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Original Research

Forecasting Soil Erosion Risk Using GIS and Remote Sensing for the Nam Un Basin, Sakon Nakhon Province, Thailand

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Abstract

Geohazard mapping using remote sensing and GIS is effective. Nam UN classic terrain with soil erosion and other geohazards. The Nam UN Basin's yearly soil loss and high erosion potential are estimated using RUSLE, remote sensing, and GIS. 14.26 t/ha/year of soil erosion is seen on the map. Soil erosion zones are also shown on the map. According to the study, 33.40 percent of the whole area (457.07 kilometers) is prone to severe soil erosion, while 7.72 percent (105.76 kilometers) is prone to high erosion. To decrease soil erosion, decision-makers use soil erosion prognosis analysis. The Analytical Hierarchy Process (AHP) was utilized to identify key soil erosion prone locations by incorporating geo-environmental variables such land use/land cover, geomorphology, Dem, drainage density, slope, elevation, LS factor, rainfall, soil texture, and soil depth. 33.40% of the region is highly prone to soil erosion.

Keywords: soil erosion, GIS, RUSLE, AHP, Nam Un Basin

Introduction

The huge precipitation surpasses the soil's infiltration capacity, causing substantial runoff and erosion [1]. Soil erosion is a natural process produced by several natural occurrences such as wind, precipitation, and water flow. Human activities such as deforestation, road construction, and intensive farming frequently cause erosion. It impacts agriculture, construction operations, and homeowners near rivers, oceans, and slpes on land. The rate of soil erosion over a specific area of land is determined by the loss of soil mass over time; it can be calculated by measuring the loss of soil mass over a particular time [2]. The key difficulty is draining the flood so that there is no or limited silt scour in downstream locations. A water flow in the form of a high-energy free jet finally reaches a location downstream of the dam, causing the displacement of bed materials and the formation of sour holes, which can ultimately fail the spillway [3].

In addition, soil erosion is a type of soil degradation characterized by the detachment, transport, sedimentation, and deposition of soil particles. Particles are transported from one area to another by the dynamic force. Regarding the effectiveness of eroding agents, The elements of water, ice (glaciers), snow, air (wind), plants, and animals make up the erosive agents.humans. Sometimes, water erosion is distinguished from soil

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erosion. The erosion caused by glacier, snow, wind, and aeolian processes According to scientific literature, both zoogenic and human-caused erosion occur. The primary reason [4]. Water and wind are the principal agents of soil erosion; strong winds erode mostly loose soil arising from a flat or hilly environment, and soil energy produced by falling and running water is the primary cause of soil erosion.Soil particles are also separated and transported at the surface. Global research has been conducted on soil erosion. The loss in soil fertility, land degradation, and drainage are among the several ecological and environmental concerns that are a focus of attention. Significant river siltation is the consequence of its occurrence [5].

In addition, it reduces reservoir capacity and has detrimental effects on aquatic habitats, hydrologic systems, and downstream water quality. Typically, sediments bind nutrients, hazardous chemicals, and metals [6]. Due to the influence of precipitation, soil erosion processes also enhance the likelihood of floods. Erosion of the soil is a natural process creates undesirable global economic and environmental impressions However, human actions, such as the overexploitation of land resources, have accelerated the rate of soil erosion in a number of places of the world. Several natural and anthropogenic variables that enable the initiation and acceleration of soil erosion are often responsible for the majority of soil deterioration. These constituents are characterized as quasi-static (infiltration, erodibility, and morphology) and temporally variable (erodibility, erodibility, and morphology) factors (vegetation cover, soil temperature, precipitation, etc. [7]. Land use, intensity of precipitation, and agriculture. According to Bouhadeb et al., soil erosion is also considered a climate change risk factor. As a spatial-temporal land degradation process with significant adverse impacts in a number of countries. In the Nam UN Basin of Thailand's Sakon Nakhon Province, water erosion is the leading driver of soil degradation, albeit to varying degrees. around the entire Nam UN Basin. The geography, geology, and geomorphology of the Nam UN Basin are diverse, as are the land-use patterns present there. Nam UN basin is also significantly impacted by soil erosion, silt transport, and land degradation. Significant soil erosion occurrences in the Nam UN Basin include splash, stream, and channel forms. The occurrence of gullies throughout the Nam UN basin has not only resulted in the loss of agricultural areas but also in insufficient space for the development of sustainable infrastructures. Regarding the assumed growing threat of soil contamination, it is necessary to assess soil loss and designate degraded regions to aid in effective decision-making and conservation planning in light of the pervasiveness and severity of erosion. Various models have been created and deployed by a number of researchers with the purpose of analyzing soil loss and determining the most effective soil preservation strategies. The revised Universal Soil Loss Equation (RUSLE), the Watershed Erosion Prediction Project (WEPP), the agricultural non-point source model (AGNPS), the regional non-point source watershed environment response simulation (ANSWERS) model, the Limburg Soil Erosion Model (LISEM), the European Soil Erosion Model (EUROSEM), and the Soil Erosion Model for Mediterranean Regions (CREAMS) Mosavi et al. (DTs) [8, 9].

In addition, they suggested that extensive research and investigation be performed for future development and advancement. Those previously mentioned Multiple studies have implemented and demonstrated that the combination of remote sensing and GIS technologies with the USLE and RUSE approaches simplifies soil erosion assessment by providing more accurate estimates of soil erosion at diverse locations [10] confirmed that the integration of RS, GIS, and RUSLE provides reliable estimates of soil erosion at the cellular level. In a GIS environment, a digital elevation model (DEM) facilitates the creation and processing of the primary soil erosion modeling input data (terrain, slope, gradient, and slope length), whereas multi-temporal satellite images contribute to the provision of information on land use and land cover dynamics. In addition, the Analytical Hierarchy Process (AHP) was designed for models that heavily rely on the opinions of experts. 1980 publication by Saaty is also readily available [9, 10]. This model assigns unique weights to each contributing element by comparing the multiple pairwise relationships. Due to the importance of Thailand's soil to its economy, qualitative approaches are generally successful for regional studies despite their subjectivity. When it comes to food security, it is essential to use management and conservation techniques to prevent soil erosion. This will reduce and halt the continuing loss of soil fertility, and it is anticipated that agricultural practices and output would increase substantially. Consequently, the objectives of this work were to integrate the RUSLE model, the, AHP model, RS, and GIS techniques to predict erosion risk and hotspots in the Nam UN Basin and to generate state-wide maps of soil erosion intensity. These maps may be essential for making decisions regarding sustainable land protection and conservation.

