Geosfera Indonesia
p-ISSN 2598-9723, e-ISSN 2614-8528
available online at : https://jurnal.unej.ac.id/GEOSI
Vol. 9 No. 3, December 2024, 394-417

https://doi.org/10.19184/geosi.v9i3.3603 Research Article

Erosion Prediction Based on Terrestris Survey and RUSLE Method (Revised Universal Soil Loss Equation) in Precet Forest Park, Wagir, Malang

Listyo Yudha Irawan[1]*, Hyundra Zakiya Putri Wahyu[1], Ayunda Laras Firdausa[1], Andhika Ananda Wijaya[1], Vischawafiq Azizah[1], Widodo Eko Prasetyo[2]
[1]Department of Geography, Faculty of Social Sciences, State University of Malang, Semarang St. No. 5 Malang 65145, Indonesia
[2]Department of Geomatics Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia
*Corresponding author: listyo.fis@um.ac.id

ARTICLE INFO

Received :
9 February 2024

Revised :
28 November 2024

Accepted :
6 December 2024

Published :
30 December 2024

ABSTRACT

Erosion was a process that led to decreased land productivity and soil layer depletion. Four factors affected erosion, including erosivity, erodibility, slope and land cover. This study aimed to assess erosion predictions based on the results of field measurements or terrestrial surveys and the RUSLE method. Precet Forest Park was the location of the research facility. Erosion prediction was conducted by measuring slopes using Total Station. The RUSLE technique with five variables was used to calculate erosion values. These factors included the slope factor (LS), plant management index and ground cover vegetation (C), soil erodibility (K), rain erosion (R), and soil conservation measures (P). The calculation results indicated that the erosivity value (R) was 254.5, the K value was 0.46, the average LS value is was 8.39, the C value was 0.1, and the P value was 0.9. Calculations using the RUSLE method yielded an average value of the amount of eroded soil in Precet Forest Park of 86.37 tons/ha/year with a soil solum depth of >90 cm. Based on the erosion classification, the grade was classified as class II (Medium). In general, erosion was categorized as high to very high in the middle slope areas of the mountain. This was due to land cover characterised by thick vegetation. In addition, the soil management practices also reduced the value of erosion in Precet Forest Park.

Keywords: Erosion; RUSLE; Precet Forest Park

INTRODUCTION

As a consequence of landslides brought on by ongoing erosion, the quality of the soil degraded. Estimating ground erosion was essential in order to implement control measures against the extent of erosion (Maqsoom et al., 2020; Banuwa, 2013). The process or occurrence of losing the soil's uppermost layer due to the movement of the water or wind is known as soil erosion (Fernández et al., 2003; Suripin, 2002). There are two main events in the erosion process, namely detachment and transportation (Commelin et al., 2024; Wang et al., 2022). Both occurrences are fundamental factors contributing to soil erosion. During erosion, soil grains detach before being transported (Vadari et al., 2004). Soil erosion progresses via three phases: detachment, conveyance, and deposition (Das et al., 2020; Asdak, 2002; Ghidey & Alberts, 1997). Several factors influence the occurrence of the erosion process.

Four main factors affecting erosion are erosivity, erodibility, slope, and land cover (Morgan, 2009). Erosivity refers to the energy exerted by rainwater impacting the ground surface (Marzen et al., 2021; Issaka & Ashraf, 2017). Rainfall intensity and the state of the area impacted on erosion rates (Huang et al., 2020; Almeida et al., 2021; Sidi Almouctar et al., 2021; Lhoussaine Ed-daoudy et al., 2023). Erodibility refers to the resistance of soil aggregates to detachment or their stability (Amézketa, 1999; Le Bissonnais, 1996; Parhizkar et al., 2020; Lee et al., 2022; Han et al., 2023; Peng et al., 2024). Several factors influence erodibility, including infiltration rate, soil permeability, structure, and aggregate stability. Other aspects that also influence erodibility are soil particle binders, such as adsorbed cations, organic matter (e.g., Ca, Mg, and divalent bases), and the activity of soil microorganisms, including Actinomycetes fungi (Chen et al., 2023).

Factors influencing the magnitude of erosion are slope gradient, relief, topography, slope length, and terrace distance (Lu et al., 2020; Pijl et al., 2020; Buryak et al., 2023). Greater soil relief results in reduced erosion. Rough slopes reduce soil transport energy and decrease erosion rates (Li & Shi, 2024). One way to identify slopes is to conduct a terrestrial survey. A terrestrial survey involves collecting data through field measurements to determine points in the form of X, Y, and Z coordinates, which are then used to generate contour lines and other topographic data. Effective land cover for reducing erosion includes vegetation such as large trees, canopied vegetation, and shrubs. Large trees have extensive root systems that absorb more water, while canopied vegetation helps intercept falling rainwater, preventing it from directly impacting the soil (Gao et al., 2023). In addition, shrubs help to reduce soil displacement by rainwater and minimize the impact of raindrops on the soil surface (Zhang et al., 2023; Tonolli et al., 2024). The RUSLE method is frequently used to predict the average rate of soil erosion.

A key soil erosion model for determining the long-term average of soil erosion in agricultural areas with specific crops and management practices is the RUSLE approach (Hidayatulloh & Agusta, 2022; Thapa, 2020; Ganasri & Ramesh, 2016; Zhang et al., 2013). Erosion represents a type of landform development within geomorphological processes (Mulya & Khotimah, 2021; Roslee & Sharir, 2019). One significant concern that can lead to subsoil loss and decreased soil productivity is soil erosion (Abdi et al., 2023; Biratu et al., 2021; Kebede et al., 2020; Rashmi et al., 2022; Brahim et al., 2020). Previous study has mainly focused on using secondary data and modeling without highlighting geomorphological aspects (Yusuf et al., 2020; Mohapatra, 2022). A few researchers have focussed focused on understanding the complicated interaction between land use practices and erosion impacts (Dharmawan et al., 2023; Mahleb et al., 2022; Nut et al., 2021; Xu et al., 2021; Sumiahadi & Acar, 2019; Gaubi et al., 2016; Tamene & Le, 2015). However, study on the correlation between specific agricultural areas and their unique management systems remains limited (Gioia et al., 2021; Nziguheba et al., 2021; Bhattacharya et al., 2020; Suprayogo et al., 2020; Susanti et al., 2019). Comprehensive studies examining the relationship between land use practices and erosion in specific agricultural areas are still scarce (Taslim et al., 2019; Chalise et al., 2019).

Many researchers estimate erosion by solely using mathematical approaches, particularly formulas, especially for the soil erodibility factor/parameter K (Thapa, 2020; Khademalrasoul, 2020). However, different locations have different soil properties, including erodibility of soil (Putra et al., 2018; Rahmad et al., 2018). As recent research highlights that soil properties differ across locations due to climatic impacts on soil moisture and organic carbon (García-García et al., 2023). These variations can make mathematical approaches less accurate. This limitation is addressed through laboratory testing. Conducting lab tests reveals the true properties of soil erodibility. Additionally, most researchers rely on secondary data in erosion estimation (Atoma, et al., 2020; Behera et al., 2020). Utilisation of the use of secondary data can be highly beneficial for extensive regions, but its accuracy diminishes when applied to small and specific areas. Thus, this work seeks to close the gap by conducting a thorough investigation of erosion in agricultural areas within Precet Forest Park. This study aims at assessing erosion predictions based on field measurements or terrestrial surveys, laboratory testing, and the RUSLE method. The Revised Universal Soil Loss Equation (RUSLE) is a widely used model for predicting soil erosion, incorporating factors such as rainfall, soil type, and topography. Recent advancements integrate RUSLE with Geographic Information Systems (GIS) and Remote Sensing, enhancing spatial accuracy and enabling detailed assessments of erosion risks. Terrestrial surveys further improve the model by providing precise field data on soil properties and slope gradients, which are critical for accurate predictions. Compared to other models like SWAT or WEPP, the RUSLE model combined with terrestrial surveys offers superior accuracy, especially in complex terrains, by capturing local variability that remote sensing alone might miss. This approach is particularly valuable for small-scale studies where detailed local conditions are essential for effective soil conservation planning (Ganasri & Ramesh, 2016). To address the limitation of the RUSLE model, which is primarily applicable to predicting sheet and rill erosion, it is crucial to integrate additional erosion models or methods that account for complex erosion processes such as gully erosion and mass wasting (Zhang et al., 2023).

The research problem centres on the need for precise erosion prediction in Precet Forest Park, Wagir, Malang, a significant location that functions as a developing natural tourism destination, managed by the Disparbud of Malang Regency in collaboration with Pokdarwis of Sumbersuko Village. Positioned on the middle slope of Mount Kawi, the park's geomorphological features render it highly vulnerable to erosion, especially as the area undergoes development. The absence of existing erosion prediction data, particularly those based on direct measurement and detailed geomorphological analysis, highlights the importance of this study. By addressing this gap, the research seeks to offer valuable insights into erosion risks, which are crucial for sustainable park management and conservation efforts in this emerging tourist area. This research aims to determine the erosion estimate and how to use soil in certain conditions. First, to estimate the erosion rate in the Precet Forest Park, given its high erosion potential due to its location on the central slope of Mount Kawi; and second, to determine optimal land use practices under certain conditions, thus providing valuable insights for sustainable land management in the area.

METHODS

The research was carried out at Precet Forest Park, Sumbersuko Village, Wagir District, Malang Regency. Elevation approximately 1059 masl with coordinates 7°59'58" S – 112°30'32" E. The methods used in this study were the terrestrial survey and the RUSLE method. A terrestrial survey involves field measurements to obtain data points in the form of X, Y, and Z coordinates using the Total Station tool. Then, the data was processed using the Surface application to produce contour images and slope topography data at the research site. In addition, the RUSLE approach was used for forecasting the mean erosion rate. The RUSLE (Revised Universal Soil Loss Equation) approach was used in the study to forecast erosion. Erodibility (K), slope length and slope factors (LS), land usage (C), land processing (P), and erosion (R) are the five variables that are employed. This method was chosen because it is well-suited for calculating the long-term average soil erosion in an agricultural area with specific cropping and management systems. The empirical equation of the RUSLE method (Renard et al., 1997), is given at Equation 1.

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

Note :

A = represents the calculated spatial average soil loss and temporal average soil loss per unit area, expressed in the units chosen for K and for the specified time for R. Typically, A is represented in tonne* $acre^{-1}$ * yr^{-1}, however other units such as t* ha^{-1} * yr^{-1} might be used.

R= represents the rainfall-runoff erosivity factor, which is calculated by adding the rainfall erosion index to a factor accounting for any substantial runoff resulting from snowmelt.

