Assessment of Soil Erosion and Neotectonics Geomorphology of Bannu Basin using RS and GIS Techniques

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Citation | Batool. S, Mahmood. S. A, Tahir. Z, Masood. A, Qureshi. J, Khan. B. Z, "Assessment of Soil Erosion and Neotectonics Geomorphology of Bannu Basin using RS and GIS Techniques", IJIST, Special Issue.pp.387-407, June 2024

Received | June 09, 2024, **Revised |** June 13, 2024, **Accepted |** June 16, 2024, **Published |** June 24, 2024.

Soil erosion poses a critical environmental challenge in Bannu District, with adverse effects on agricultural productivity and land sustainability. This research article presents a comprehensive approach to assess and mitigate soil erosion risk in the region by utilizing the Revised Universal Soil Loss Equation (RUSLE) model in conjunction with hypsometry. The study integrates various geospatial data sets, including mean annual rainfall, digital elevation models, soil maps, land use/land cover classification, and satellite imagery. These data are crucial for mapping five key factors of the RUSLE model: Rainfall Erosivity (R), Soil Erodibility (K), Slope Length And Steepness (LS), Land Cover Management (C), and Support Practice (P). By individually mapping and then integrating these factors, the study estimates soil erosion rates in Bannu District. The researchers divide soil erosion risk into five levels, from very low to excessive, for practical assessment. Sustainable land management and agriculture use this classification to identify areas requiring quick attention and intervention. The study article emphasizes combining Remote Sensing (RS) and Geographic Information System (GIS) with the RUSLE model. This combination allows policymakers and land managers to evaluate and reduce soil erosion at a broader scale. Hypsometry's involvement in topography and erosion dynamics is also examined. The RUSLE model explains Bannu District soil erosion trends by adding topographic elements using hypsometric analysis. This article's soil erosion risk assessment in Bannu District is scientifically sound and practical. The RUSLE model and GIS data with hypsometry help solve soil erosion and promote sustainable land use in the region. The findings help policymakers and stakeholders safeguard agricultural productivity and land sustainability in Bannu District.

Keywords: Soil Erosion; Geospatial Assessment; RUSLE; Hypsometric Integral; Drainage density; Transverse Topographic Asymmetry Factor.

Introduction:

Soil loss is regarded as one of the great global challenges of the during the nineteenth and twentieth centuries; it has a direct impact on agriculture, people's health, and the worldwide environment. Soils are an important part of land systems work that support the production of valuable ecosystem services. But still, anthropogenic activities and environmental factors may deteriorate the soil [1]. Population expansion, degradation, and desertification are the three key variables that generate and worsen soil degradation. Erosion has numerous harmful consequences that are cause for serious concern for a wide range of reasons [2][3]. For example, erosion reduces the productivity of crops and soil fertility by removing the fertile top layer of soil (topsoil). Secondly, erosion reduces storage capacity and function while also degrading downstream quality of the water [4]. Thirdly, soil degradation increases contaminants and deposition in rivers and streams, causing them to become clogged and decreasing biodiversity. Fourth, erosion takes land water downstream, where it can form sediment layers that obstruct the flow of rivers and streams and eventually create floods. Finally, erosion degrades land, allowing few plants to absorb CO_2 from the atmosphere [5]. Soils might potentially retain more greenhouse gases (GHG) in a certain year to equal about 5% of total human-made GHG emissions [6]. Soil erosion destroys approximately 10 million hectares of agriculture each year, according to an estimation. As a response, agricultural production diminishes, leading in weakening economics and an increase in starvation [7].

According to Chuenchum [8], worldwide, about 0.5-1% of sediment disrupts overall annual decrease of reservoirs storage space. It is also expected that by the 2050s, most dams around the world will be reduced to half their current volume, which is a very alarming ratio. Similarly, in Asia, researches indicate that sediment occupy 40% of overall reservoirs retention, resulting in significant storage capacity reduction [9]. These elements have an effect on the future stability of freshwater resources. Past research indicates that developing nations are at great danger of soil degradation; for example, India has an area impacted by water erosion of roughly 30 to 32.8 M. ha (million hectares) [10]. According to a latest report, Iran suffers from an average annual soil degradation of 24 tons/ha/year [11]. In Pakistan, around 16 million hectares of area, or nearly 20% of total land, is influenced by soil disturbance; of all this, 11.2 million hectares (around 70%) is soil decrease due to water [12]. Sediment production amounts to roughly 20 billion tonnes worldwide, with 80% of sediments reaching the oceans yearly from all large rivers [13].

Soil erosion poses severe concerns to global food supply and, eventually, the economies of damaged countries [14]. Soil degradation is more likely on steeper slope fields with greater rainfall distribution. Yearly, roughly 1 billion tonnes of fertile soil are decomposed and they are deposited in dams and exported into the Arabian Sea. According to, the Warsak Dam in Pakistan lost 70% of its output capability due to sedimentation. As a result, estimating the amount of soil erosion is critical in order to adopt preventive actions against the damaged quantity [15]. A reduction in the rate of yield loss at the Warsak Dam enhances the dam's power producing capability. It will also assist in decreasing the dangers to food security in agricultural fields.

Soil erosion has caused a difficult scenario for humankind because of its diversity and the various factors that influence its rate. Slope, precipitation, land use, altitude, and plants are all variables affecting the extent of soil erosion [16]. Separately or in combined, these conditions inflict serious damage to agricultural areas and diminish reservoirs carrying capacity. Many studies have demonstrated that changes in land cover have a major impact on soil loss. As the intensity of rainfall rises as a result of climate change, so does soil degradation in that region. Soil erosion prediction is required to mitigate the effects of these causes [17]. Soil erosion is a serious issue in rivers because it eliminates nutrients needed for growth and causes reservoir sedimentation. Controlling soil erosion is achievable after identifying risk of the region, in which the amount of erosion is estimated in tonnes per hectare per year. Various models have been employed by different scholars in different regions around the world.

Risk mapping is seen as a necessary first step in mitigating any difficult scenario. Erosion models are fundamental instruments that will assist in upcoming soil management strategies [18]. GIS and remote sensing technology are often regarded as the most effective methods to determine climatological and physiological restrictions at various spatial scales. While conventional techniques are expensive and time demanding [19], it is not practical to estimate soil loss using them. As a result, the Revised Universal Soil Loss Equation (RUSLE) model is the most commonly used since it is straightforward, quick to implement, and takes less time and data [20]. The RUSLE model is more accurate when combined with GIS and remote sensing data. This methodology is simple to apply, and the necessary data is readily available in most places [21]. The study's findings will be valuable in overcoming mismanaged difficulties, and well-founded strategies to minimise yield losses in regions with greater soil erosion levels should be implemented.

Several experimental and statistical models were employed in previous research to determine the losses, yet they were time consuming and expensive [22]. Soil erosion can be estimated using GIS and the RUSLE model. GIS analysis algorithms were utilised to identify various RUSLE variables, which were then used to determine total soil loss in the area. According to Prem Rangsiwanichpong [23], whenever the physical factors are available, the RUSLE model in connection with GIS can give long-term results of soil erosion assessment, especially for steep slope areas. The RUSLE approach is a combination of the Universal Soil Loss Equation (USLE) model and the Modern Universal Soil Loss Equation (MUSLE) model, and it has gained popularity because of its straightforwardness, viability, and effectiveness in findings [24][10].