Materials and Methods

Study Area

The Nam Un Basin serves as the Songkhram River's most important tributary in Thailand's upper northeastern region. The Phu Phan Mountain Range in Sakon Nakhon Province's Kut Bak District is the watershed, and the river reaches its confluence with the Mekong River in Nakhon Phanom Province's Tha Uthen District. The two sites are separated by 295 kilometers. The Nam Un Dam, in Sakon Nakhon Province's Phang Khon District, is an earthen dam that blocks the Nam Un watercourse. The area has a tropical monsoon environment, with mean rainfall measuring 1,651.10 mm annually, while the mean daily wind speed stands at 1.70 m/s, and the mean temperature measures 26.7ºC [41].

Data Source

Data from multiple sources were checked to analyze soil loss in the study area in Table 1. Using a shuttle radar topography mission (SRTM) digital elevation model (DEM) in Fig. 2 with a 30-meter resolution generated by the USGS Earth Explorer, the slope length and slope gradient factor of the study watershed were determined Fig. 1. Additionally, a soil sample was utilized to determine the soil erodibility factor (K value) examination of precipitation Meteorological station yearly precipitation data was used to calculate the erosivity factor (R value), and Landsat 8 OLI satellite pictures were digitally processed to create the cover image management C coefficient. The figure illustrating the study's estimation of soil loss. Fig. 5 depicts the watershed by the RUSLE model utilizing GIS and the RS program.

Acquiring RUSLE Parameters

Rainfall Erosivity Factor (R factor)

The digital precipitation statistics for the provinces of Sakon Nakhon were received from the Thai Meteorological Department. There were 15 rainfall monitoring stations in the watershed, and data from these stations were used to calculate the annual mean rainfall for 2018. For the evaluation of erosivity at each of the 15 sites, the monthly rainfall data was reduced to the annual mean rainfall in millimeters. Due to the limited number of stations in the study area, rainfall data from surrounding stations were also utilized. The R-factor was calculated using the best available equation Equation (1), which was defined by the land development Department for Northeastern Thailand [38].

$$R = 0.4669X - 12.1415 \quad (1)$$

where R is the rainfall-runoff erosivity factor in MJ.mm. $ha^{-1}.h^{-1}$ yr^{-1} and X is the average yearly precipitation (mm):

Soil Erodability Factor (K)

The K factor is an empirical soil erodibility measurement that is affected by intrinsic soil parameters. It represents a number of characteristics, including soil erodibility, sediment transportability, and runoff quantity and velocity. Using a soil texture map provided from Land Development Department, the K factor map was generated. Using the soil erodibility nomograph and taking into account particle size, organic matter concentration, and permeability class, the corresponding K values for the soil types were found. Soils with low soil erodibility have a value of 0, whereas soils with high soil erodibility have a value of 1 [11].

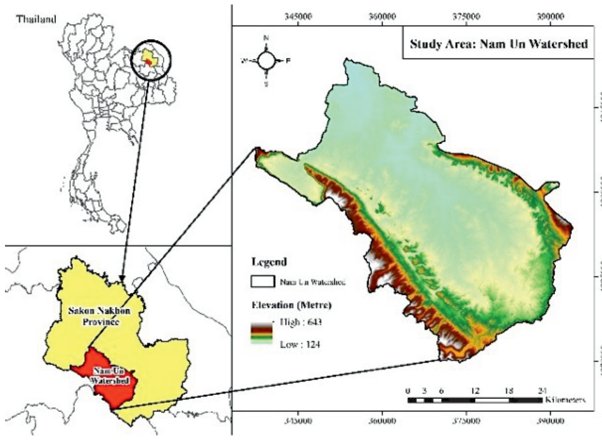

Fig. 1. Study of the Nam Un Basin.

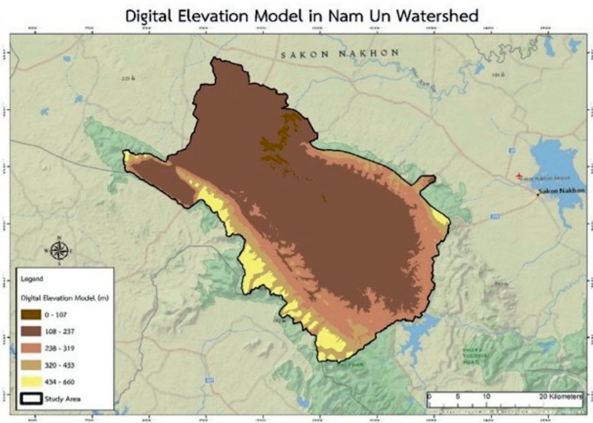

Fig. 2. The study watershed's digital elevation model (DEM).

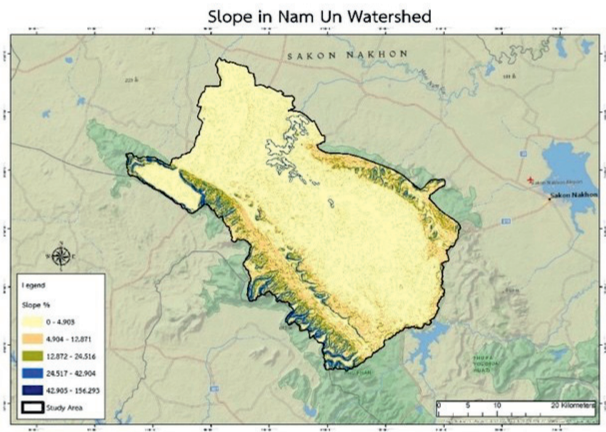

Fig. 3. Watershed slope map for the study.

Table 1. Description of the datasets.

Type of Data	Description	Source
DEM	SRTM 30 m resolution Digital topographic and Contour Line	USGS https://earthexplorer.usgs.gov/ The Royal Thai Survey Department
Soil data	Digital soil map of the Nam Un basin Digital geology map of the Nam Un basin	Land Development Department, Thailand Department of Mineral Resources, Thailand
LULC	Digital LULC map of the Nam Un basin	Land Development Department, Thailand
Rainfall Data	Annual mean rainfall in 2018 using data from 15 measuring sites	Royal Irrigation Department, Thailand Electricity Generating Authority of Thailand The Thai Meteorological Department
Land conservation activities	Current conservation methods in the watershed	Land Development Department, Thailand Department of Mineral Resources

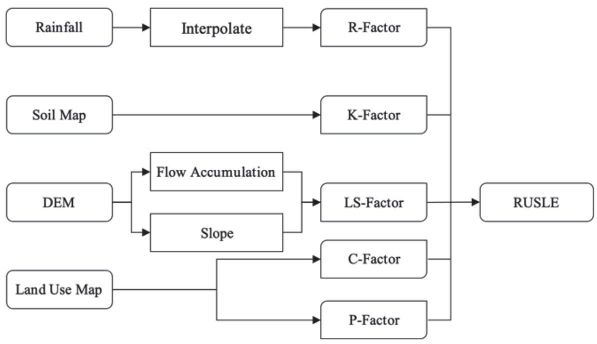

Fig. 4. Framework for the analysis of soil loss applied to the RUSLE model.