K = soil erodibility factor, which is the rate of soil loss per erosion index unit for a certain soil type, measured on a standard plot. The standard plot is a 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow.

L = slope length factor, which is the ratio of soil loss from the field slope length to soil loss from a 72.6-ft length under the same conditions.

S = slope steepness factor, which is the comparison between soil loss on a field slope gradient and soil loss on a 9% slope under the same conditions.

C = cover-management factor, which is the ratio of soil loss from a certain area with certain cover and management practices to soil loss from an equivalent area under continuous tilled fallow.

P = support practice factor, which is the comparison between soil loss when using support practices such as contouring, stripcropping, or terracing, and soil loss while using straight-row farming up and down the slope.

According to the quantity of soil material lost or the degree of soil erosion in a field, erosion can be classified into levels. These levels are divided into several classes, as shown in Table1.

Table 1. Erosion Class

Ground Solum (cm)	Erosion (tons/hectare/year)				
	< 15	**15 -60**	**60 -180**	**180 – 480**	**> 480**
In > 90	SR	R	S	B	SB
	0	I	II	III	IV
Average 60 – 90	R	S	B	SB	SB
	I	II	III	IV	IV
Shallow: 30 –60	SR	B	SB	SB	SB
	II	III	IV	IV	IV
Very shallow < 30	B	SB	SB	SB	SB
	III	IV	IV	IV	IV

Source: Ministry of Forestry (1998 & 1989)

1) Rainfall Erosivity Factor (R)

Rain has kinetic energy that can damage the arrangement of soil aggregate particles. Erosion can be calculated using the RUSLE formula as follows (Arsyad, 2009):

$$EI30 = 6.119(RAIN)^{1.21}.(DAYS)^{-0.47}.(MaxP)^{0.53} \quad (2)$$

Where:
EI30 = Monthly rain erosion (ton/ha/year)
RAIN = Mean monthly rainfall (cm)
DAYS = average number of wet days each month
MaxP = Highest level of rainfall

2) The Erodibility Factor (K) of the Soil

Soil erodibility (K) is determined by the soil's texture, structure, permeability, and organic content (Wischmeier & Smith, 1978; Wischmeier et al., 1971). The soil erodibility factor in the RUSLE technique can be determined using Renard's equation, which is an updated version of the USLE approach (Renard et al., 1997; Addis & Klik, 2015). The equation for finding the value of K using the RUSLE method is given below:

$$100K = 2.1M\,1.14(10-4)(12-a) + 3.25\,(b-2) + 2.5\,(c-3) \quad (3)$$

Note:
K = factor of soil erodibility
M = (% extremely fine sand + dust) (100 - % clay)
a = percentage of organic materials
b = soil composition code
c = permeability of dirt

Table 2. Grain size assessment (M)

Texture Class (USDA)	Value of M
Heavy clay	210
Medium clay	750
Sandy clay (light clay)	1.213
Sandy clay	1.685
Dusty clay	2.160
Loamy clay	2.830
Sand	3.035
Sandy loam	3.245
Dusty clay	3.770
Clay	4.390
Dusty clay	6.330
Dust	8.245

Source: Hardjowigeno (1987)

Table 3. Land structure value (*b*)

Soil structure class (diameter size)	Value
Extremely fine granular	1
Little granular particles	2
Granules are medium to coarse in size	3
Plate-like, solid, and blocky	4

Source: Arsyad (2009)

Table 4. Permeability of soil value (*c*)

Soil Permeability	Value
Very slow—less than 0.5 cm/h	6
Sluggish (0.5-2.0 cm/h)	5
Moderately slow (2.0–6.3 cm/h)	4
Mild (6.3-12.7 cm/hour)	3
Medium-fast (12.7-25.4 cm/hour)	2
Quick (more than 25.4 cm/h)	1

Source: Arsyad (2009)

3) Slope Factor (LS)

The aspect of slope is determined by multiplying the slope steepness factor by the slope length (Manyevere et al., 2016). The value of slope length is computed using the following formula: (Renard et al., 1997):

$$LS = L \, x \, S \tag{4}$$

$$L = (\frac{l}{22}.1)^m \tag{5}$$

$$S = 10.8 \, sin \, \alpha + 0.03 \, for \, s < 9\% \tag{6}$$

$$S = 16.8 \, sin \, \alpha - 0.5 \, for \, s \geq 9\% \tag{7}$$

Note :
LS = length of slope and slope factor
L = factor of slope length
l = length of slop (m)
m = variable slope length, which is 0.5
S = slope slope factor

α = slope slope (0)

In this study, the slope and length of each slope were obtained from the results of a terrestrial survey in Precet Forest Park. Three types of slopes were measured: regional slopes, local slopes, and hills.

4) Land cover crop factors and crop management (C)

Basically, the determination of the C value must take into account the protective properties of plants against rain erosion. Plants can break down and even inhibit the flow of water, thereby reducing the flow speed (Matthews et al., 2022; Chen et al., 2022). The reduced velocity of water affects its ability to transport materials (Preiti et al., 2022). The following table may be used to determine the value of the crop management factor (C):

Table 5. Value of Plant Management Factor (C) (Arsyad, 2009)

Land Use	C grade
Open ground, without crops	1.0
Forest	0.001
Settlement	1.0
Paddy	0.01
Potato	0.40
Peanut	0.20
Corn	0.70
Banana	0.60
Mixed garden, high density	0.10
Mixed garden, medium density	0.20
Mixed garden, low density	0.50
Shrubs	0.30
Taro	0.85
Sorghum	0.242
Cassava + soybeans	0.181
Cassava + peanuts	0.195

5) Practical Conservation Factor (P)

Conservation is defined as human actions aimed at conserving soil. Conservation efforts may alter how much erosion occurs on a site (Du et al., 2021; Xie et al., 2024). Tillage and land usage use significantly impacts the soil's chemical, biological, and physical characteristics. Land use and cultivation have led to, changes in soil resistance to erosion. The CP value factor can be found in the Table 6.

Table 6. Soil Conservation Action Factor Value (P) (Arsyad, 2009)

No	Special measures of soil conservation	P Value
1	Terrace benches:	
	- Well-built	0.04
	-Mmoderately built	0.15
	- Bad building quality	0.35
	- Conventional patio	0.40
2	*Bahia grass* plant strip	0.40
3	Managing soil and plants in accordance with contour lines:	
	-Slope: 0-8%	0.50
	-Raise 9–20%	0.75
	-Gradient exceeds 20%	0.90
4	No conservation measures	1.00

The research flow begins with the determination of objectives and scope, followed by the preparation of necessary instruments and field logistics. In the field, observations focus on identifying various slopes, with precise slope measurements taken using a Total Station and simultaneous sample collection for laboratory analysis. Data from the field is analyzed, and combined with secondary precipitation data collected over the past decade, it facilitates erosion calculation using the RUSLE method. The process culminates in mapping the area through 3D visualizations and thematic maps, and the final step involves documenting the findings in papers and creating infographics for effective communication with stakeholders involved in managing Precet Forest Park.

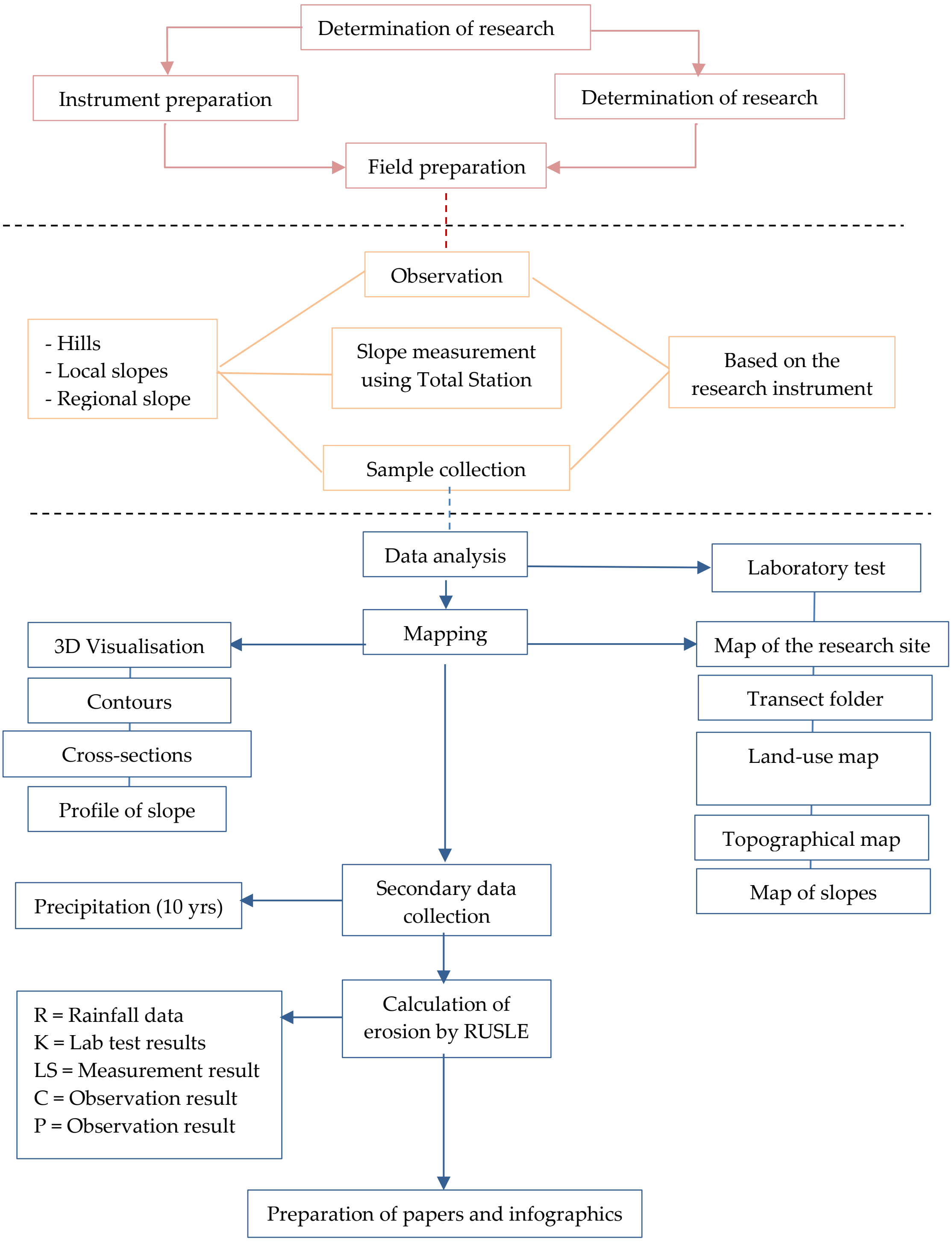


Figure 1. Research Framework

RESULTS AND DISCUSSION

Precet Forest Park in Wagir District, Malang Regency, is the location of the study site. At a height of more than 1000 metres above sea level, Precet Forest Park is situated on Mount Kawi's middle slope. This area was formed through geomorphological processes involving volcanic activityPrimary geomorphological processes observed include erosion, which occurs in forms such as splash erosion, rill erosion, and gully erosion. The type of land processing applied is terracing, with vegetation primarily consisting of elephant grass and napier grass (*Pennisetum purpureum Schaum*). In addition, there are other types of vegetation in Precet Forest Park including pine trees and *sengon* trees. The RUSLE (Revised Universal Soil Loss Equation) approach was used in the study to forecast erosion. Erodibility (K), slope length and slope factors (LS), land usage (C), land processing (P), and erosion (R) are the five variables that were used. The condition of the measurement and sampling location is seen in the accompanying figure can be seen in the accompanying Figure 2.