This approach is dependent on observations, so it may not provide an accurate image of the outcomes, but it is a useful approach because of the simplicity with which data may be obtained [25][26]. It produces significant benefits in agricultural fields and waterways. The land degradation rates in Yunnan region [27] reservoirs were analysed using the USLE model. In Pakistan's Potohar region, Saleem Ullah [28] employed the RUSLE model in collaboration with GIS. There are several other research on land destruction caused by soil erosion [29][30][31].

The above- mentioned research clearly demonstrates the shortcomings of the RUSLE structure. The RUSLE model was created to better predict the extent of soil erosion that could occur in a given area. Numerous sources, including books, statistics, and observations, can all be used as inputs in the RUSLE model combine with a GIS. Authenticity of RUSLE's outcome for estimating water-induced soil erosion has been demonstrated. The findings of this study will help researchers and technicians prepare for future regulation of soil disturbance, making accurate estimates of soil erosion essential. Soil erosion data can be quantified with the help of the GIS-based RUSLE model [23][8][28] which has been used in previous studies with similar aims.

- The goal of this study is to create a soil loss profile in the bannu, district in order to calculate the amount of soil that has been lost due to erosion. The RUSLE model will be used to integrate Remote Sensing data and GIS to create the maps. To identify and mark areas of active deformation using remote Sensing Data, in Bannu depression.
- Main objective is to generate Iso Base and Transverse topographic asymmetry maps of Bannu region to recognize neo tectonic activity.
- The purpose is to analyze that changes in drainage are tectonically induced or geologically controlled.

Erosion hotspots and contributing factors can be pinpointed with greater accuracy with the help of maps. After this study is completed, authorities and policymakers can focus their efforts where they will have the greatest impact: in regions with elevated soil erosion values. It might improve agricultural output, help preserve biodiversity, and extend the lifespan of dams.

Justification:

1. In this research Bannu Depression has taken as a study area because of its location and tectonic activity in that area.
2. Free availability of remote sensing data makes research easier in this area.
3. Maps of ISO Base and drainage basin asymmetry developed for first time in this area.

Materials and Methods:

Study Site:

The research will be performed in District Bannu basin, which is in the southern part of Khyber Pakhtunkhwa, Pakistan[32]. The coordinates for its location are 32°43' to 33' 06' North latitude, 70°22' to 70°57' East longitude. The basin that is Bannu district is surrounded to the west by the Waziristan Mountains, to the north by Kohat, and to the south (where it meets the Gomal Plain) and east by small ranges of hills (on the boundary with the Indus Plain). It covers an area of about 1,227 square kilometers, of which 74,196 are cultivated and is part of the Trans Indus District in the Northwest Frontier Province. Around 400 communities can be traced back to the three largest tribes, the Bannuchi, Marwat, and Wazir. In the hottest months, temperatures can reach as high as 48 degrees Celsius, while in the coldest months, they float around 6 degrees Celsius[33]. From January 9th through October 25th, the rainy season lasts 9.5 months, with at least 0.5 inches of rain falling on at least 31 of those 31 days. August is the wettest month in Bannu, with an average of 2.0 inches of precipitation that month. Approximately two and a half months, from October 25th through January 9th, are completely dry.

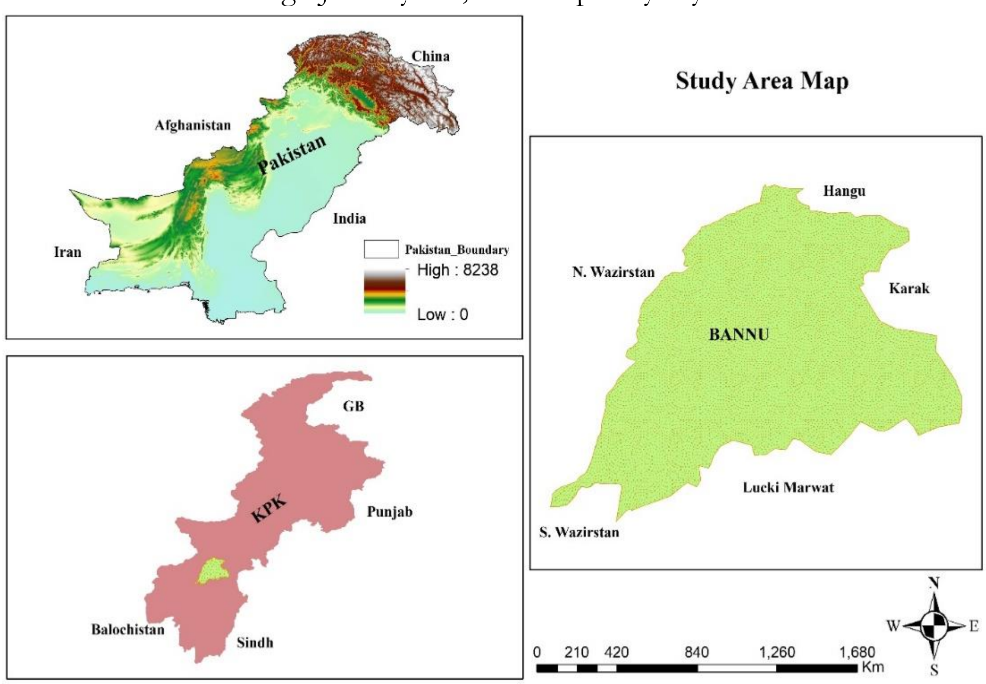

Figure 1: Location of study area.

Data Source Processing:

Mountain ranges tropical water ways, massive watersheds, agrarian dominant waterways, regions with unique dry and wet seasons, and regions with continuous change in land use / cover trends, agronomic croplands, and advancement are just some of the places where RUSLE has been implemented using a GIS approach. There are three main datasets that make up the RUSLE model. For the purposes of calculating the soil erodibility factor, slope, and steepness factors, it is important to have access to the following:

1. A climate and surveying dataset, which includes monthly rainfall and temperature values, and Natural curves (LS).
2. The surface cover variable relies on information stored in the crop dataset (C).
3. The erodibility factor (K) is determined by using the survey and characterisation data contained in the soil collected data

Table 1: Description of data sources and its types

Type of data	Data sources	Description
Digital Elevation Model (DEM)	Earth Explorer (usgs.gov)	SRTM DEM (30 s resolution) Grid format
Soil data	Food and Agriculture Organization of the United Nations https://www.fao.org	FAO Digital soil Map of the World (DSMW)
Rainfall data	https://www.pmd.gov.pk/en/	Rainfall data yearly annual period
Satellite images	Earth Explorer (usgs.gov)	Landsat 8, 30m Resolution