Slope Length and Steepness

The Royal Thai Survey Department provided digital topographic contours at a scale of 1:50,000 for 20 m. The digital topographic contours were interpolated into a raster digital elevation model (DEM), and the slope was determined using the Topography-to-Raster Map function of the ArcGIS software. Using a revised equation for the study (Equation 3), the LS factor layer was obtained from the DEM [38]:

$$\text{(a) slope length } L = (\lambda / 22.13)\, m, \quad (2)$$

where, λ = Slope length (cell size in meters), m = a variable slope-length exponent related to the ratio β of rill erosion (caused by flow) to inter-rill erosion (principally caused by raindrop impact) according to Equation (4) [38]:

$$m = \beta / (1 + \beta) \quad (3)$$

where β can be computed from (McCool et al., 1997) using Equation (5) [38]:

$$\beta = (\sin\theta / 0.0896) / (3.0(\sin\theta)0.8 + 0.56) \quad (4)$$

where, θ = slope gradient map (degrees) (b) steepness factor This factor was computed using Equations (6) and [38]:

$$S = (10.8\sin\theta + 0.03) \text{ for slope} < 9\% \quad (5)$$

$$S = (16.8\sin\theta - 5) \text{ for slope} \geq 9\% \quad (6)$$

where, θ = slope gradient map (degrees) The Map-Algebra function in the ArcGIS software was used for factor calculations because it has many user-friendly functions

Vegetative Cover

The vegetative cover factor (C) is possibly the most important RUSLE element since it reflects the conditions that may be handled most simply to decrease erosion. The map of land uses land cover classes (LULC) was created using data from the United States Geological Survey.2019 land use maps are derived from the LDD. The C-factor values established by LDD (2002) for different types of vegetation cover were assigned.according to Table 2, this is the case [38].

Practices for Field Support

The support practice factor, P, is a soil loss ratio for a certain support practice to the equivalent soil loss on an ascending and descending slope tillage [12]. In Thailand, a price is because P is not determined for any agricultural cover types other than paddy. In situations where there There was no precedent, and the maximum value was 1. assigned. The P values utilized in this study, according to LDD, there are nine distinct classes. presented in Table 2.

Revised Universal Soil Loss Equation (RUSLE)

RUSLE, which calculates soil erosion rate based on climate, soil characteristics, topography, and vegetation, anticipated the spatial distribution of A in the Nam UN

Table 2. Classifications of land cover by vegetative cover (C) and field support practice (P) (LULC).

LULC Class	LULC Code	C Value	P Value
Mixed crops (MC)	A0	0.255	1
Paddy field (PF)	A1	0.280	0.1
Field crops (FC)	A2	0.525	1
Perennial trees (PT)	A3	0.150	1
Orchards (Oc)	A4	0.300	1
Horticulture crops (HC)	A5	0.600	1
Grassland (GL)	A7	0.100	1
Shifting cultivation (SC)	A9	0.250	1
Evergreen forest (EF)	F1	0.003	1
Deciduous forest (DF)	F2	0.048	1
Forest plantation (FP)	F5	0.88	1
Agro forestry (AF)	F6	0.88	1
Natural grassland (NG)	M	0.015	1
Water body	W	0	0
Urban	U	0	0

basin protection and human actions A by Wischmeier and Smith is computed by RUSLE [13].

$$A = R \times K \times LS \times C \times P \quad (7)$$

where A is the computed spatial average soil loss and temporal average soil loss (in t ha^{-1} year^{1}), R is the rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} year^{1}), K is the soil erodibility factor (t h $^{-1}$ MJ $^{-1}$ mm), LS is the slope-length and slope steepness factor (-), C is the cover management factor (-), and P is the support[14-20]. Practice factor (-) In order to compute the geographically distributed soil loss in the Nam UN Basin, the input variables of the RUSLE model Equation (7) were included into ArcGIS 10.5. Water bodies within the Nam UN Basin were omitted from the calculation of A since the mechanism of soil erosion and delivery differs substantially between land and water [20, 21].

Analytic Hierarchy Process (AHP)

The Revised Universal Soil Loss Equation (RUSLE) takes soil erosion into account Saatin is credited with introducing the Analytic Hierarchy Process (AHP) as a multi-criteria decision-making strategy that is widely employed [4, 5]. This method appealed to the researcher due to the simplicity of its mathematical qualities, specifically the ease of access to the essential inputs. Another advantage of this method is its applicability to a variety of sectors of scientific study and industrial applications that require optimal decisions [7, 8]. It is built on a multilevel hierarchical framework of objectives, criteria, sub-criteria, and options. To collect the essential data, a pairwise comparison is utilized. The purpose of employing the objective of the comparisons is to determine the relative weights of each decision criterion based on its degree of importance and relative performance. A flawless consistency and on the basis of a literature review and expert opinion, the most influential environmental factors on soil erosion were determined. This analysis takes into account land use/land cover, geomorphology, drainage density, stream frequency, lineament frequency, slope, and relative relief. The AHP method was then used to assess the contributions of several elements to soil erosion risk and potential. In the AHP, decisions are made based on a pairwise comparison of the elements of a problem with respect to their relative impact ("weight" or "intensity") on a property they share; i.e., the factors are compared with one another to determine the relative preference of each factor, which is expressed as a numeric value and The elements of the matrix of pair-wise comparisons may be represented as follows [7-9]:

$$M = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \quad (8)$$

Where

$$aij = \frac{\text{weight for attribute (i)}}{\text{weight for attribute (j)}} \quad (9)$$

the weight might fluctuate between 1 and 9 The element 1/1 suggests that I and j are of equal value, however the element 9/1 indicates that I is much more important than j. By estimating the Eigenvalues and accompanying normalized Eigenvectors, the relative weights of the matrix's elements were determined. The Eigenvector corresponding to the biggest Eigenvalue of the matrix (i.e., the primary Eigenvector) indicates the relative importance of the factors. To evaluate the level of consistency of an n-by-n matrix, the consistency index (CI) was developed as follows [6, 7]:

$$CI = \frac{\lambda max - n}{n-1} \quad (10)$$

where max is the matrix's greatest Eigenvalue. max will equal n if there are no inconsistencies in the pair-wise comparisons, resulting in a CI of zero. Since CI is dependent on n, the consistency ratio (CR) was also created to assess the coherence of pair-wise comparisons [7, 8]

$$CR = \frac{CI}{RI} \quad (11)$$

RI is the averaged capable of functioning resulting from randomly generated comparisons; it changes based on the matrix's order. As a general rule, a CR of 0.1 is appropriate to maintain the matrix's consistency. Otherwise, all or a portion of the pair-wise comparisons must be redone to remove the differences. The R software package "probability models for ranking data" was used to develop AHP processes in this study. Since the AHP method produces quantitative values for the contributions of different components to soil erosion risk, a weighted linear sum approach can be implemented in GIS [7, 9].