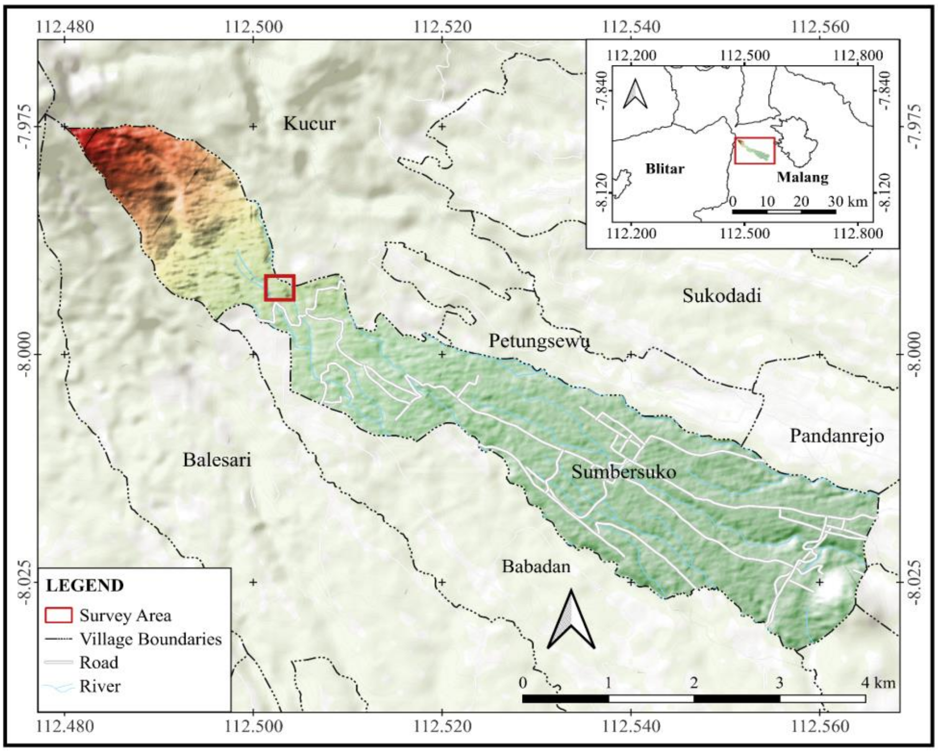


Figure 2. Study Area

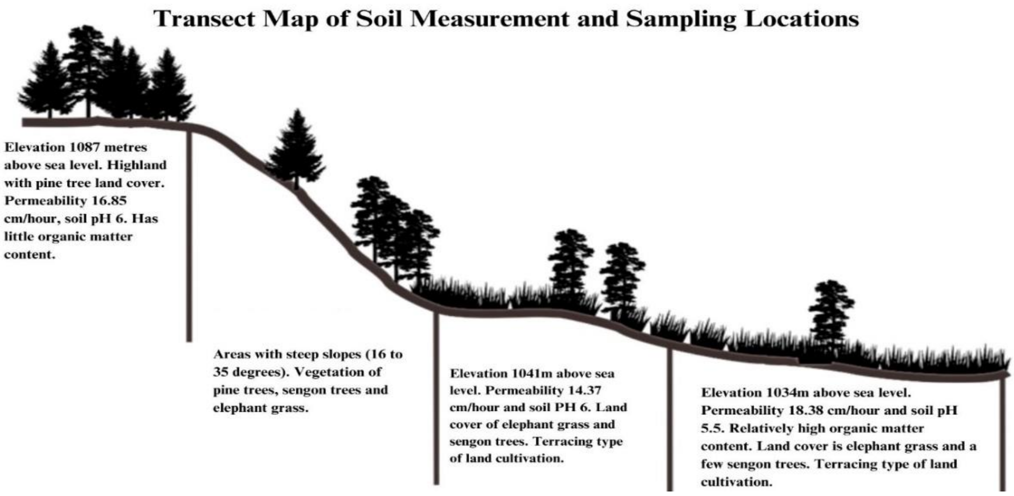


Figure 3. Transect map of soil measurement

There are woods and other land uses at the research location, including plantations with dense vegetation, characterized by more than 10 trees per 10 m^2 (Figure 4).

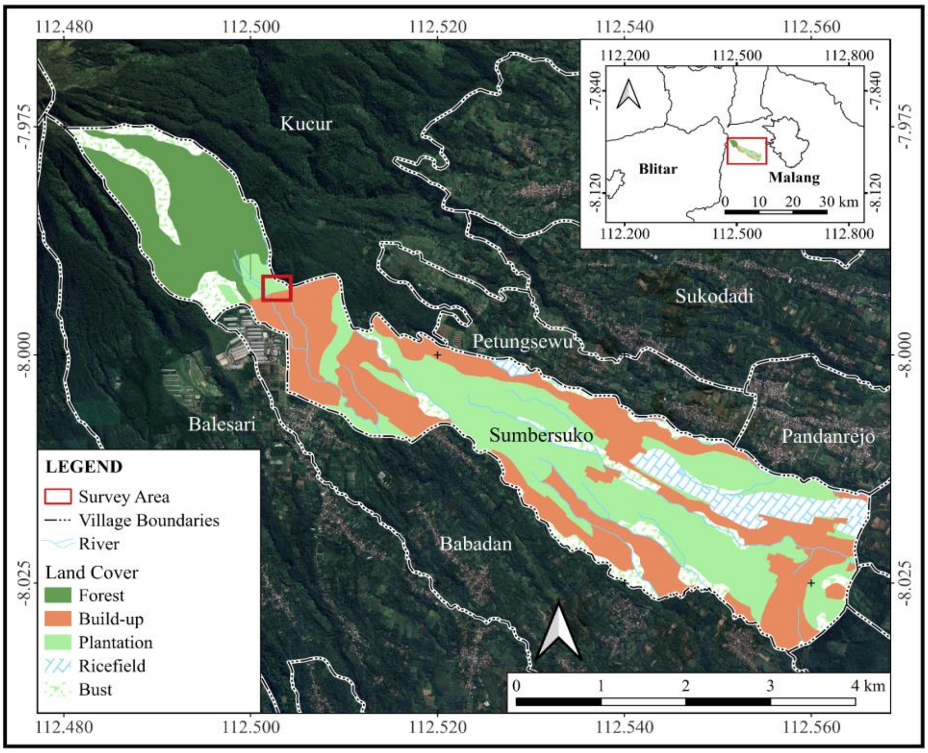


Figure 4. Land Use

The elevation at the measurement location is greater than 1000 meters above sea level, with mountainous topography. In erosion studies, topographic shapes and slopes significantly influence the range of erosion values. The slope is classified moderately steep (15–30%) to very steep (>30%). The topographic shape and slope details can be seen in the Figure 5.