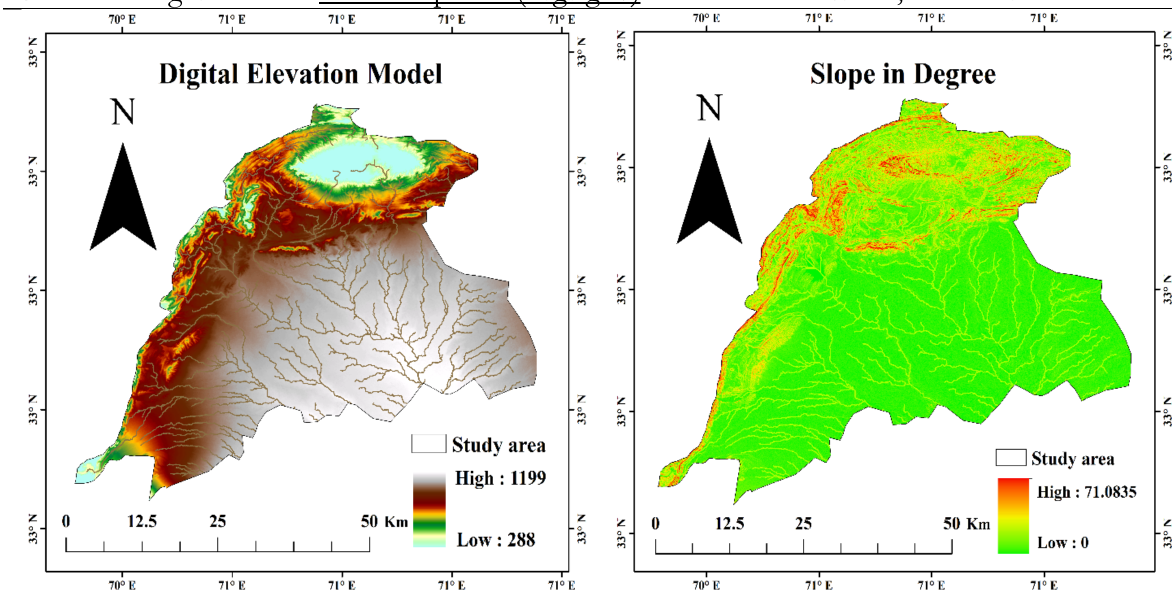

Figure 2: DEM and Slope of Bannu Basin.

RUSLE Model:

Estimating model elements commonly uses RUSLE. Using meteorological data, soil and geological maps, remotely sensed satellite images, empirical equations, and digital elevation models (DEM) from various sources, previous researchers predicted these values. This article presents the model variable development process and results.

Annual average soil loss is calculated using the RUSLE model, which takes in the five components mentioned in Equation 1 [34].

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

Where "A" is the mean annual soil decrease in tons / ha (t ha^{-1} $year^{-1}$), "R" is the rainfall erosivity factor in millimeters of water per hectare per year (MJ mm ha^{-1} h^{-1} $year^{-1}$), "K" is the soil erodibility index in metric tons per cubic meter per meter of water (t hr./MJ mm), "LS" is the topographic factor equal to the length and steepness of slopes (dimensionless), "C" refers to "cover management," which is similar with "cropping management" (also dimensionless), and "P" refers to "support measures" or "practice controls" (dimensionless).

Erosion was calculated using the mathematical feature map, and all other components were derived independently using raster data. The area was defined using the ArcGIS (10.8) Mapping And analysis technique. In order to calculate the RUSLE variables, a different equation was used, with satellite imagery and digital elevation model data serving as inputs. Table 1 contains the data utilized in the analysis, where it came from, and the equations that were employed. The research was repeatedly searched to find the best equations for computing the variables, and those equations were chosen based on their ability to generate estimates equivalent to the published ground erosion observations. Further information on how we came at these numbers for each variable is provided in the sections that follow; for a visual representation of this process, see Figure 2.

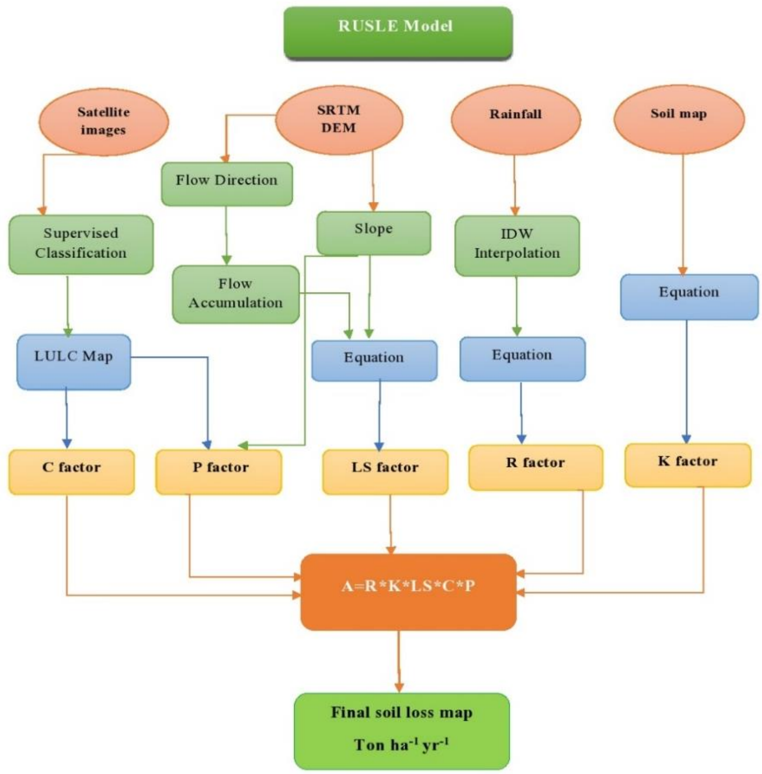

Figure 3: Flowchart of study area

R_Factor:

The component related to annual rainfall is crucial in determining precipitation's overall amount and severity. To obtain this information, monthly precipitation data for ten years (2012-2022) were collected from the Pakistan Meteorological Department for each of the five weather stations in the research area. The annual precipitation data (in millimeters) are essential for calculating rainfall's erosivity factor (R); conversely, high annual precipitation results in a higher R-value. By knowing the average annual rainfall, it becomes possible to determine the rainfall R factor. The inverse distance weighting (IDW) method was employed in ArcMap to map the rainfall across the region. IDW is recognized as one of the most effective tools for estimating precipitation patterns over a given area [35][36][37]. According to Numan [38] the following Equation is the most accurate way to calculate R.

$$R = -8.12 + 0.562 \times PCP \qquad \textbf{2}$$

PCP indicates the average annual precipitation in mm.

Topographic LS Factor:

In this study, the L and S variables in the RUSLE model represent the influence of topography on erosion rates. Soil erosion and overland flow tend to increase with greater slope length and steepness [39]. We utilized the DEM within the ArcGIS environment to calculate the LS (length and steepness) value. It provides detailed information about the length and steepness of slopes across the landscape. Flow accumulation and slope steepness were taken into account during the LS calculation. By integrating the characteristics of slope steepness and flow accumulation into the DEM using the ArcGIS Spatial Analyst add-on, we determined the runoff accumulation rate and slope. Equation (3), as proposed by Moore and Burch [40];[41], was employed to derive the LS factor for our analysis.

$$LS = \frac{(\text{Flow accumulation} \times \text{CellSize}^{0.4}}{22.13} \times \frac{(\text{SinSlope})^{1.3}}{0.0896} \quad (3)$$

Where "Flow Accumulation" is the grid cell's total upslope supporting area, "LS Factor" is a combination of length and steepness of slop. The 'Cell Size' variable provides the size of a single grid cell, while the 'Sin slope' is in sin, indicating the slope's degree.

Soil Erodibility (SE.) K_Factor:

The K_Factor is a metric that measures how easily soil particles can be detached from their host soil and carried away by precipitation and runoff. It is mostly determined by the soil's texture, organic matter content, structure, and permeability. SE is the "rate of erosion per unit of the erosion index from a typical unit plot of 22.13 meters in length with a slope gradient of 9%" [42]. It reflects the rate of soil loss per erosivity of rainfall (R) index.