Categorization Evaluation Process

$$OA = \frac{\sum_{k=1}^{n} C_{kk}}{n} \quad (12)$$

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_i + X_{x+1})}{N^2 - \sum_{i=1}^{r}(x_{ii}X_{x+1})} \quad (13)$$

developed the confusion matrix approach for providing overall accuracy OA and Kappa statistics K. OA is calculated by dividing the number of correctly classified pixels (TCS or the sum of the diagonals) by the number of reference pixels (TS) in the error matrix using equations (1), reference sample, TScj is the total number of pixels in column j, and TSri is the total number of pixels in row i. The amount of agreement was quantified using the kappa statistic (K) with the assumption that a K of 1 represents perfect agreement and a kappa of 0 implies agreement similar to chance for correctly classifying the pixels, as calculated by the following equation (13):

TS is the entire reference sample, TScj is the total number of pixels in column j, and TSri is the total number of pixels in row I [10]. Kappa values show strong auditing accuracy and compatibility of over 75% and 67.98% for total accuracy. It provides significant field-based classification and reference data. examine this image.

Results and Discussion

Rainfall Erosivity (R)

The rainfall erosivity factor (R) describes the probability of soil deterioration due to precipitation [22]. The R-factor exposes the effect of precipitation concentration on soil loss, and its calculation demands exhaustive, continuous rainfall data. The calculated R-factor for the research area is between 37.05 and 52.06, which represents the rainfall regime. From the center to the south of the research zone, precipitation and erosivity are generally increasing. The incidence is more prevalent in the southern region of the state. The occurrence of more erosive and intense precipitation causes the erosivity of rainfall to increase as the mean annual precipitation rises. The R-factor for Nam UN Basin is illustrated in Fig. 4. Consequently, rapid climatic change may affect the soil's composition.

Soil Erodibility (K)

The element of soil erodibility that investigates the susceptibility of soil constituents or external constituents to conveyance and disengagement as a result of rainfall volume and runoff contribution. Renard et al. discovered that the K-factor explains the influence of soil characteristics on soil loss in the Highlands during rainstorms. K-factor is influenced collectively by precipitation, runoff, and infiltration [22]. The K-factor measures the cohesiveness of a soil type as well as its resistance to extrication and conveyance under the impact of rainfall and shear forces of flow across land [23]. Depending on soil type, the amount of energy required to extract and transport soil varies a soil's ability to erode is low if it has a low silt content, even if it has a high sand and clay concentration. The digital soil map of the study area identified seven distinct soil types with unique features [24-28]. With K-factor values ranging from 0.05 to 0.36 tons per hour, ha^{-1}, MJ^{-1}, mm^{-1}, the erodibility of the existing soils in the study area varied. As the K-factor approaches 1, the soil's susceptibility to erosion increases, and as the K-factor approaches 0, the soil's resistance to erosion increases. Table 3 displays the soil type, features, and K-factor for each soil type found in the Nam UN basin. Fig. 5 illustrates a map of the K-factor for all types of soil.

Slope Length and Steepness (LS)

L-factor is the length function of the slope, whereas S-factor is the steepness function of the slope. Together, they are used to characterize the topographical feature as the LS factor. The LS-factor accounts for the topography component of soil erosion at any particular site. Slope length is the distance between the beginning of flow across land and either the point at which sedimentation begins or the point at which runoff enters

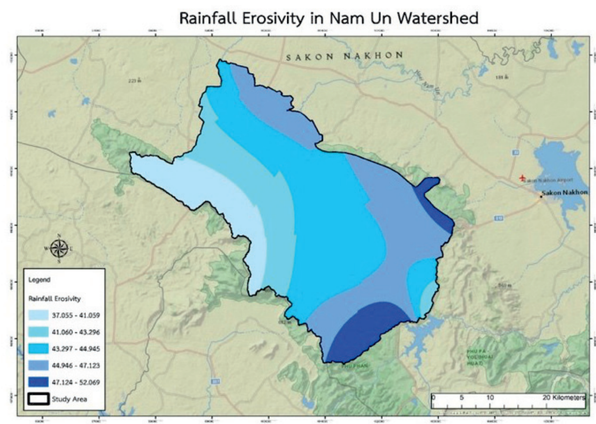

Fig. 4. Map depicting the erosivity due to rainfall in the Nam Un Dam Watershed.

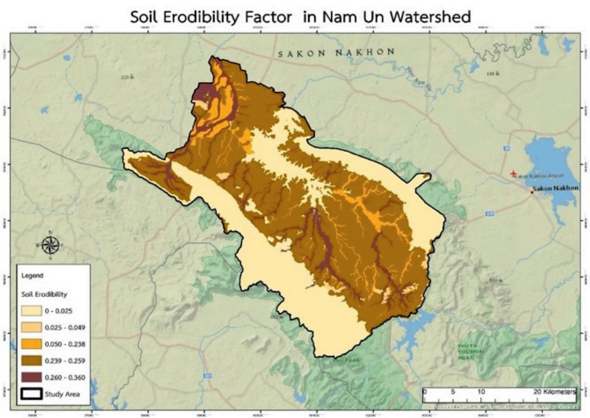

Fig. 5. Map depicting the erosivity due to rainfall in the Nam Un Watershed.

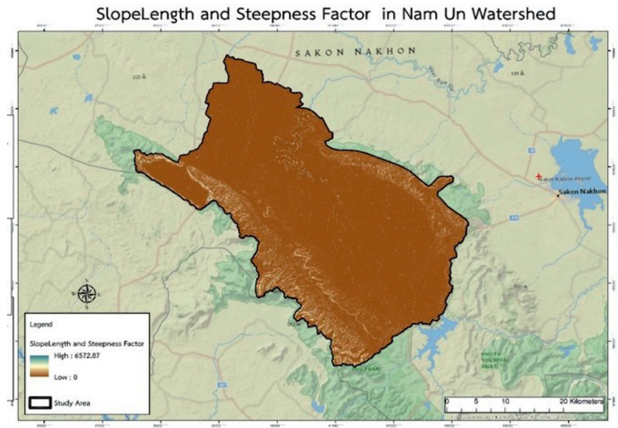

Fig. 6. Slope length and steepness map of the Nam Un Watershed.

distinct streams [29-33]. The concentration of water is determined by the length of the slope. The longer a region is, the stronger its flow and runoff, and the higher its slope [34]. The steepness (S-factor) describes the slope or altitude's effect on erosion. The risk of soil erosion increases with increasing slope steepness and length. In this study, the LS-factor fluctuated between 0 and 6572 (lower and flatter portion) Fig. 6. In the Nam UN River Basin, higher LS-factor values are prevalent, indicating that these areas are mountainous and hilly. Several other sections are Hills and riverbanks may provide a little amount of high LS-factor [35]. These regions have stronger LS-factors due to the fact that LS-factor values increase with slope gradient. Consequently, locations with smaller LS-factor values experience less soil erosion due to this factor, while regions with bigger LS-factor values experience more soil erosion due to this factor. How much dirt is lost depends on the relationship between the slope's length and slope [36-37].