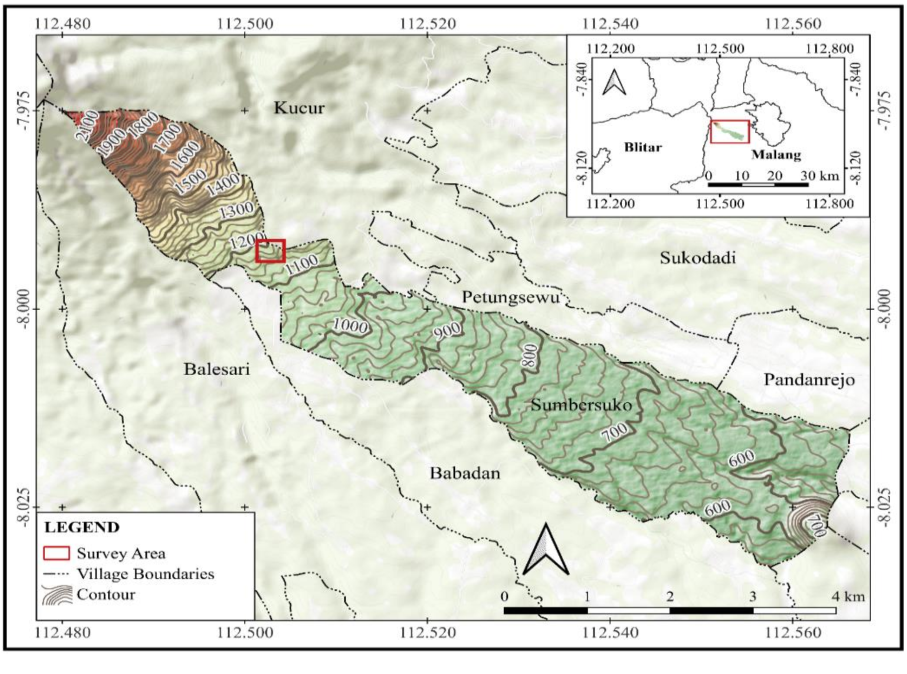


Figure 5. Topography

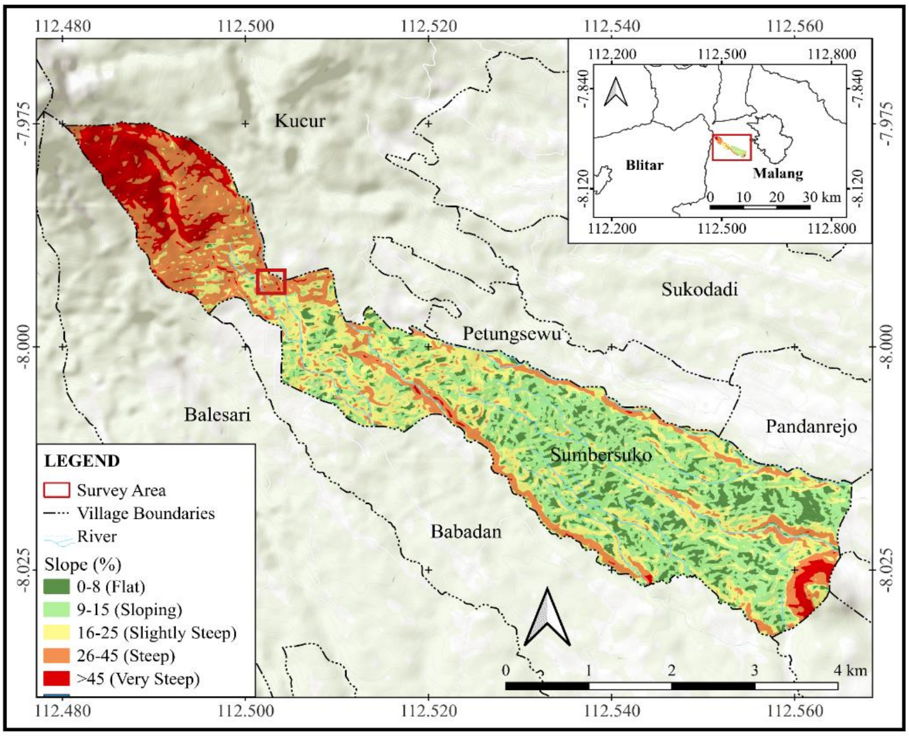


Figure 6. Slope

The value of erosion (R) indicates the magnitude of the kinetic energy of raindrops falling to the earth. Data used for the R parameter or erosion is rainfall data taken from the Wagir station at coordinates 03°03'52" S – 112°36'40" E, at 480 meters above sea level. Ten years' worth of rain data was used in this analysis, covering the period from 2007 to 2016. The value of rainfall for ten years is then averaged to be the main variable in determining the R value or erosivity. Erosion is calculated using the Bols equation as described by Arsyad (2009). The rain data used was recorded using ordinary rain gauges (Manual Rain Gauge). The rainfall data used was taken from one rain measuring station, namely Wagir station. This is done because data from different climatological measurement posts cannot be combined and averaged because the data specifically describes the climate conditions in the region around the monitoring post. Data from climatology monitoring posts have a relatively narrow coverage area, so they cannot be generalized to wider areas. Based on the calculation results, it is known that the average rainfall is 23.8 cm, and the value of rain erosion (R) is 254.5.

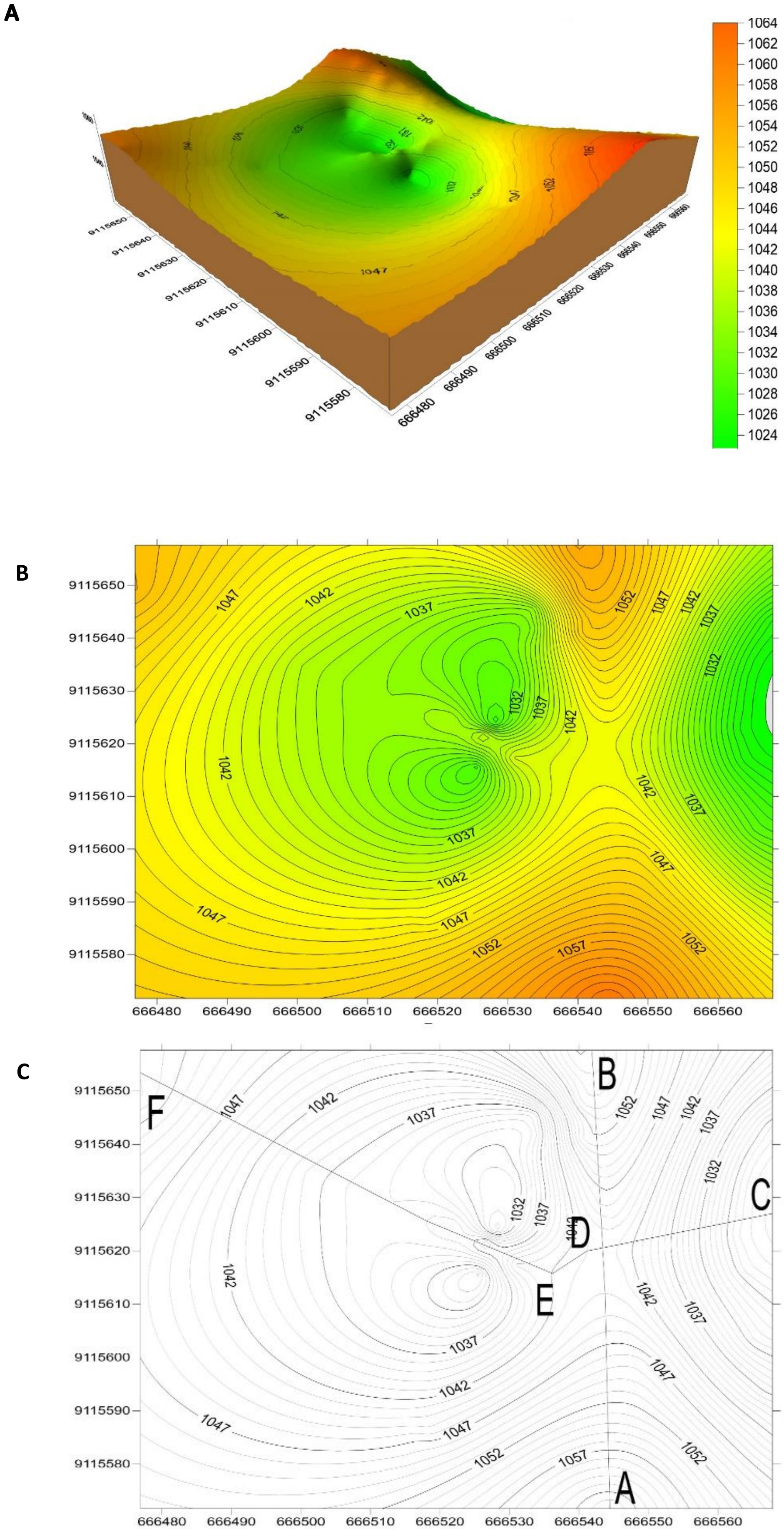
Utilising the formula presented by Renard, the value of erodibility (K) is computed (Renard et al., 1997). The variable used to obtain the erodibility value pertains to soil characteristic data. There are several variables used in the calculation of erodibility value, specifically the proportion of organic content, the amount of sand, dust, and clay, the soil's structure, and its permeability value. Erodibility refers to the soil particles' resistance to erosion. According to laboratory test findings, the soil permeability value is 18.38 cm / hour, 14.37 cm / hour, and 16.85 cm / hour. Based on USDA and shp soil types, it is known that the soil types in the Precet Forest Park area are Inceptisol, Eutrudeptd group and key subgroup Andic Eutrudepts. The soil solum is >90 cm thick with a PH between 5.0 to 6.0. This type of soil is often found in forest ecosystems, grasslands, agricultural land and active volcanic areas. The soil texture is dusty loam with 20% BO content and crumb soil structure. Based on the grain size assessment table, it is known that the land in Precet Forest Park has an M value of 6.330, with a classification of three (medium to coarse granular) for soil structure and two (medium to fast) for permeability. The result of calculating the K value is 0.46.

Several studies have employed the RUSLE method in erosion prediction, often integrating it with Geographic Information Systems (GIS) and Remote Sensing (RS) technologies. For instance, Ganasri & Ramesh (2016) demonstrated the effectiveness of combining RUSLE with GIS and RS for assessing soil erosion in the Nethravathi Basin, India. Similarly, Bhandari et al. (2021) utilized the RUSLE model alongside GIS to predict soil loss in the Siwalik Hills of Nepal, showing how the integration of spatial data can enhance erosion prediction accuracy. However, unlike these studies, the current research emphasizes the integration of terrestrial surveys with RUSLE, a combination less frequently explored in the literature. Terrestrial surveys provide high-resolution, on-the-ground data that can significantly improve the accuracy of RUSLE parameters, particularly the slope length and steepness (LS) factor, and the soil erodibility (K) factor. Pandey et al. (2022) highlighted the benefits of using detailed field measurements in erosion studies, noting that terrestrial data could reduce uncertainties associated with remotely sensed or interpolated data.This study's approach allows for a more precise estimation of soil erosion in areas with complex topography, such as Precet Forest Park, where remote sensing alone might not capture the necessary detail. In contrast, studies relying solely on GIS and remote sensing may not achieve the same level of accuracy, especially in heterogeneous landscapes where local variations in soil and vegetation can significantly impact erosion processes (Ganasri & Ramesh, 2016; Bhandari et al., 2021).

The value of LS or slope factor is obtained from measurement in the field and calculations using the formula suggested by Renard (Renard et al., 1997). Variables used in this calculation are slope in percent and slope length in cm. Here is a 3D visualization, contours, cross section of slopes in Forest Park recet. The image below was created from measurements using Total Station and data processing using surver. An image of the study site may be seen below and the results of data processing.

Figure 7. Landscape in study area

Figure 8 illustrates the characteristics of local slopes, which are crucial for understanding erosion processes at smaller scales. The LS calculation results in Table 7 indicate varying lengths and steepness among local slopes, resulting in distinct LS values that reflect their erosion potential. For instance, the 20 m slope with a steepness of 27° yields an LS value of 11.7, suggesting a high susceptibility to erosion. Conversely, the 30 m slope at the same steepness produces a lower LS value of 8.26. This discrepancy may stem from the interaction between slope length and steepness; shorter, steeper slopes tend to promote more concentrated runoff, thereby enhancing soil erosion. Such dynamics highlight the importance of considering both physical dimensions of local slopes when evaluating their impact on soil stability and erosion risk.