Cover Management Factor (C):

Regarding soil loss, LULC classifications are characterized by the C factor. Information about soil management, the role of crop a, soil moisture, and soil surface variation are all required for calculating the C factor [43]. In this investigation, we employed LULC categorization to establish the C factor, following the guidelines of [44];[45]. We used the LULC map of the basin to get the C parameter. Table 2 presents the values for the cover management factor ranging from 0 to 1. The C-factor is an important parameter used in soil erosion modelling to estimate the susceptibility of an area to soil loss. In this table, higher values of the C-factor indicate that the corresponding areas have a greater vulnerability to soil erosion. This implies that areas with higher C-factor values have less effective vegetation cover or management practices, making them more prone to soil erosion processes.

Table 2: C factor for LULC Classes

Sr. No	Land Cover	C_Factor
1	Grass Land	0.7
2	Forest Cover	0.004
3	Water Bodies	0
4	Crop Land	0.65
5	Buildup Area	0
6	Snow Cover	0
7	Bare Land	1

Erosion Control Practice (P) Factor:

The P-factor in soil erosion modelling represents the effectiveness of erosion control practices in reducing soil loss under specific topographic conditions, particularly in up-and-downhill plowing. It considers various land treatments and measures to prevent soil particle movement and minimize erosion. Practices such as contouring, compaction, constructing sediment basins, and implementing erosion control structures influence the effectiveness of erosion control measures and thus contribute to the P-factor. In the case of Pakistan, little effort has been made to implement erosion control practices, and there is a lack of comprehensive erosion control measures across the region. As a result, for the entire study area, the P-factor was assigned a value of 1, indicating the absence of specific erosion control practices and limited resistance against soil erosion [10];[46].

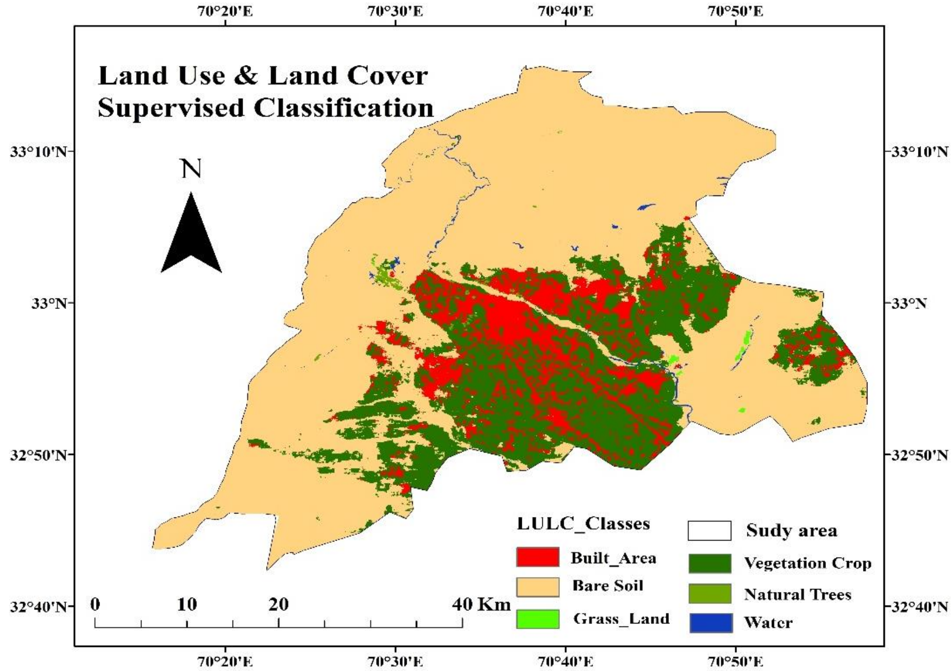

Figure 4: Land Use Land Cover Classification of Bannu

Table 3 : List of software used for this research

Software Name	Application
Arc GIS 10®	For Map making and Re-projection
ENVI	Import and Export
MATLAB 7.6.0 (R2008a) Robocop version	Extraction geomorphic Indices and DEM Processing

Hypsometric Integral:

The hypsometric integral of Bannu Basin is a geomorphological metric used to analyze the elevation distribution within the basin. This integral is computed by graphically plotting the cumulative area of the basin against its cumulative elevation, and then calculating the area under the hypsometric curve. The hypsometric integral provides valuable information about the basin's overall shape and relief characteristics, allowing geologists and geomorphologists to gain insights into its geological evolution, tectonic activity, and erosional history. By studying the hypsometric integral of Bannu Basin, researchers can better understand the basin's geomorphic development and make important inferences about landscape processes, uplift rates, and tectonic influences that have shaped the region over geological timescales.

Transverse Topographic Basin Symmetry:

Transverse topographic basin symmetry is an innovative technique used to assess the asymmetry of topographic basins. It distinguishes between random and regional stream migration while determining the direction of stream movement. While this method does not offer conclusive evidence of ground tilting or tectonic movement, it can identify factors related to ground tilting in neotectonic regions, particularly in areas where active faults are concealed or poorly exposed. River migration can be influenced by two main categories of processes: external forces and internal fluvial processes. External forces, such as monoclinal shifting and tectonic ground tilting, consistently affect the lateral migration of all affected streams. The extent of their impact depends on various factors, including the stream's orientation, size, and substrate resistance. On the other hand, internal fluvial processes influence the migration of different streams independently, meaning that they do not result in a well-defined mean migration direction for a stream population.

Drainage-basin symmetry is a method used to compute the mean migration direction for all streams of a certain order and greater, thereby allowing the differentiation between migrated streams due to external forces or internal fluvial processes. The deflection of the active meander belt from the drainage basin midline is used to determine an asymmetry vector for each valley segment of a specific length. These data are then used to calculate a mean vector and statistically determine the likelihood that it is not a product of random processes. This technique proves valuable in assessing recent tectonic activity in regions with poorly exposed or absent surface faults. Basin asymmetry is an indirect method that relies on geomorphic variations in the basin, stream organization, and watershed asymmetry. Large water channels have a significant capacity to choose their courses, but they are highly sensitive to tectonic activity due to their lower elevations, which are more susceptible to minor fluctuations.

Drainage analysis is a crucial tool for assessing channel behavior, especially when direct measurements are challenging due to variations in stream power and active tectonics. The close relationship between large waterways and their tectonic setting is widely acknowledged. Stream response to tectonics can be measured by factors such as channel size, energy, and uniform geology within a watershed. Asymmetry analysis can provide valuable information for evaluating neotectonics, allowing the characterization of geomorphic regions of stream movement related to emerging folds or faults in settings with unconsolidated sediments. Changes in tributary directions can be indicative of subsidence or uplift in tilting regions.

By utilizing basin asymmetry methods, a spatially averaged trajectory field can be produced, and the direction of stream relocation can be estimated in terms of ground tilting. This technique is particularly useful for identifying regional geological landscape developments related to recent ground tilting.

In conclusion, transverse topographic basin symmetry is a powerful tool for evaluating topographic basin asymmetry and assessing recent tectonic activity in regions with concealed or poorly exposed surface faults. By differentiating between external forces and internal fluvial processes, it offers valuable insights into stream migration and ground tilting in neotectonics regions. Basin asymmetry, though indirect, proves to be a useful method for understanding geomorphic regions and landscape evolution, providing significant information for neotectonics evaluations.