Length of the slope. The longer a region is, the stronger its flow and runoff, and the higher its slope [37]. The steepness (S-factor) describes the slope or altitude's effect on erosion. The risk of soil erosion increases with increasing slope steepness and length. In this study, the LS-factor fluctuated between 0 and 6,572. (lower and flatter portion).

Table 3. The relationship of soil loss with K values.

Hydrologic Soil Group	K Factor	Area (km^2)	%
C	0.00	90.94	6.63
A	0.04	19.06	1.39
B	0.05	72.88	5.32
C/A/A/C/B	0.24	676.31	49.34
B	0.26	119.69	8.73
B	0.29	391.87	28.59
C	0.36	0.06	0.00
Total		1,370.80	100.00

Conservation Practices (P)

The P-factor compares the soil erosion induced by a certain erosion management approach to that caused by upslope and downslope tillage [39]. It describes the amount of soil loss induced by particular management practices. Depending on land usage and soil type, plants prevent soil loss and reduce erosion [40]. When farmers till their fields without caring for the soil with contouring, stippling, and terracing, phosphorus levels rise. Farmers who followed conservation techniques would have P-values that are lower. These activities primarily affect soil loss by affecting the watercourse's form, gradient, or manner of overland flow and by reducing runoff volume and intensity [39, 40]. The P-value for the Land Development Department of Thailand has been set to 1 since there are no specified management procedures in the region. However, because slope steepness has a significant impact on P-factor values, the Nam UN Basin of the study area had greater P-factor values Table 4. There is also a possibility that P-factor values in other locations are less than 1 due to the current low slope gradient Fig. 7.

Crop Management (C)

The C-factor provides essential information regarding the effect of land use and land cover (the key indicator of spatial impact extent) on erosion rates and how land is currently and will be used in the future [42]. The C-factor illustrates how plant cover, agricultural practices, and policymaking influence the erodibility of soil. It is the ratio of soil erosion at a specific location with a given cover and management to soil erosion at a standard division. Describe, this as the ratio between the amount of soil erosion caused by a certain crop and the amount of soil erosion caused by an uncultivated, bare environment. This analysis evaluates the effects of cover, crop order,

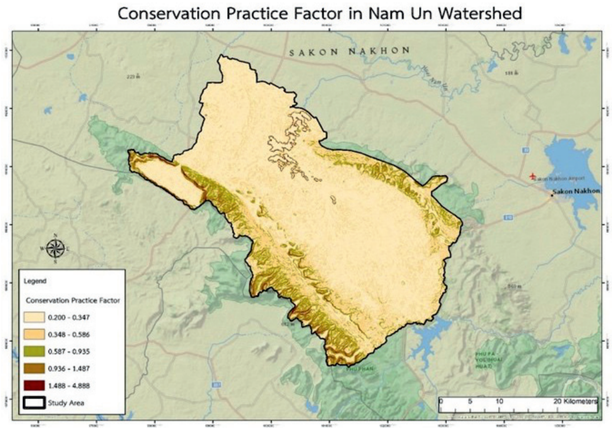

Fig. 7. Map illustrating conservation practices in the Nam Un Watershed.

Table 4. P factor of erosion.

P Factor	Area (square km)	%
0.00	166.54	12.15
0.10	323.16	23.57
1.00	881.10	64.28
Total	1,370.80	100.00

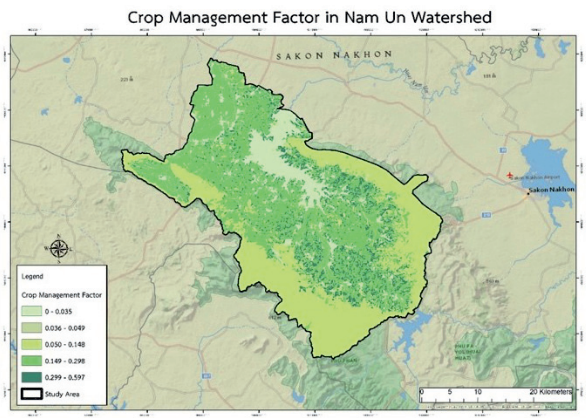

Fig. 8. Map presenting crop management in the Nam Un Watershed.

production level, cropping season length, cultivation system, residue management, and the expected temporal spread of eroding precipitation. The C factor depicts the relationship between erosion on bare soil and observed erosion within an agricultural system. It explains how soil is protected by the type and density of cover [43-45]. The C-factor values over the study area range from 0.00 (low) to 0.59 (high) (high). C-factor levels closer to 0 suggest well-protected land cover and effective conservation practices, whereas C-factor values closer to 1 imply unprotected land and inadequate conservation policies. Some of these sites have high values because they are agricultural lands that are exposed to direct precipitation during crop production; soil erosion from these places was expected to be substantial due to the absence of protection from intense rainfall events. Larger C-factor values result in greater soil erosion, and vice versa. Consequently, the Nam UN Basin has a low C-factor, but the opposite side of the Nam UN Basin contributes moderately to significantly to soil erosion in the watershed. Fig. 8 demonstrates the C-factor [46].

Potential Soil Erosion Estimation

To assess the way erosion is distributed spatially across the area of the study, the erosion model was combined with RS and GIS, while a number of factors were assumed to influence erosion patterns, including the slope length and steepness, the rainfall erosivity, the soil erodibility, land usage and management, and conservation measures taken to protect the soil. Modeling results when these variables are taken into consideration can be seen in Fig. 9 and 10.

The models of rainfall erosivity presented in Fig. 9 clearly indicate that the duration of the rainfall will affect the extent of the resulting erosion, with longer rainstorms causing greater damage. Meanwhile it shows the outcomes when the model makes use of data concerning slope length and steepness. Steeper slopes result in greater runoff over time, so clearly shows that with increasing slope steepness comes increased erosion due to the rising speed of the runoff. The work of Wischmeier and Smith confirms this finding, while shows the outcome when this factor is taken into consideration in the model, with a particular focus upon the resulting influence upon land cover patterns [47].