A
1064
1062
1060
1058
1056
1054
1052
1050
1048
1046
1044
1042
1040
1038
1036
1034
1032
1030
1028
1026
1024
9115650
9115640
9115630
9115620
9115610
9115600
9115590
9115580
666480
666490
666500
666510
666520
666530
666540
666550
666560
1047
B
9115650
9115640
9115630
9115620
9115610
9115600
9115590
9115580
666480
666490
666500
666510
666520
666530
666540
666550
666560
1047
1042
1037
1032
1052
1057
C
F
B
C
D
E
A
9115650
9115640
9115630
9115620
9115610
9115600
9115590
9115580
666480
666490
666500
666510
666520
666530
666540
666550
666560
1047
1042
1037
1032
1052
1057

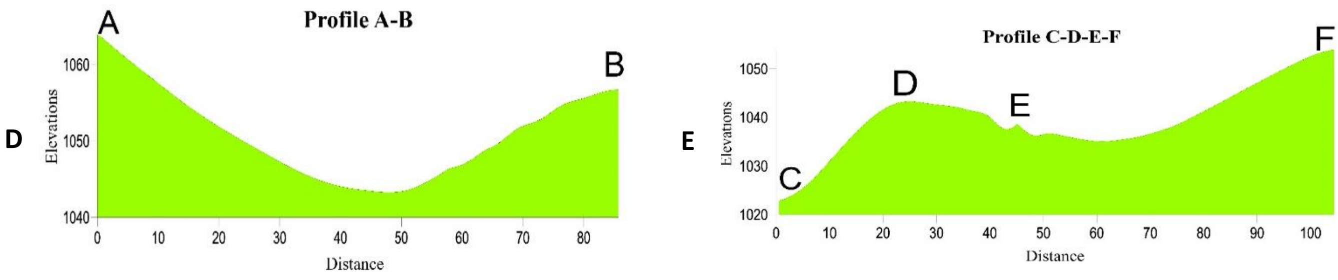
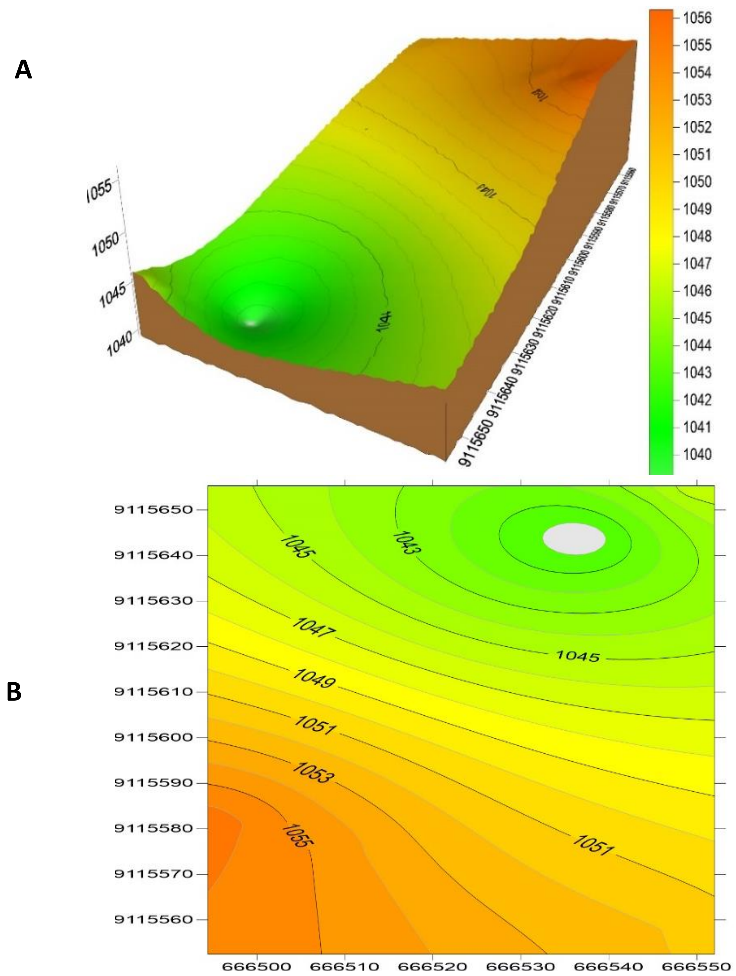
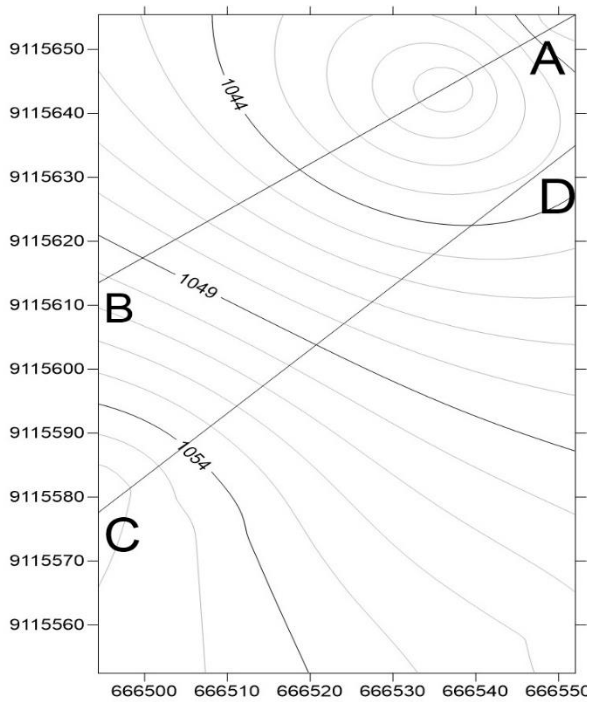


Figure 8. Characteristics of local slopes, A: Surface; B: Contour; C: Cross Section; D: Profile A-B; E: Profile C-F

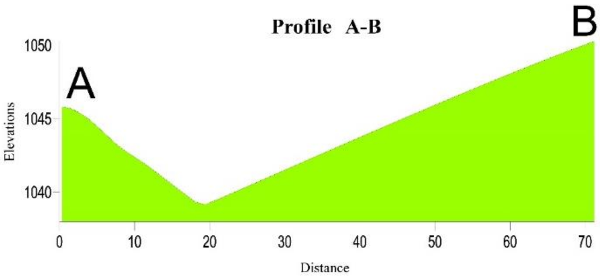
In Figure 9, the regional slopes are depicted, representing broader landscape features with more gentle gradients. According to Table 7, the LS values for regional slopes are notably lower, with the highest LS value being 4.26 for a 70 m slope at 10°. This indicates that the extended length combined with the moderate slope steepness results in reduced erosion potential compared to local slopes. The gradual incline of regional slopes leads to less concentrated runoff, thus diminishing the likelihood of severe soil loss. Consequently, while regional slopes cover larger areas, their erosion dynamics are fundamentally different, suggesting that land management strategies must differentiate between local and regional contexts to effectively mitigate erosion risks.



C



D



E

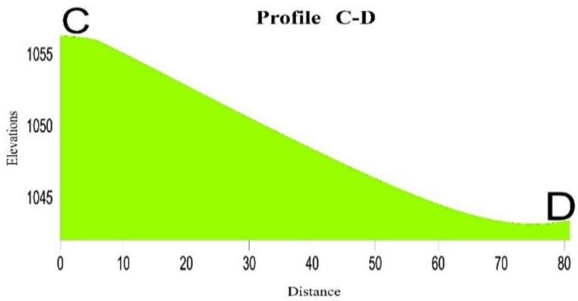


Figure 9. Characteristics of regional slopes ,A: Surface; B: Contour; C: Cross Section; D: Profile A-B; E: Profile C-F

Figure 10 showcases the hill slopes, which demonstrate a unique interplay of slope length and steepness that significantly influences erosion outcomes. The LS calculation in Table 7 reveals that the hill slope, measuring 200 m with a 14° steepness, produces an LS value of 10.5. This relatively high value indicates a considerable erosion risk, primarily due to the combination of a longer slope that allows for greater accumulation of water and a moderate gradient that can facilitate runoff. The elevated LS value compared to regional slopes underscores the potential for hill slopes to contribute significantly to soil erosion, especially in the context of heavy rainfall events. These findings suggest that effective erosion control measures should be prioritized on hill slopes, particularly given their ability to channel runoff and exacerbate soil loss in adjacent areas. Overall, the comparative analysis of local, regional, and hill slopes reveals critical insights into how slope characteristics influence erosion dynamics, highlighting the need for targeted approaches in soil conservation and land management practices across different topographical contexts.

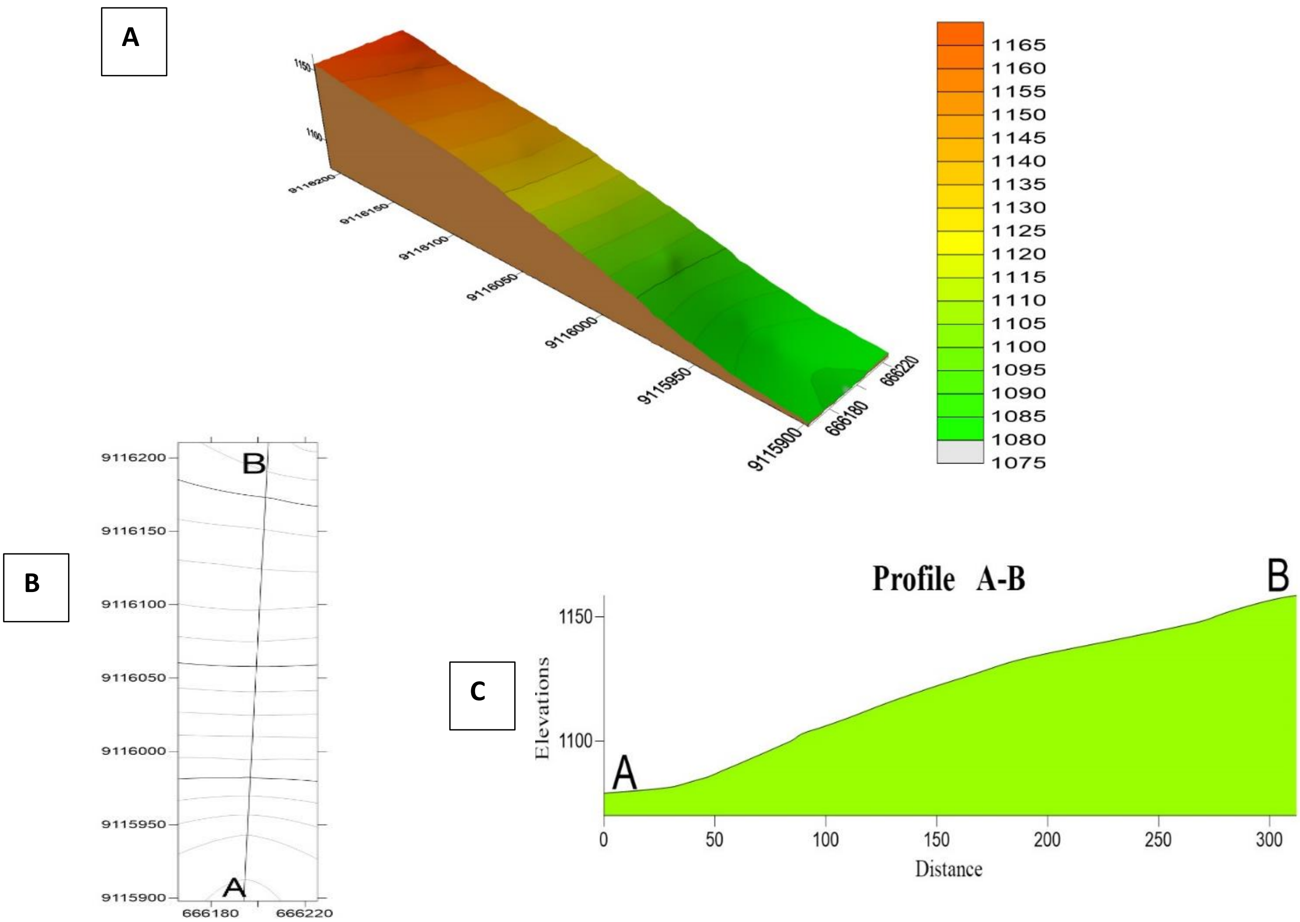


Figure 10. Characteristics of regional slopes, A: Surface; B: Cross Section; C: Profile A-B

The following is a table of LS (Table 7) calculation results on each slope.