ISO Base Level:

Base-level maps (or "isobase maps", as initially characterized by Filosofov, 1960), express a relationship between geology and valley order. The base-level map might be seen as an "improved" form of the first topographic surface, from which the "noise" of the low-order stream disintegration was uprooted. This system can distinguish zones with conceivable tectonic impact even inside lithological uniform areas. The idea of base level was characterized by as a level "beneath which the dry grounds can't be disintegrated". In spite of the fact that the ocean level remains a definitive base level, a few researchers have recognized that local base levels could be characterized as stated by diverse geological/temporal conditions over areas or even inside the same watershed.

Base-level maps express a relationship between valley order and geology. The valley order states to the relative position of tributaries portions in a stream network, where streams of comparative orders identify with comparable geographical occasions also are of comparable topographical age. Each one base-level surface is identified with comparative erosional stages, and might be viewed as a result of erosional-tectonic occasions, predominantly the latest ones.

The stream network is an authentic pointer of tectonic activity. Stream long profiles are sensitive to different powers than tectonics, for example, climate and lithology. A lithological border of two rocks of distinctive erosional properties will brings about a change in the channel incline and the local base level will accordingly be diverse even without distortion.

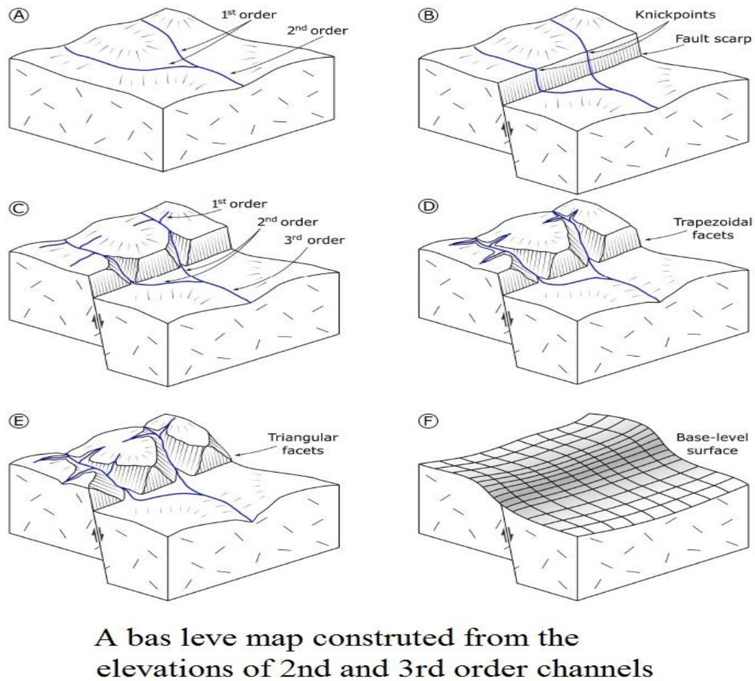

Figure 5: Generation of base level map

Results and Discussion:

Topographic LS Factor:

Figure 6 shows the Bannu Basin's length-slope (LS) factor variation. Slope length and steepness affect soil erosion potential via the LS factor. The map shows LS values across the basin, suggesting erosion susceptibility. Steeper slopes and longer lengths may increase erosion in regions with higher LS values. Elevated LS variables assist in determining erosion control and preservation in the Bannu Basin. The values of LS factor ranging from 0 to 8.75 across the study area. Slopes with a higher LS value are more likely to be eroded since they are both steeper and longer. Soil erosion is less likely to occur in areas with low LS values since these areas have softer and shorter slopes.

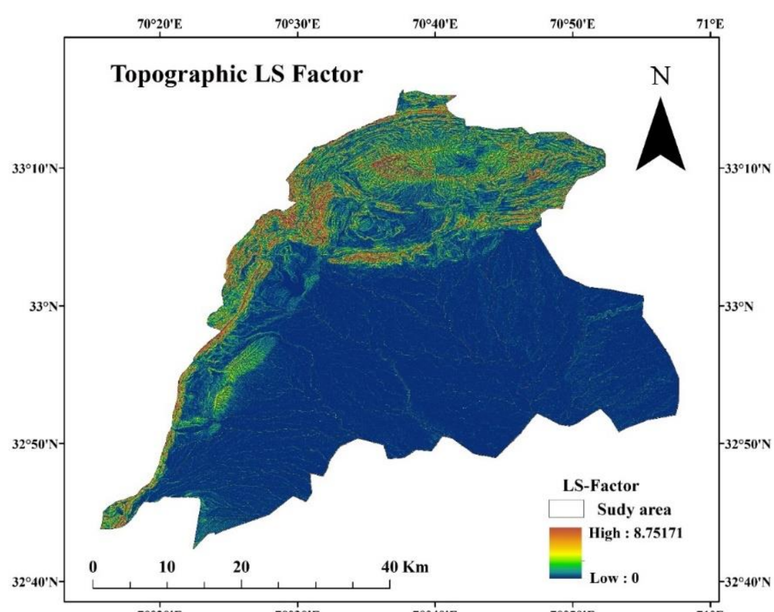

Figure 6: Length and Slope (LS) factor

Rainfall Erosivity Factor:

The R-factor map for the Bannu Basin was constructed using mean annual rainfall data obtained from weather stations. To create a comprehensive representation of rainfall erosivity potential across the study area, the Inverse Distance Weighting (IDW) method was employed to interpolate the rainfall values. Figure 7 vividly illustrates the spatial distribution of the R-factor values throughout the Bannu district, showcasing a range from 26.9 to 29.8 MJ mm/ha/h/year. The R-factor, a key component of the Revised Universal Soil Loss Equation (RUSLE) model, quantifies the erosive power of rainfall in terms of its ability to cause soil erosion. R-factor variability across the study region is significant. Regions with R-factors closer to 29.8 MJ mm/ha/h/year have more intense and erosive rainfall patterns. Due to raindrop impact energy and surface runoff, these regions are particularly susceptible to soil erosion. Conversely, areas with lower R-factor values, around 26.9 MJ mm/ha/h/year, experience less intense and less erosive rainfall patterns. Consequently, these locations have a lower propensity for soil erosion, which may be attributed to factors like gentler rainfall intensity and a better ability to infiltrate water into the soil.

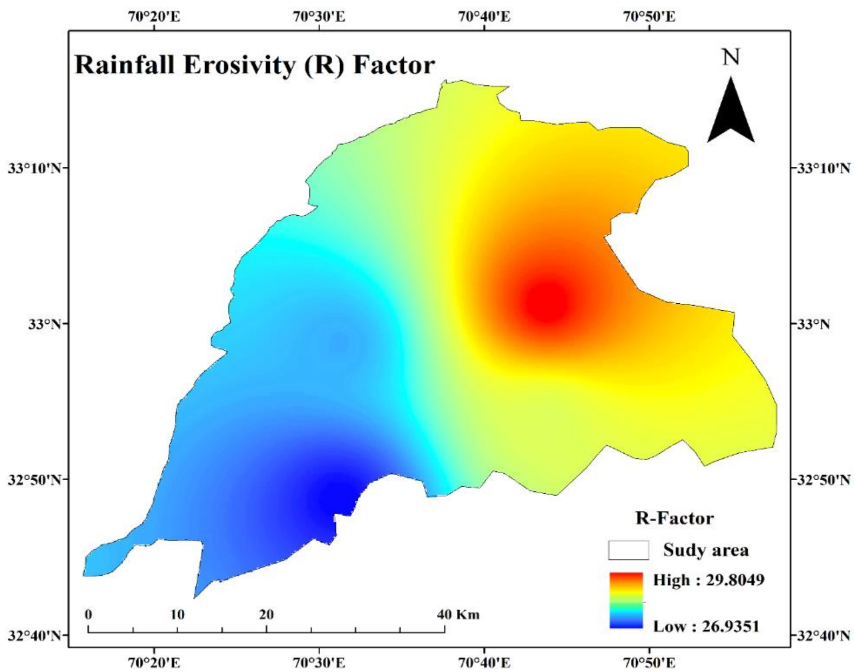

Figure 7: Rainfall Erosivity (R) factor

Soil Erodibility Factor:

