5 for agricultural areas. The P values are 0.1 for forested areas and 1 for urban areas. Practices such as contour farming and other agricultural methods can significantly mitigate soil erosion.



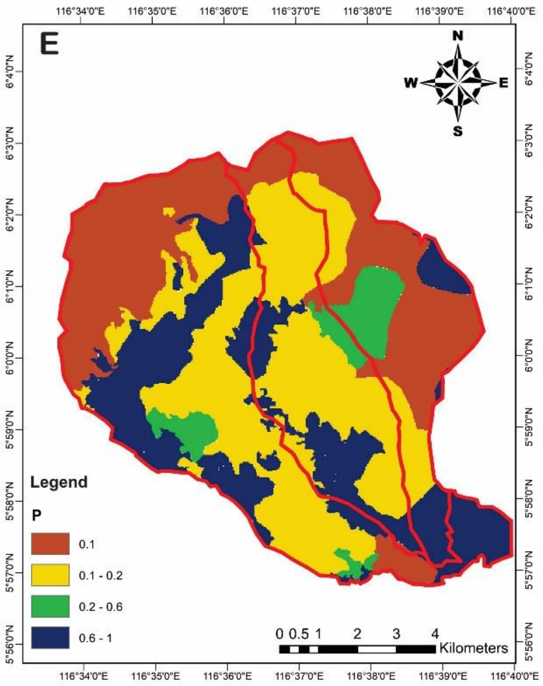


Figure 3. A) Rainfall erosivity factor (R), B) Soil erodibility factor (K), C) Slope length and steepness factor (LS), D) Cover management factor, E) Support practice factor (P)

Table 2. C and P factors for the land use map

Land Use	C factor	P factor
Urban Area	0.15	1
Scrub	0.35	0.2
Agriculture	0.38	0.14
Grassland	0.03	0.6
Cleared Land	1	1
Forest	0.01	0.1

Sources: DID (2010) and Morgan (2005)

The total value of A was calculated and categorized according to the soil erosion risk classification established by the Department of Irrigation and Drainage (DID, 2010). An assessment of potential soil erosion in the Ranau area, utilizing the RUSLE erosion model, indicated that the soil erosion risk class categorized as extremely high (>150 ton/ha/yr) accounts for approximately 4.7 – 9.66% of the Ranau area (Rendana et al., 2014; Roslee and Sharir, 2018). This finding was observed in the western part of Ranau, covering the highland regions of Tudan, Kundasang, Bundu Tuhan, and extending southward to the Nampasan area.

In this study, it was found that the Liwagu River basin has annual average soil erosion rates distributed as follows: 58.91% (5,150.71 ha) classified as very low risk, 27.63% (2,415.25 ha) as low risk, 9.63% (841.98 ha) as moderate risk, 3.11% (271.92 ha) as high risk, and 0.72% (62.51 ha) as very high risk (Table 3). The estimated annual potential soil loss for the basin ranges from 0 to 11,323.6 (ton/ha/year) (Figure 4). It is noteworthy that approximately 86.54% of the Liwagu River Basin is categorized within the very low to low erosion risk levels, indicating that the overall erosion conditions in the basin are effectively managed. The prevalence of low to very low erosion risk can likely be attributed to the extensive forest coverage and the predominantly gentle slope topography throughout much of the area.

Table 3. Average annual soil erosion rate

Class of Average Soil Loss Risk	Risk Level	Area (ha)	Soil Loss (%)
Very Low	Very Low	5150.71	58.91
Low	Low	2415.25	27.63
Moderate	Moderate	841.98	9.63
High	High	271.92	3.11
Very High	Very High	62.51	0.72
Total		**8742.37**	**100**

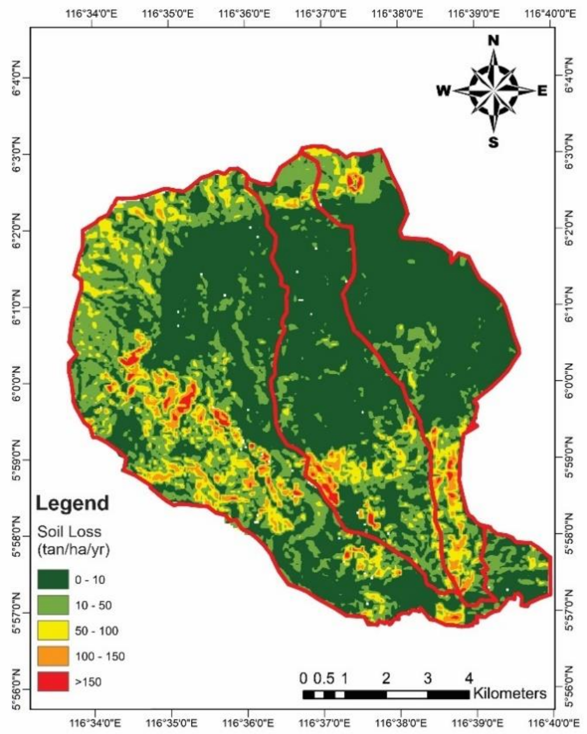


Figure 4. Average annual soil loss map (A) of the study area

CONCLUSIONS

According to the GIS-integrated RUSLE equation prediction model, the majority of the erosion potential in the Liwagu Basin is classified as very low risk and low risk, comprising 86.54% of the area, which equates to 7,565.96 ha. Conversely, only 3.83% of the basin is categorized as having a very high or high risk of erosion. The primary source of erosion in the area is attributed to newly opened agricultural land. While the potential soil loss remains low at present, any future plans for agricultural development or clearing of forested areas in the basin should take into account the potential for increased erosion. Additionally, it is crucial to conserve soil to prevent direct erosion effects, particularly from ultrabasic soils, which could contaminate surface areas, river water, and groundwater. Further research is recommended to enhance these findings and to devise context-specific strategies for erosion mitigation in Kundasang. Effective planning can help protect the well-being of the highland agricultural area while also preserving the health of the surrounding environment.

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