The results demonstrate that erosion is strongly influenced by the extent of vegetation cover since plants are able to halt or slow the flow of rainwater, while increasing the penetration it achieves. Fig. 9 and 10 illustrates the effects of soil erodibility, whereby the overall susceptibility to erosion is examined in connection with the runoff rate and volume. The model can then be employed to determine the extent of any change in the soil on a unit basis when water is introduced at varying levels of external force, such as a light splash or a strong surface flow. Figs 9, 10 shows the outcome when the soil loss model is employed in developing a map of the erosion potential within the area examined in the study. This allows areas which are at the greatest risk of erosion to be readily identified. Field studies conducted in other similar areas were used to provide the supporting data to uphold the findings The areas in question offered a high degree of soil erosion which caused problems downstream as a consequence of sediment deposits [48].

Erosion tendencies on the basis of LULC and slope along with the five key factors previously described were modeled and the outcomes are shown in Table 5. Using the RUSLE model, the soil loss anticipated for a one-year period within the study site would amount

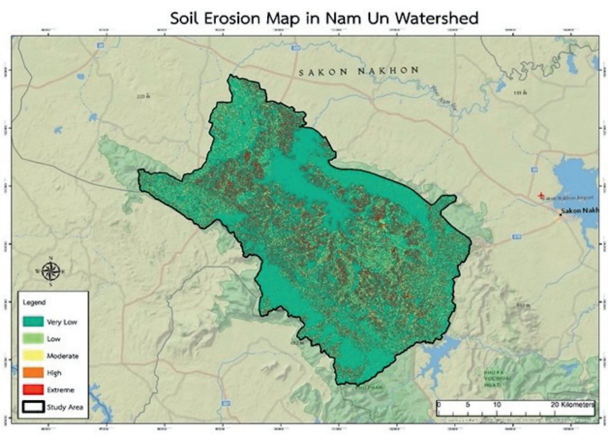

Fig. 9. Map illustrating soil erosion in the Nam Un watershed.

to around 823 t ha^{-1} (Fig. 9). Within each of the five classes, the anticipated soil losses lay in the range of 0-500 tons per hectare annually. In this study location, the annual mean soil loss due to erosion was 14.26 t ha^{-1}. The majority of the research area, 33.40 percent (457.07 kilometers), has low soil erosion, according to the results of the study. Only 7.72 percent (105.76 kilometers) of the region is seriously damaged by soil erosion.zone having the most soil eroding (Table 5).

Soil, precipitation, and land use all have an impact on soil loss. Land Development Department and Thailand Department of Mineral Resources district soil maps were used to classify the soil texture of the research region into fourteen soil textural classes Fig. 11a). Regional differences in precipitation intensity are the most influential element in soil erosion. However, there are few metrological stations in the area of inquiry. To address this issue, gridded precipitation data from the Royal Irrigation Department of Thailand were utilized. The Electricity Generating Authority of Thailand Using data from 15 measurement sites, the Thai Meteorological Department calculated the annual mean precipitation for 2018 (Fig. 11b). Annual precipitation ranges between 402 and 1212

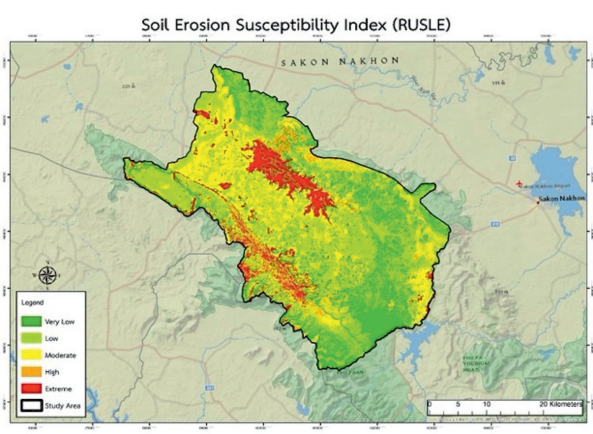

Fig. 10. Map illustrating RUSLE Map in the Nam Un watershed.

Table 5. Soil loss classes and range of the Nam Un Dam watershed.

Erosion Classes	Range (t/ha/year)	Soil loss (ha/year)	%
Low	0-10	110,017.98	80.26
Moderate	Oct-50	15,943.23	11.63
High	50-150	6,735.33	4.91
Very High	150-500	3,559.86	2.6
Severe	> 500	823.5	0.6

Table 6. Soil loss classes and range of the Nam Un Dam watershed (Continue).

Soil Erosion Class	Area (KM^2)	AREA (%)
Very Low	353.21	25.8
Low	457.07	33.4
Moderate	380.83	28
High	72.93	5.25
Extremely	105.76	7.72

millimeters. Given that the suggested location is in a wetland region of the Nam UN Basin, it is vital to understand the current land usage in order to identify regions prone to soil erosion. Encircling the plateau are forested mountains. Its terrain makes it susceptible to soil erosion on rainy days, resulting in substantial losses. The LULC map was generated by supervising the categorization of Landsat 8 Oli images, which were separated into six LULC categories Fig. 12b).

Geomorphology, Slope and Drainage Density

Mapping geomorphology entails the identification and description of numerous types of landforms. The creation of landforms is influenced by several factors, including slope, existing drainage pattern, and subsurface lithology [49]. The region of study is comprised of slope geomorphology classes. These geomorphology files are from Level 2 USGS and Royal Thai Survey Department data Fig. 12c).The topography of the study area is dominated by hills and valleys that are somewhat dissected and structurally derived. Slope is the angle formed at the junction of two surfaces, namely the surface of the earth and a horizontal datum [50]. The slope is a significant contributor to soil erosion. The gradient was calculated with a USGS DEM with a high resolution (12.5 m resolution). The angles between 0 and 135 degrees are categorized by the Royal Thai Survey Department. The relative relief at a certain location describes the variation in altitude.