Figure 9 presents the regional distribution of K values in the Bannu region, ranging from 0.19 to 0.27. These values suggest low-to-moderate soil erodibility in the study area. The K factor represents the susceptibility of the soil to erosion, and lower K values indicate soils that are less prone to erosion, while higher values suggest soils with a higher erosion potential. To further understand the spatial variation of soil erodibility, the K factor is classified into two main categories: lithosols and haplic xerosols. The map uses a color scheme to represent these categories. In the map, areas with low erosion capacity are denoted by the color green, while areas with high erosion capacity are represented by the color blue. The transition from green to blue on the map indicates increasing soil erosion potential across the Bannu region. Areas classified as lithosols typically exhibit low soil erodibility, suggesting that these soils are relatively resistant to erosion processes. In contrast, haplic xerosols have a higher erosion potential, making them more susceptible to soil loss under erosive conditions.

Cover Management Factor:

Figure 4 indicates that the land cover in the bannu region has been classified into six categories: bare land, built-up areas, water bodies, natural trees, vegetation crop and grassland. Figure 9, it shows the "C factor" of the Revised Universal Soil Loss Equation (RUSLE) model. The "C factor" in the RUSLE model represents the "cover and management" factor, which quantifies the influence of land cover and land management practices on soil erosion. The "C factor" varies based on the type of land cover and land management in a particular region. Different land uses and practices have varying abilities to protect the soil from erosion. Natural forests and grasslands usually have high C factors because their vegetation cover offers significant protection against erosion. Detailed information on the classification accuracy can be found in Table 2.

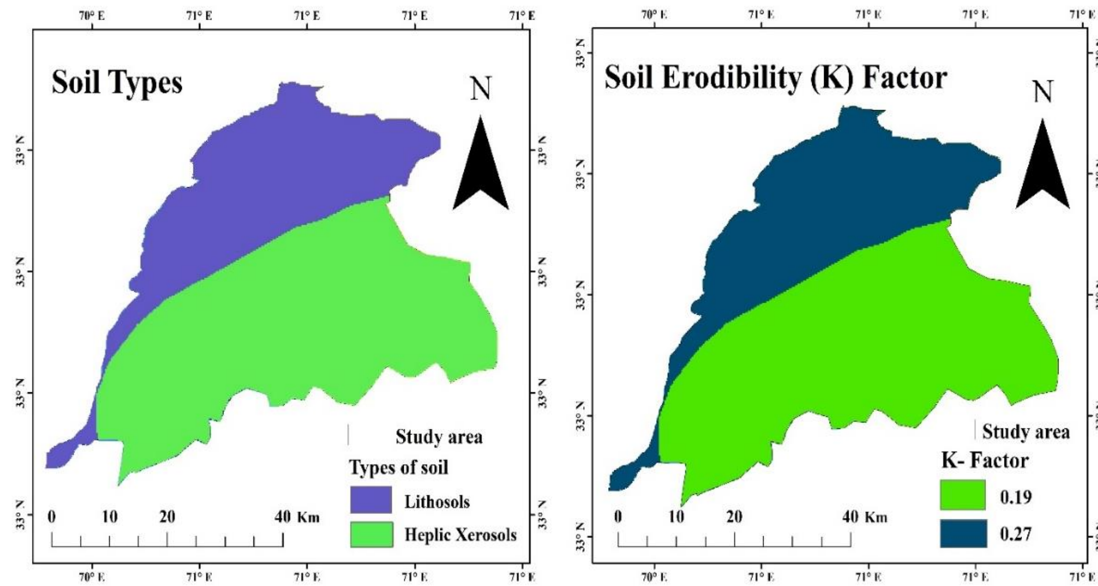

Figure 8: Soil Types and Soil Erodibility factor

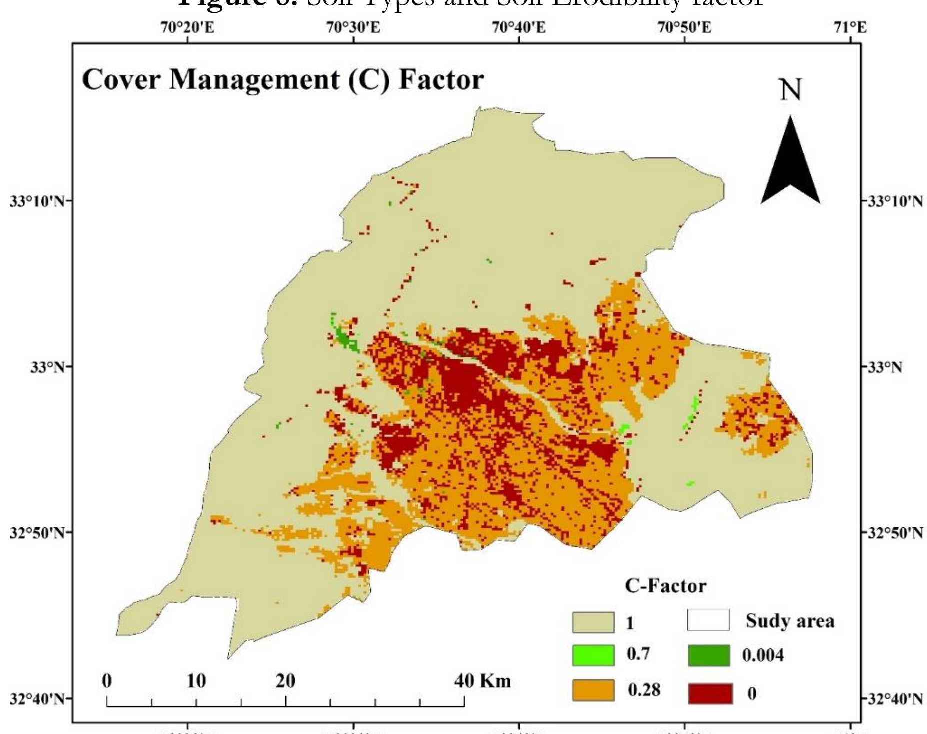

Figure 9: Cover Management C factor of Bannu basin

Soil loss Estimation:

Spatial variations in soil erosion patterns were identified in the studied region, leading to the need for categorizing areas experiencing soil erosion for simplified analysis. Accurately assessing soil erosion hazards is essential for identifying regions at high risk and developing effective preventive strategies. To evaluate the extent of soil erosion risk in the study area, this research adopted a classification system based on the boundaries defined by the OECD, which is commonly used in similar studies within the region. Similar soil erosion classification methods have been employed in previous research conducted in the same general area.