Table 7. LS calculation of local, regional and hill slopes

	Slope Length (L)	Slope Slope (S)	LS
Hill	200 m	14o (20%)	10.5
Local slopes	40 m	26 º (50%)	9.1
	30 m	27 º (51%)	8.26
	20 m	27 º (51%)	11.7
	40 m	31 º (56%)	10.9
Regional slopes	50 m	11 º (18%)	4.05
	70 m	10 º (14%)	4.26

The following is a table (Table 8) method determining each slope's approximate rate of erosion:

Table 8. Estimated erosion rate

Location	Slope	R	K	LS	C	P	A (ton/ha/yr)
Hill	A - B	254.5	0.46	10.5	0.1	0.9	110.63115
Local	A - A'	254.5	0.46	9.1	0.1	0.9	95.88033
	B - B'	254.5	0.46	8.26	0.1	0.9	87.029838
	D - C	254.5	0.46	11.7	0.1	0.9	123.27471
	F - E	254.5	0.46	10.9	0.1	0.9	114.84567
Regional	A - B	254.5	0.46	4.05	0.1	0.75	35.5600125
	C - D	254.5	0.46	4.26	0.1	0.75	37.403865
Average LS				**8.395714**	**Average A**		**86.37508221**

The average LS value based on the three slopes is 8.39. The variables C and P are related to each other, where P is the land unit descriptor and C is the vegetation coefficient. The C value is obtained through qualitative observation and descriptive based on a table of plant management factors. Based on the table, the C value is 0.1 with the description of mixed gardens and high vegetation density. The P value is influenced by slope slope, based on the table of soil conservation action factors, the P value is 0.9 on local hills and slopes (slope >20%), while on regional slopes (slope slope 9-20%) the P value is 0.75.

The research highlights erosion prediction in Precet Forest Park using a terrestrial survey integrated with the RUSLE (Revised Universal Soil Loss Equation) method, providing a detailed map as the main finding. This approach combines field data on soil properties and topography with the RUSLE model to accurately estimate erosion rates (refer to figure 7-10). One of the significant advantages of the current study is the use of terrestrial surveys to obtain accurate data on soil properties, slope gradients, and land management practices. This data is crucial for calculating the RUSLE parameters with greater precision, leading to more reliable erosion predictions. This method addresses some of the limitations observed in previous studies, where reliance on remote sensing and GIS data might introduce errors due to the generalization of terrain and land cover features (Panagos et al., 2021).

Furthermore, the terrestrial survey approach allows for the inclusion of micro-topographical variations, which can have a substantial impact on erosion processes but are often overlooked in large-scale remote sensing studies. Another advantage is the potential for ground-truthing, where field data collected through terrestrial surveys can be used to validate and calibrate the RUSLE model outputs. This process enhances the credibility and reliability of the model's predictions, as demonstrated by Chen et al. (2022), who successfully used field measurements to validate erosion models in the Loess Plateau of China.The prediction of erosion values is done using the RUSLE formula by Renard where this formula is a revision of the formula proposed by Wischmeier (Wischmeier et al., 1971; Wischmeier & Smith, 1978; Renard et al., 1997). The estimation of soil erosion in Precet Forest Park at 86.37 tonnes per hectare per year, classified as Class II (Medium), aligns with findings from several recent studies that have utilised the RUSLE (Revised Universal Soil Loss Equation) method. For instance, a study in the Swat River Basin in the Eastern Hindukush region reported average soil erosion rates ranging from 50 to 100 tonnes per hectare per year, which also fall within the medium erosion risk category. This suggests that the erosion rates at Precet Forest Park are comparable to those observed in regions with similar topographical and climatic conditions.

Despite the advantages, there are also limitations to the approach used in this study. One limitation is the labor-intensive and time-consuming nature of terrestrial surveys, which require significant resources and expertise to conduct, especially over large or inaccessible areas. This contrasts with the relative ease and efficiency of remote sensing and GIS methods, which can cover extensive areas with minimal ground-based data collection (Khosravi et al., 2022).

Moreover, the precision of terrestrial survey data, while beneficial, may not always be necessary for broader regional studies where general trends are more critical than fine-scale accuracy. For example, Panagos et al. (2021) argue that for large-scale erosion assessments across Europe, the benefits of using detailed field data might be outweighed by the logistical challenges involved. Another limitation is the potential for bias in data collection during terrestrial surveys. The accuracy of the RUSLE model heavily depends on the quality and representativeness of the input data.

Another study conducted in the Nethravathi Basin in India found erosion rates varying between 50 and 150 tonnes per hectare per year, depending on the land use and slope steepness. This further supports the classification of Precet Forest Park's erosion rate as medium, given the park's terrain and ongoing development activities, which likely influence soil disturbance and erosion patterns. Overall, these comparisons indicate that the erosion rates observed in Precet Forest Park are within the range documented in other regions with similar environmental and geomorphological conditions, underscoring the importance of erosion control and conservation measures to mitigate soil loss (Khan & Rahman, 2024; Ghosal & Das Bhattacharya, 2020). Based on calculations that have been done, According to estimates, Precet Forest Park experiences 86.37 tonnes of soil erosion per hectare year on average. The grade is classified as class II (Medium) based on erosion categorization.

CONCLUSION

It has been established that the RUSLE model, which is supported by terrestrial survey and GIS software, is an appropriate instrument to predict soil erosion. Based on the calculation of each variable, it is known that the erosivity value (R) is 254.5, the K value is 0.46, the average LS value is 8.39, the C value is 0.1, and the P value is 0.9. Based on the calculation of the amount of eroded soil using the RUSLE formula, an estimated erosion rate value of 86.37 tons / ha / year was produced. According to the erosion class table, the value belongs to class II (Medium). In general, erosion that occurs in the middle slope area of the mountain is included in the high to very high class. However, in Precet Forest Park belongs to the middle class category. The amount of thick vegetation on the land affects this. In addition, soil management can also reduce the estimated value of erosion rates in Precet Forest Park.

ACKNOWLEDGMENTS

We would like to thanks of the Universitas Negeri Malang through Research and Community Services Institute (LP2M) for providing us an internal funding (Grant Number: 5.4.1/UN32/KP/2023).

DECLARATIONS

Conflict of Interest

We declare no conflict of interest, financial or otherwise.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

DATA AVAILABILITY

Data used to support the findings of this study are available from the corresponding author upon request.

REFERENCES

Abdi, B., Kolo, K., & Shahabi, H. (2023). Soil erosion and degradation assessment integrating multi-parametric methods of RUSLE model, RS, and GIS in the Shaqlawa agricultural area, Kurdistan Region, Iraq. *Environmental Monitoring and Assessment, 195*(10). https://doi.org/10.1007/s10661-023-11796-4

Addis, H. K., & Klik, A. (2015). Predicting the spatial distribution of soil erodibility factor using USLE nomograph in an agricultural watershed, Ethiopia. *International Soil and Water Conservation Research, 3*(4), 282–290. https://doi.org/10.1016/j.iswcr.2015.11.002

Almeida, W. S. de, Seitz, S., Oliveira, L. F. C. de, & Carvalho, D. F. de. (2021). Duration and intensity of rainfall events with the same erosivity change sediment yield and runoff rates. *International Soil and Water Conservation Research, 9*(1), 69–75. https://doi.org/10.1016/j.iswcr.2020.10.004

Amézketa, E. (1999). Soil Aggregate Stability: A Review. *Journal of Sustainable Agriculture, 14*(2-3), 83–151. https://doi.org/10.1300/j064v14n02_08

Arsyad, S. (2009). *Konservasi Tanah dan Air*. PT Penerbit IPB Press.

Asdak, C. (2002). *Hidrologi Dan Pengelolaan Daerah Aliran Sungai*. Gadjah Mada University Press.

Atoma, H., Suryabhagavan, K. V., & Balakrishnan, M. (2020). Soil erosion assessment using RUSLE model and GIS in Huluka watershed, Central Ethiopia. *Sustainable Water Resources Management, 6*(1). https://doi.org/10.1007/s40899-020-00365-z

Banuwa, I. S. (2013). *Erosi*. Prenada Media.

Behera, M., Sena, D. R., Mandal, U., Kashyap, P. S., & Dash, S. S. (2020). Integrated GIS- based RUSLE approach for quantification of potential soil erosion under future climate change scenarios. *Environmental Monitoring and Assessment, 192*(11). https://doi.org/10.1007/s10661-020-08688-2

Bhandari, D., Joshi, R., Regmi, R. R., & Awasthi, N. (2021). Assessment of Soil Erosion and Its Impact on Agricultural Productivity by Using the RMMF Model and Local Perception: A Case Study of Rangun Watershed of Mid-Hills, Nepal. *Applied and Environmental Soil Science*, 5747138. https://doi.org/10.1155/2021/5747138

Bhattacharya, R. K., Chatterjee, N. D., & Das, K. (2020). Land use and Land Cover change and its resultant erosion susceptible level: an appraisal using RUSLE and Logistic Regression in a tropical plateau basin of West Bengal, India. *Environment, Development and Sustainability, 23*(2), 1411–1446. https://doi.org/10.1007/s10668- 020-00628-x

Biratu, A. A., Bedadi, B., Gebrehiwot, S. G., Hordofa, T., Asmamaw, D. K., & Melesse, A. M. (2021). Implications of land management practices on selected ecosystem services in the agricultural landscapes of Ethiopia: a review. *International Journal of River Basin Management, 21*.1(3-20), 1–18. https://doi.org/10.1080/15715124.2020.1870991

Brahim, B., Sarita Gajbhiye Meshram, Abdallah, D., Larbi, B., Sadkaoui Drisss, Khalid, M., & Khaled Mohamed Khedher. (2020). Mapping of soil sensitivity to water erosion by RUSLE model: case of the Inaouene watershed (Northeast Morocco). *Arabian Journal of Geosciences, 13*(21). https://doi.org/10.1007/s12517-020-06079-y