The safety factor diminishes with increasing altitude. Therefore, comparing two slopes with comparable

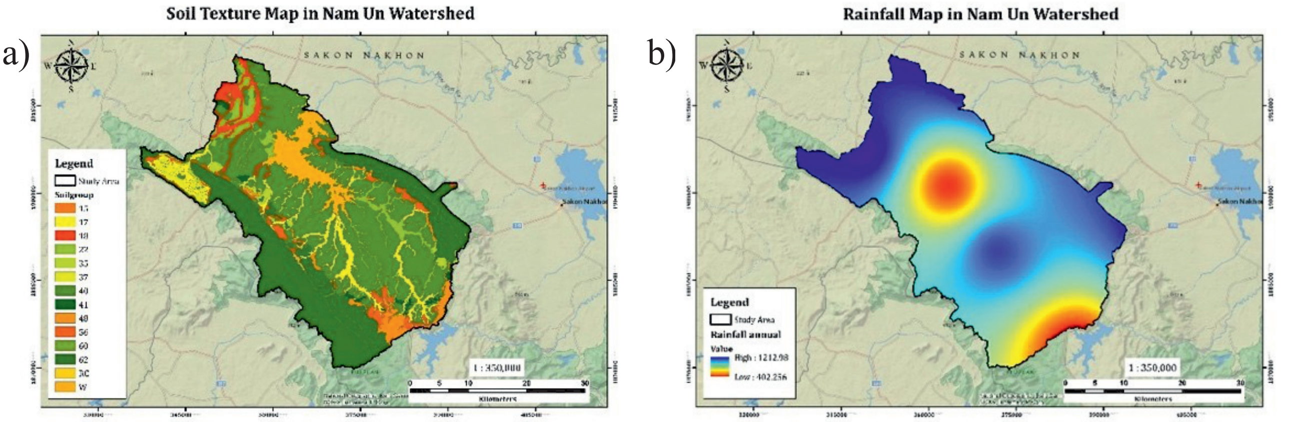

Fig. 11. The study area's soil texture a) and precipitation map b).

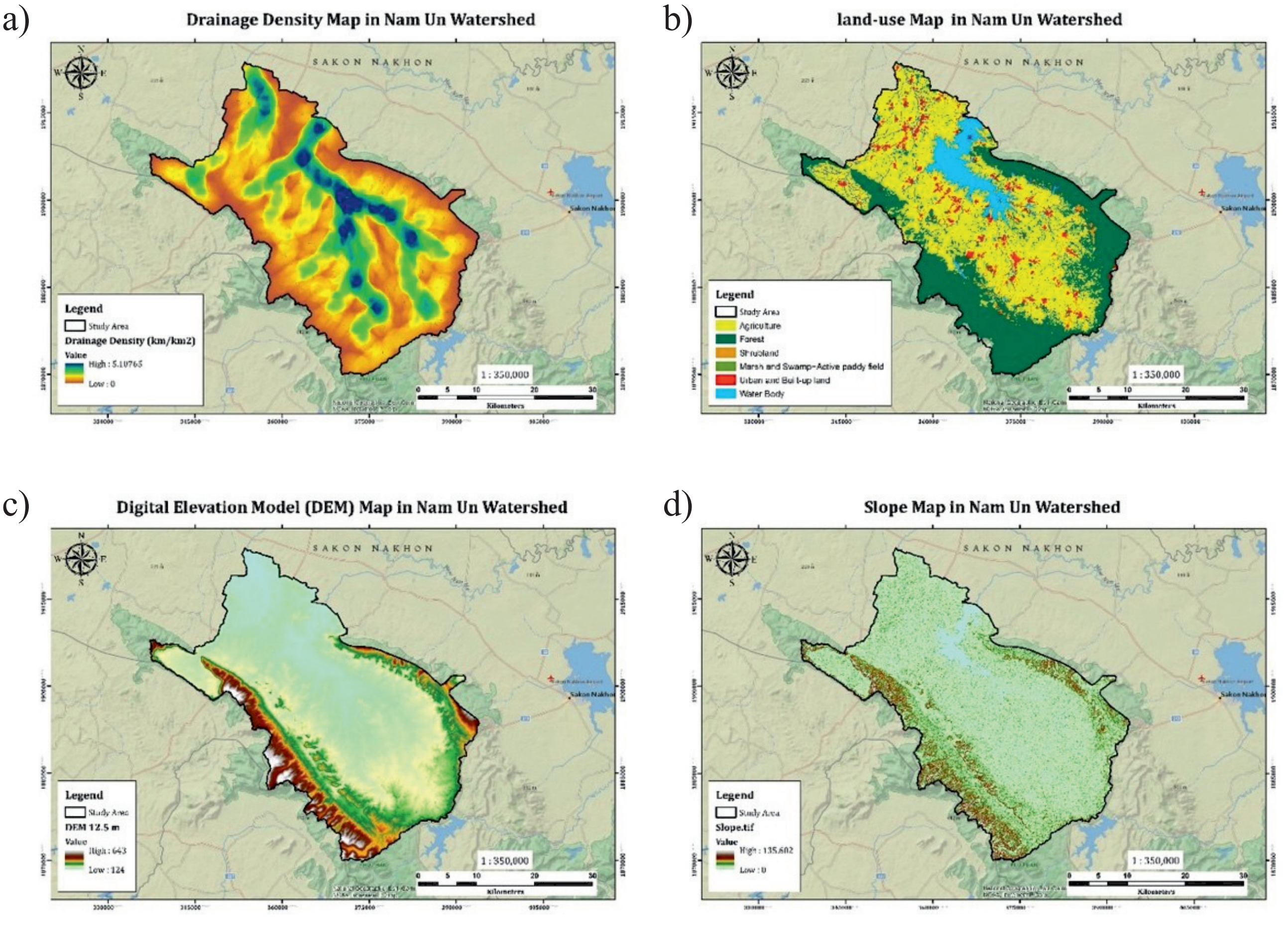

Fig. 12. a) Drainage density; b) LULC; c) DEM; d) Slope map of the study area.

features other than height, the steeper slope will have a higher probability of landslides and soil erosion [51]. Both runoff and infiltration are exacerbated due to the steepness of this terrain. Besides this, the slope Fig. 12d). By decreasing the shear resistance of the slope, saturation also increases shear forces via drag. The geographic extension tool's neighborhood function for the Nam UN watershed. Soil erosion is affected by the drainage network. The process of transferring sediments along streams by means of erosion. It is a crucial characteristic that influences landslide and soil erosion processes in mountainous environments Greater population density correlates with a greater number of streams, resulting in a greater potential for soil erosion. The drainage network of the research area was recovered from the Nam UN Basin DEM Fig 12a). in order to generate the drainage density map. Between 0 and 5.10 km/km, the study region is categorized.

Table 7. Assigned theme weighting and class score for the Analytical Hierarchy Process (AHP).

Factor	Rank	Level	Risk
Rainfall	400-600	1	Very Low
	601-800	2	Low
	801-1,000	3	Moderate
	1,001-1,100	4	High
	1,101-1,3000	5	Very High
Slope	0-3	1	Very Low
	3-9	2	Low
	9-18	3	Moderate
	18-34	4	High
	>35	5	Very High
Drainage density	0-1.25	1	Very Low
	1.25-2.43	2	Low
	2.43-3.65	3	Moderate
	3.65-5.55	4	High
	5.5-10	5	Very High
Soil text	15	5	Very High
	17	3	Moderate
	18	3	Moderate
	22	2	Low

Table 8. Assigned theme weighting and class score for the Analytical Hierarchy Process (AHP) (Continue).