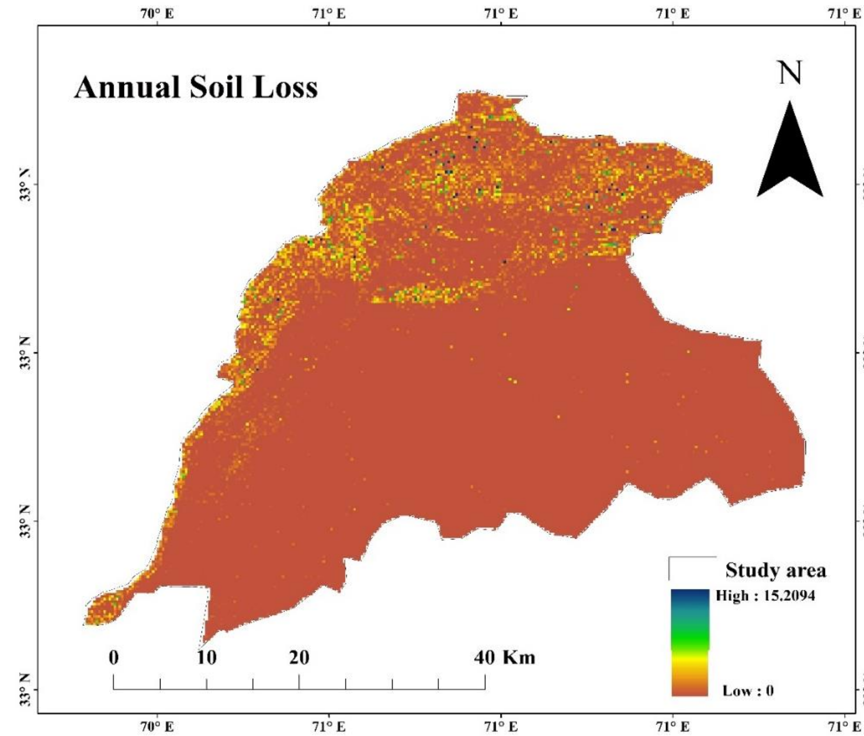

Figure 10: Annual Soil loss map for study area

These erosion maps were developed by consolidating the relevant parameters mentioned earlier and applying Equation (1) using the raster calculator in ArcGIS. Afterward, the resulting maps underwent calibration and analysis to evaluate the severity of soil erosion risk within the watershed. In these maps, higher values of parameter indicated a greater erosion rate, while lower values represented a lesser sediment yield. Figure 10 visually depicts the yearly soil loss, ranging from 0 to 15 tons per hectare. The map clearly demonstrates the spatial variations in soil erosion, with some areas exhibiting low soil loss values while others display higher values. The findings reveal that bare areas and highlands characterized by steep slopes are particularly susceptible to soil erosion, as indicated by the map.

ISO Base level:

The use of Iso Base maps allows for the examination of landscape variations and changes in the characteristics of stream Strahler orders. These maps display lines of equal uplift, indicating erosional stages. In the case of the Bannu depression, Iso Base maps have been generated for the first time, with contours created at intervals of 25m, 50m, 75m, and 100m using Arc GIS 10. The resulting maps provide valuable insights into tectonic activity, where thicker Iso Base lines in red highlight areas with significant tectonic activity, while broader contour lines indicate relatively lower tectonic activity. The different stages of erosion are also clearly depicted by the Iso Base contour lines, enabling a comprehensive understanding of the region's geomorphic development and offering valuable information for analyzing tectonic influences and landscape processes.

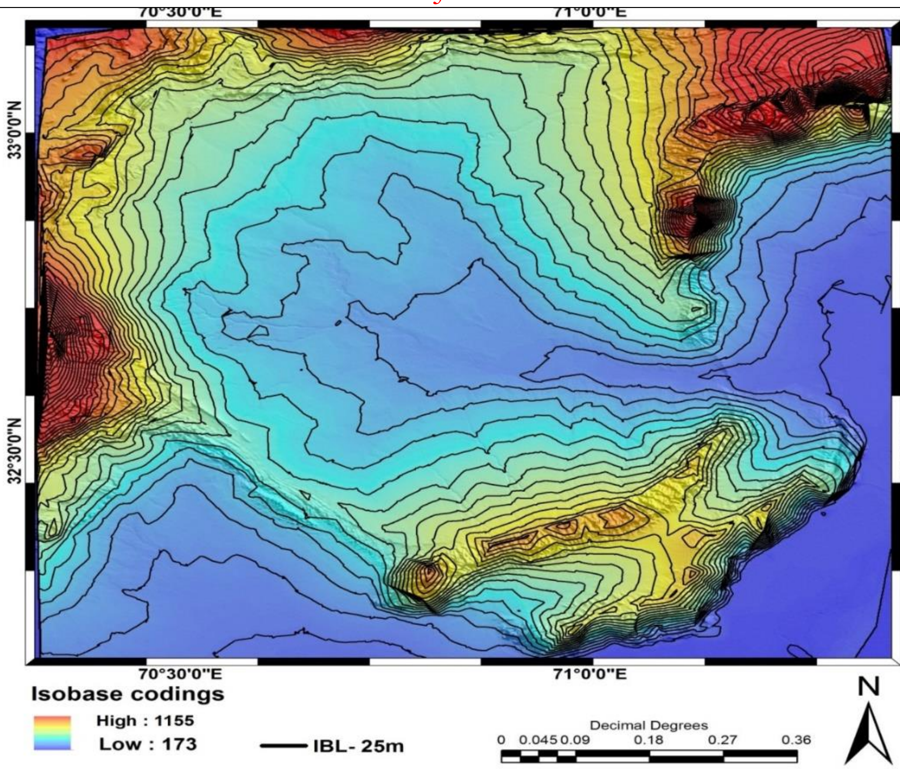

Figure 11: Iso Base map of Bannu with Contours of 25m

Areas of high tectonic activity (represented by red) are depicted on the map by a thicker iso basis line, whereas areas of relatively lower activity are depicted by contour lines that are wider. Because of the map's 50m contour interval, its contours are wider than those of a map with a 25m interval, but its contour lines are thicker in the same places.

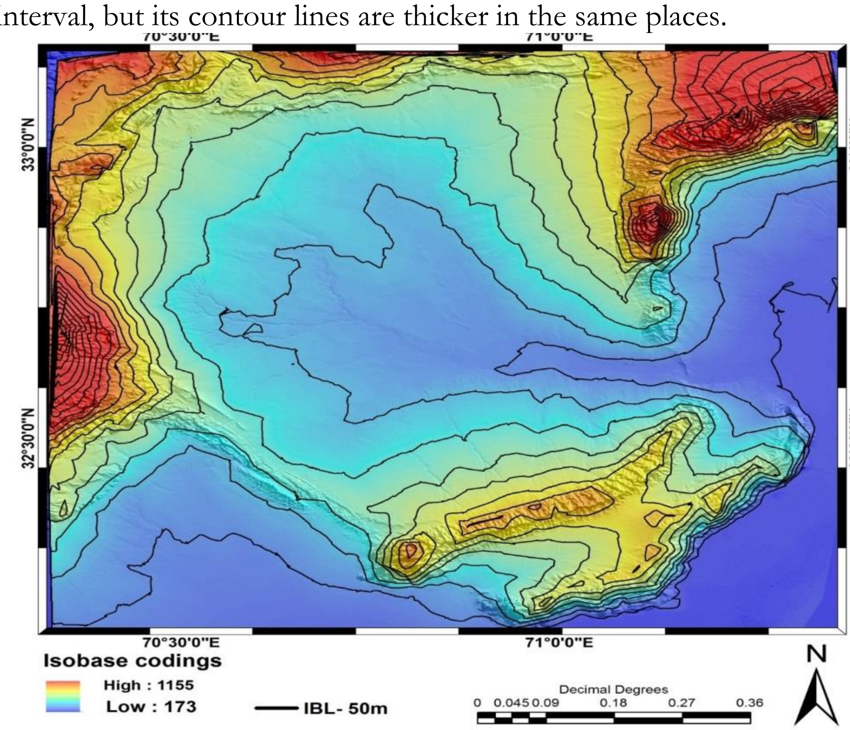

Figure 12: Iso Base map of Bannu with Contours of 50m

In this map contours are generated at the interval of 75m, but they are broader than the contours generated at the interval of 25m and 50m but the contour lines are thicker at same locations/points.