Buryak, Z. A., Ukrainsky, P. A., Gusarov, A. V., Lukin, S. V., & Beylich, A. A. (2023). Geomorphic factors influencing the spatial distribution of eroded Chernozems in automated digital soil erosion mapping. *Geomorphology, 439*, 108863. https://doi.org/10.1016/j.geomorph.2023.108863

Chalise, D., Kumar, L., & Kristiansen, P. (2019). Land Degradation by Soil Erosion in Nepal: A Review. *Soil Systems, 3*(1), 12. https://doi.org/10.3390/soilsystems3010012

Chen, L., Rejesus, R. M., Aglasan, S., Hagen, S. C., & Salas, W. (2022). The impact of cover crops on soil erosion in the US Midwest. *Journal of Environmental Management, 324*, 116168. https://doi.org/10.1016/j.jenvman.2022.116168

Chen, Z., Guo, M., Wang, W., Wang, W., & Feng, L. (2023). Response of soil erodibility of permanent gully heads to revegetation along a vegetation zone gradient in the loess- table and gully region of the Chinese Loess Plateau. *Science of the Total Environment, 892*, 164833–164833. https://doi.org/10.1016/j.scitotenv.2023.164833

Commelin, M. C., Baartman, J. E., Wesseling, J. G., & Jetten, V. (2024). Simulating event-based pesticide transport with runoff and erosion; OpenLISEM-pesticide v. 1. *Environmental Modelling & Software, 174*, 105960. https://doi.org/10.1016/j.envsoft.2024.105960

Das, S., Deb, P., Bora, P. K., & Katre, P. (2020). Comparison of RUSLE and MMF Soil Loss Models and Evaluation of Catchment Scale Best Management Practices for a Mountainous Watershed in India. *Sustainability, 13*(1), 232. https://doi.org/10.3390/su13010232

Dharmawan, I. W. S., Pratiwi, Siregar, C. A., Narendra, B. H., Undaharta, N. K. E., Sitepu, B. S., Sukmana, A., Wiratmoko, M. D. E., Abywijaya, I. K., & Sari, N. (2023). Implementation of Soil and Water Conservation in Indonesia and Its Impacts on Biodiversity, Hydrology, Soil Erosion and Microclimate. *Applied Sciences, 13*(13), 7648. https://doi.org/10.3390/app13137648

Du, X., Jian, J., Du, C., & Stewart, R. D. (2021). Conservation management decreases surface runoff and soil erosion. *International Soil and Water Conservation Research, 10*(2). https://doi.org/10.1016/j.iswcr.2021.08.001

Fernández, C., Wu, J., McCool, D. K., & Stöckle, C. O. (2003). Estimating water erosion and sediment yield with GIS, RUSLE, and SEDD. *Journal of Soil and Water Conservation, 58*(3), 128–136.

Ganasri, B. P., & Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin. Geoscience Frontiers, 7(6), 953–961. https://doi.org/10.1016/j.gsf.2015.10.007

Gao, G., Liang, Y. T., Li, J., Dunkerley, D., & Fu, B. (2023). A modified RUSLE model to simulate soil erosion under different ecological restoration types in the loess hilly area. *International Soil and Water Conservation Research.* https://doi.org/10.1016/j.iswcr.2023.08.007

García-García, A., Cuesta-Valero, F. J., Miralles, D. G., Mahecha, M. D., Quaas, J., Reichstein, M., Zscheischler, J., & Peng, J. (2023). Soil heat extremes can outpace air temperature extremes. *Nature Climate Change, 13*(11), 1–5. https://doi.org/10.1038/s41558-023-01812-3

Gaubi, I., Chaabani, A., Ben Mammou, A., & Hamza, M. H. (2016). A GIS-based soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) (Lebna watershed,Cap Bon, Tunisia). *Natural Hazards, 86*(1), 219–239. https://doi.org/10.1007/s11069- 016-2684-3

Ghidey, F. & Alberts. E.E. (1997). Plant Root Effects On Soil Erodibility, Splash Detachment, Soil Strength, And Aggregate Stability. *Transactions of the ASAE, 40*(1), 129–135. https://doi.org/10.13031/2013.21257

Ghosal, K., & Das Bhattacharya, S. (2020). A Review of RUSLE Model. *Journal of the Indian Society of Remote Sensing, 48*(4), 689–707. https://doi.org/10.1007/s12524-019-01097-0

Gioia, D., Amodio, A. M., Maggio, A., & Sabia, C. A. (2021). Impact of Land Use Changes on the Erosion Processes of a Degraded Rural Landscape: An Analysis Based on High- Resolution DEMs, Historical Images, and Soil Erosion Models. *Land, 10*(7), 673. https://doi.org/10.3390/land10070673

Han, Y., Zhao, W., Ding, J., & Sofia, C. (2023). Soil erodibility for water and wind erosion and its relationship to vegetation and soil properties in China's drylands. *Science of the Total Environment, 903*,166639–166639.

Hardjowigeno, S. (1987). *Ilmu tanah*. Akademika Pressindo.

Hidayatulloh, A. M., & Agusta, R. P. (2022). Soil Erosion Estimation Using RUSLE Method. In R. Trialih, F. E. Wardiani, R. Anggriawan, C. D. Putra, & A. Said (Eds.), Indonesia Post-Pandemic Outlook: Environment and Technology Role for Indonesia Development (pp. 69–80). BRIN Publishing. https://doi.org/10.55981/brin.538.c507

Huang, F., Chen, J., Yao, C., Chang, Z., Jiang, Q., Shu, L., & Guo, Z. (2020). SUSLE: a slope and seasonal rainfall-based RUSLE model for regional quantitative prediction of soil erosion. *Bulletin of Engineering Geology and the Environment, 79*(10), 5213–5228. https://doi.org/10.1007/s10064-020-01886-9

Issaka, S., & Ashraf, M. A. (2017). Impact of Soil Erosion and degradation on water quality: a review. *Geology, Ecology, and Landscapes, 1*(1), 1–11. https://doi.org/10.1080/24749508.2017.1301053

Kebede, B., Tsunekawa, A., Haregeweyn, N., Adgo, E., Ebabu, K., Meshesha, D. T., Tsubo, M., Masunaga, T., & Fenta, A. A. (2020). Determining C- and P-factors of RUSLE for different land uses and management practices across agro-ecologies: case studies from the Upper Blue Nile basin, Ethiopia. *Physical Geography, 42*(2), 160–182. https://doi.org/10.1080/02723646.2020.1762831

Khademalrasoul, A., & Amerikhah, H. (2021). Assessment of soil erosion patterns using RUSLE model and GIS tools (case study: the border of Khuzestan and Chaharmahal Province, Iran). *Modeling Earth Systems and Environment, 7*(2), 885-895. https://doi.org/10.1007/s40808-020-00931-6

Khan, A., & Rahman, A. U. (2024). Spatial analysis and extent of soil erosion risk using the RUSLE approach in the Swat River Basin, Eastern Hindukush. *Applied Geomatics, 16*(3), 545-560. https://doi.org/10.1007/s12518-024-00567-6

Khosravi, V., Gholizadeh, A., & Saberioon, M. (2022). Soil toxic elements determination using integration of Sentinel-2 and Landsat-8 images: Effect of fusion techniques on model performance. *Environmental Pollution, 310*, 119828. https://doi.org/10.1016/j.envpol.2022.119828

Lee, S., Chu, M. L., Guzman, J. A., & Flanagan, D. C. (2022). Modeling soil erodibility and critical shear stress parameters for soil loss estimation. *Soil and Tillage Research, 218*, 105292. https://doi.org/10.1016/j.still.2021.105292

Le Bissonnais, Y. (1996). *Soil characteristics and aggregate stability*. In: M. Agassi (Ed.), Soil Erosion, Conservation, and Rehabilitation. Dekker, New York, pp. 41-60.

Lhoussaine Ed-daoudy, Nouh Lahmam, Moncef Benmansour, Haitam Afilal, Abdessalam Ben harra, & Brahim Damnati. (2023). Hydric erosion rates in Raouz watershed, Morocco: RUSLE, GIS, and remote sensing. *Remote Sensing Applications: Society and Environment, 32,* 101056–101056. https://doi.org/10.1016/j.rsase.2023.101056

Li, H., & Shi, D. (2024). Spatio-temporal variation in soil erosion on sloping farmland based on the integrated valuation of ecosystem services and trade-offs model: A case study of Chongqing, southwest China. *CATENA, 236*, 107693–107693. https://doi.org/10.1016/j.catena.2023.107693

Lu, S., Liu, B., Hu, Y., Fu, S., Cao, Q., Shi, Y., & Huang, T. (2020). Soil erosion topographic factor (LS): Accuracy calculated from different data sources. *CATENA, 187,* 104334. https://doi.org/10.1016/j.catena.2019.104334

Mahleb, A., Riheb Hadji, Farid Zahri, Rania Boudjellal, Abdelmohcen Chibani, & Hamed, Y. (2022). Water-Borne Erosion Estimation Using the Revised Universal Soil Loss Equation (RUSLE) Model Over a Semiarid Watershed: Case Study of Meskiana Catchment, Algerian-Tunisian Border. *Geotechnical and Geological Engineering, 40*(8), 4217–4230. https://doi.org/10.1007/s10706-022-02152-3

Manyevere, A., Muchaonyerwa, P., Mnkeni, P. N. S., & Laker, M. C. (2016). Examination of soil and slope factors as erosion controlling variables under varying climatic conditions. *CATENA, 147*, 245–257. https://doi.org/10.1016/j.catena.2016.06.035

Maqsoom, A., Aslam, B., Hassan, U., Kazmi, Z. A., Sodangi, M., Tufail, R. F., & Farooq, D. (2020). Geospatial Assessment of Soil Erosion Intensity and Sediment Yield Using the Revised Universal Soil Loss Equation (RUSLE) Model. *ISPRS International Journal of Geo-Information, 9*(6), 356. https://doi.org/10.3390/ijgi9060356

Marzen, M., Iserloh, T., & RodrigoComino, J. (2021). Chapter 15 - *Processes of raindrop splash and effects on soil erosion.* In Precipitation (pp. 351–371). Elsevier. https://doi.org/10.1016/B9780128226995.000136

Matthews, F., Verstraeten, G., Borrelli, P., & Panagos, P. (2022). A field parcel-oriented approach to evaluate the crop cover-management factor and time-distributed erosion risk in Europe. *International Soil and Water Conservation Research*. https://doi.org/10.1016/j.iswcr.2022.09.005

Mohapatra, R. (2022). Application of revised universal soil loss equation model for assessment of soil erosion and prioritization of ravine infested sub basins of a semi-arid river system in India. *Modeling Earth Systems and Environment, 8*(4), 4883–4896. https://doi.org/10.1007/s40808-022-01388-5

Ministry of Forestry 1998. Decree of the Directorate General of Reforestation and Land Rehabilitation Number: 041 / Kpts / V / 1998 dated April 21, 1998, concerning Guidelines for the Preparation of Field Engineering Plans for Land Rehabilitation and Watershed Soil Conservation. Director General of Reforestation and Land Rehabilitation, Ministry of Forestry. Jakarta.