Factor	Rank	Level	Risk
	35	3	Moderate
	37	3	Moderate
	40	3	Moderate
	41	2	Low
	48	3	Moderate
	56	3	Moderate
	60	4	High
	62	4	High
	RC	1	Very Low
	W	1	Very Low
LULC	Agriculture	2	Low
	Forest	4	High
	Shrubland	4	High
	Marsh and Swamp+Active paddy field	3	Moderate
	Urban and Built-up land	1	Very Low
	Water Body	5	Very High
DEM	0-200	1	Very Low
	201-300	2	Low
	301-400	3	Moderate
	401-500	4	High
	501-800	5	Very High

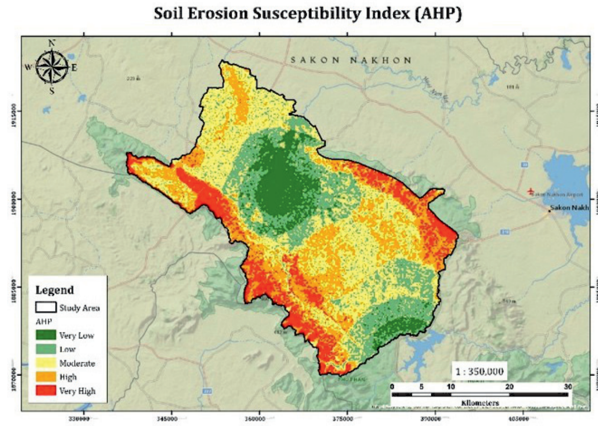

Fig. 13. Map illustrating AHP Map in the Num Un watershed.

Found that the slope has the highest normalized Eigenvector (0.31), followed by the LULC, relative relief, drainage frequency, and lineament frequency with consistency ratio 0.06. The research region's slope and LULC type affect soil erosion. Soil potential Fig. 13 categorizes erosion risk as none, low, moderate, and high.high and crucial considering all study criteria' weight and ranking. Because of its many trees, a soil erosion hazard zonation map rates the research area as moderately to very vulnerable to soil erosion. (5-table). High-to-critical soil erosion.

Higher slopes with more lineal distributions and drainage have the highest potential. Soil erosion The moderate class (273.39 KM2) covered the largest area, followed by the high erosion danger class (321.42 KM^2) and soil erosion class.

Many investigations, notably Arabameri et al., support this result (2019). 7.72% of the basin area is very high susceptibility, 5.32% is high, 27.80% is moderate, 33.37% is medium vulnerability, and 25.79% is extremely low, according to the RUSLE Model (Fig. 7). 39.70% for very high erosion threat and 5.08% for very low class were AHP results.

Recommendation

The empirical model and RUSLE-key USLE's benefits are: (1) The formula is brief and each factor is

Table 9. Statistics on the area of the soil erosion zone.

Class of Soil Erosion Hazard	Area (Km^2)
Very Low	69.55
Low	161.63
Moderate	273.39
High	321.42
Extremely	543.80

Table 10. Pair-wise comparison matrix of different parameters.

	Rainfall	Slope	DEM	Soil Texture	Land Use	Drainage density	Rating
Rainfall	0.32	0.29	0.40	0.31	0.21	0.32	0.31
Slope	0.32	0.29	0.26	0.31	0.25	0.22	0.28
DEM	0.11	0.15	0.13	0.24	0.17	0.11	0.15
Soil Texture	0.08	0.07	0.04	0.08	0.17	0.22	0.11
Land Use	0.06	0.05	0.03	0.02	0.04	0.03	0.04
Drainage density	0.11	0.15	0.13	0.04	0.17	0.11	0.12
CR	0.062						

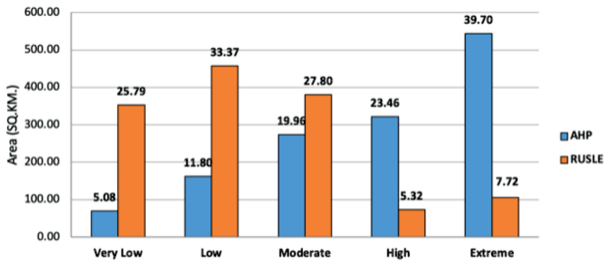

Fig. 14. Sub-areas (%) for the different soil erosion susceptibility classes simulated by RUSLE, AHP Model.

explicit. (2) The factor calculation method is mature, and the parameters are easy to obtain for model refinement. (3) The model's accuracy meets application requirements after years of testing. The soil erosion model is widely used.

This series' empirical model has drawbacks. (1) The A model's limited factors cannot fully explain the river basin's complicated and changing sediment yield and flow. (2) Observational data makes the model regional and hard to market. (3) Soil erosion and sediment transport simulation is complex. The physical process model is based on soil erosion research.Sediment yield calculations replicate soil erosion. (2) The empirical model lacks scientific theory and regional adaptability, but the physical process model does. The physical model considerably improves the empirical model, yet it has several drawbacks. (1) Soil erosion has a complicated physical mechanism. The empirical model influences some physical process model parameters. (2) The model's strict parameter requirements make the research area's size a considerable impediment. Physical structure Due to its complexity, the process model may alter. GIS can be used with experience and physical models. GIS has been used to anticipate and evaluate soil erosion.When the nonlinear procedure is error-prone, GIS will cause overlay and data errors. GIS technology will also cause huge inaccuracies if the response factor does not change in time and space or if the acquisition of the factor contains errors or uncertainty and cannot reflect scale and space–time features.

Future Research

Erosion pin (pile) study is halted. Investigating bank failures is simple. PEEP has greatly improved erosion pin technology with related technological advances. The erosion pin method enhances soil erosion research. It has developed from simple dynamic observation to examining erosion characteristics and surface roughness caused by erosion and deposition. The erosion pin approach is effective for tracking the earliest stage of gully formation and stopping soil erosion.

Conclusions

Soil erosion is caused by most of this study's drivers. In the southeast watershed zone, rainfall runoff erosivity is stronger and soil texture is sandy loam to gravelly sandy loam. Slope angle enhances soil erodibility, and the average soil erosion rate is 14.26 t/ha/year. Soil erosion is more likely with increased slope, relative relief, drainage density, lineament density, and frequency. Some regions' soil erosion may be reduced by forests. Most watersheds need sustainable management owing to soil erosion. reduce soil erosion. It's vital to research scientific management methods and establish watershed-specific conservation measures. These measures will reduce erosion, increase soil health and crop productivity, and improve life in the study area.

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Conflict of Interest

The authors declare no conflict of interest.

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