Ministry of Forestry 1989. Guidelines for Preparing Field Engineering Plans for Land Rehabilitation and Watershed Soil Conservation. Kep. Dirjen RLL no. 041/Kpts/1998.

Morgan, R. P. C. (2009). *Soil Erosion and Conservation*. Wiley.

Mulya, S. A., & Khotimah, N. (2021). Assessment of Soil Erosion Hazard in Prambanan District Using RUSLE (Revised Universal Soil Loss Equation). *IOP Conference Series: Earth and Environmental Science, 884*(1), 012010. https://doi.org/10.1088/1755-1315/884/1/012010

Nut, N., Mihara, M., Jeong, J., Ngo, B., Sigua, G., Prasad, P. V. V., & Reyes, M. R. (2021). Land Use and Land Cover Changes and Its Impact on Soil Erosion in Stung Sangkae Catchment of Cambodia. *Sustainability, 13*(16), 9276. https://doi.org/10.3390/su13169276

Nziguheba, G., Adewopo, J., Masso, C., Nabahungu, N. L., Six, J., Sseguya, H., ... & Vanlauwe, B. (2022). Assessment of sustainable land use: linking land management practices to sustainable land use indicators. *International Journal of Agricultural Sustainability, 20*(3), 265-288. https://doi.org/10.1080/14735903.2021.1926150

Panagos, P., Ballabio, C., Himics, M., Scarpa, S., Matthews, F., Bogonos, M., ... & Borrelli, P. (2021). Projections of soil loss by water erosion in Europe by 2050*. Environmental Science & Policy, 124*, 380-392. https://doi.org/10.1016/j.envsci.2021.07.012

Pandey, S., Nautiyal, R., Kumar, P., Chandra, G., & Panwar, V. P. (2022). A grey relational model for soil erosion vulnerability assessment in subwatershed of lesser Himalayan region. *Catena, 210*, 105928. https://doi.org/10.1016/j.catena.2021.105928

Parhizkar, M., Shabanpour, M., Khaledian, M., Cerdà, A., Yu, B., Asadi, H., & Lucas-Borja, M. E. (2020). Assessing and Modeling Soil Detachment Capacity by Overland Flow in Forest and Woodland of Northern Iran. *Forests, 11*(1), 65–65. https://doi.org/10.3390/f11010065

Peng, J., Wang, J., Yang, Q., Liu, L., Li, Y., Guo, Z., & Cai, C. (2024). Spatial variation in soil aggregate stability and erodibility at different slope positions in four hilly regions of northeast China. *CATENA, 235*, 107660–107660. https://doi.org/10.1016/j.catena.2023.107660

Pijl, A., Reuter, L. E. H., Quarella, E., Vogel, T. A., & Tarolli, P. (2020). GIS-based soil erosion modelling under various steep-slope vineyard practices. *CATENA, 193*, 104604. https://doi.org/10.1016/j.catena.2020.104604

Preiti, G., Antonio, C., Porto, P., Romeo, M., Monti, M., & Bacchi, M. (2022). Long-term effects of different arable cropping systems on surface erosion processes and C-factor in hilly Mediterranean environment. *Soil and Tillage Research, 223*, 105480–105480. https://doi.org/10.1016/j.still.2022.105480

Putra, A., Triyatno, T., Syarief, A., & Hermon, D. (2018). Penilaian Erosi Berdasarkan Metode USLE dan Arahan Konservasi Pada DAS Air Dingin Bagian Hulu Kota Padang-Sumatera Barat. *JURNAL GEOGRAFI, 10*(1), 1. https://doi.org/10.24114/jg.v10i1.7176

Rahmad, R., Suib, S., & Nurman, A. (2018). Aplikasi SIG Untuk Pemetaan Tingkat Ancaman Longsor di Kecamatan Sibolangit, Kabupaten Deli Serdang, Sumatera Utara. *Majalah Geografi Indonesia, 32*(1), 1. https://doi.org/10.22146/mgi.31882

Rashmi, I., S, K. K., Roy, T., C, S. K., Kumawat, A., Kala, S., & Pal, R. (2022). Soil Erosion and Sediments: A Source of Contamination and Impact on Agriculture Productivity. In M. Naeem, J. Francisco, A. A. Ansari, & S. S. Gill (Eds.), Agrochemicals in Soil and Environment: Impacts and Remediation (pp. 313–345). Springer Nature Singapore. https://doi.org/10.1007/9789811693106_14

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., Yoder, D. C., & coordinators. (1997). *Predicting Soil Erosion by Water: A Guide to Conser- vation Planning With the Revised Universal Soil Loss Equation (RUSLE)* (Agriculture Handbook, Vol. 703, p. 404). U.S. Department of Agriculture, Agricultural Research Service. https://www.ars.usda.gov/arsuserfiles/64080530/rusle/ah_703.pdf

Roslee, R., & Sharir, K. (2019). Soil Erosion Analysis using RUSLE Model at the Minitod Area, Penampang, Sabah, Malaysia. *Journal of Physics: Conference Series, 1358*, 012066. https://doi.org/10.1088/1742-6596/1358/1/012066

Sumiahadi, A., & Acar, R. (2019). Soil Erosion in Indonesia and Its Control (pp. 25–27). In Proceedings of the International Symposium for Environmental Science and Engineering Research (ISESER), Konya, Turkey.

Suprayogo, D., van Noordwijk, M., Hairiah, K., Meilasari, N., Rabbani, A. L., Ishaq, R. M., & Widianto, W. (2020). Infiltration-Friendly Agroforestry Land Uses on Volcanic Slopes in the Rejoso Watershed, East Java, Indonesia. *Land, 9*(8), 240. https://doi.org/10.3390/land9080240

Sidi Almouctar, M. A., Wu, Y., Zhao, F., & Dossou, J. F. (2021). Soil Erosion Assessment Using the RUSLE Model and Geospatial Techniques (Remote Sensing and GIS) in South-Central Niger (Maradi Region). *Water, 13*(24), 3511. https://doi.org/10.3390/w13243511

Susanti, Y., Syafrudin, S., & Helmi, M. (2019). Soil Erosion Modelling at Watershed Level in Indonesia: a Review. *E3S Web of Conferences, 125*, 01008. https://doi.org/10.1051/e3sconf/201912501008

Suripin, S. (2002). *Pelestarian Sumber Daya Tanah Dan Air.* Penerbit: Andi.

Tamene, L., & Le, Q. B. (2015). Estimating soil erosion in sub-Saharan Africa based on landscape similarity mapping and using the revised universal soil loss equation (RUSLE). *Nutrient Cycling in Agroecosystems, 102*(1), 17–31. https://doi.org/10.1007/s10705-015-9674-9

Taslim, R. K., Mandala, M., & Indarto, I. (2019). Pengaruh Luas Penggunaan Lahan terhadap Laju Erosi: Studi pada Beberapa DAS di Wilayah Tapal Kuda Jawa Timur. *Jurnal Penelitian Pengelolaan Daerah Aliran Sungai (Journal of Watershed Management Research), 3*(2), 141-158. https://doi.org/10.20886/jppdas.2019.3.2.141-158

Thapa, P. (2020). Spatial estimation of soil erosion using RUSLE modeling: a case study of Dolakha district, Nepal. *Environmental Systems Research, 9*(1). https://doi.org/10.1186/s40068-020-00177-2

Tonolli, A., Pisciotta, A., Riccardo Scalenghe, & Gristina, L. (2024). From grapes to getaways: Unraveling the residential tourism impact on land use change and soil erosion processes in Menfi district. *Land Use Policy, 137*, 107013–107013. https://doi.org/10.1016/j.landusepol.2023.107013

Vadari, T., Subagyono, & Sutrisno, N. (2004). *Model Prediksi Erosi: Prinsip, Keunggulan, Dan Keterbatasan* (pp. 31–71). Balai Penelitian Tanah.

Wang, J., Zhang, Y., Li, K., Zhang, Z., & Chen, C. (2023). Gully internal erosion triggered by a prolonged heavy rainfall event in the tableland region of China's Loess Plateau. *International Soil and Water Conservation Research, 11*(4), 610-621. https://doi.org/10.1016/j.iswcr.2022.12.003

Wischmeier, W. H., Johnson, C. B., & Cross, B. V. (1971). A Soil Erodibility Nomograph for Farmland and Construction Sites. *Journal of Soil and Water Conservation, 26*(5), 189–193.

Wischmeier, W. H., & Smith, D. D. (1978). *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning* (Vol. 537, p. 58). Department of Agriculture, Science and Education Administration.

Xie, X., Li, C., Wu, L., Gao, Z., Wang, Y., Shen, N., Zhou, X., Zhang, X., & Li, M. (2024). Improvement of land surface vegetation ecology inhibited precipitation-triggered soil erosion in the alpine-cold river source area – A case study in Southern Gansu, China. *Journal of Hydrology: Regional Studies, 51,* 101614–101614. https://doi.org/10.1016/j.ejrh.2023.101614

Xu, Q., Chen, W., Zhao, K., Zhou, X., Du, P., Guo, C., Ju, Y., & Pu, C. (2021). Effects of land-use management on soil erosion: A case study in a typical watershed of the hilly and gully region on the Loess Plateau of China. *CATENA, 206*, 105551–105551. https://doi.org/10.1016/j.catena.2021.105551

Yusuf, S. M., Murtilaksono, K., & Lawaswati, D. M. (2020, December 31). Spatial mapping of soil erosion prediction through integration USLE model into Geography Information System. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan, 10*(4).

Zhang, H., Yang, Q., Li, R., Liu, Q., Moore, D., He, P., Ritsema, C. J., & Geissen, V. (2013). Extension of a GIS procedure for calculating the RUSLE equation LS factor. *Computers & Geosciences, 52*, 177–188. https://doi.org/10.1016/j.cageo.2012.09.027

Zhang, S., Guo, M., Liu, X., Chen, Z., Zhang, X., Xu, J., & Han, X. (2024). Historical evolution of gully erosion and its response to land use change during 1968–2018 in the Mollisol region of Northeast China. *International Soil and Water Conservation Research, 12*(2), 388-402.https://doi.org/10.1016/j.iswcr.2023.08.001