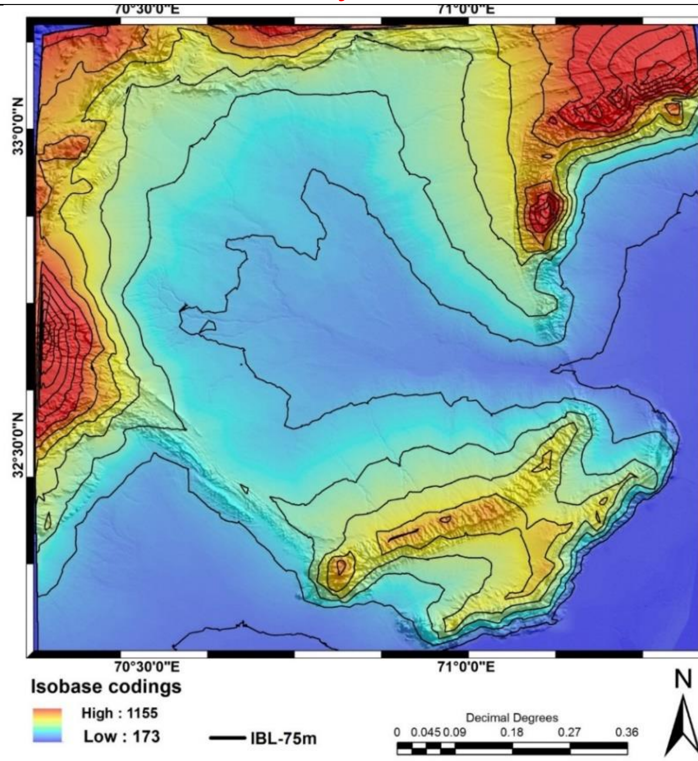

Figure 13: Iso Base map of Bannu with Contours of 75m

In this map contours are generated at the interval of 100m, but they are broader than the contours generated at the interval of 25m,50m and 75m but the contour lines are thicker at same locations/points as in the above maps.

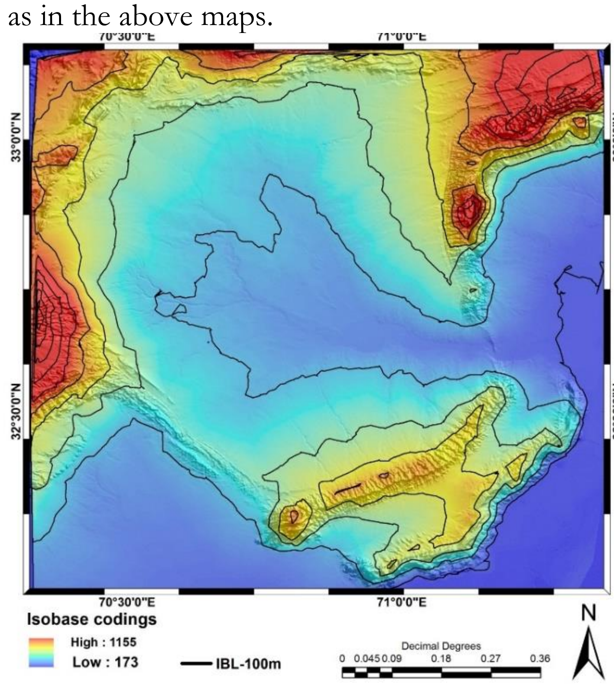

Figure 14: Iso Base map of Bannu with Contours of 100m

Aspect Map:

An aspect map of Bannu displays the directional orientation of the terrain's slopes in the region. It provides crucial information about the direction in which each point on the landscape is facing. The aspect is typically measured in degrees, with 0° indicating a north-facing slope, 90° indicating an east-facing slope, 180° indicating a south-facing slope, and 270° indicating a west facing slope.

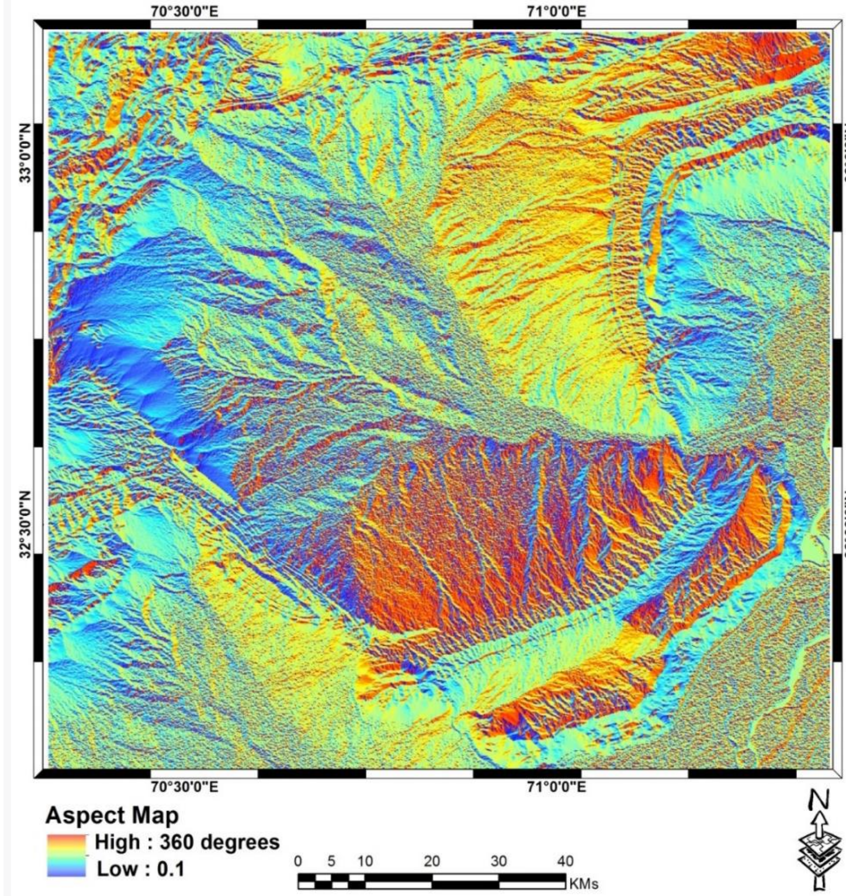

Figure 15: Aspect map of Bannu Depression.

Shaded Relief Map:

The shaded relief map of Bannu illustrates the region's topography and terrain features with the use of light and shadow effects. This map provides a visual representation of the land surface by simulating the illumination from a specific light source, creating a three-dimensional appearance. Elevations and landforms are depicted through varying shades of gray or color, with areas of higher elevation appearing brighter or lighter, and lower elevations appearing darker or shaded.

Transverse Topographic Basin Asymmetry:

This method serves as a valuable tool for assessing neo-tectonic activity in a given area by closely observing the shift in the drainage basin midline. Drainage systems are highly sensitive to tectonic activity, as even minor changes in elevation can significantly impact their configuration. This technique proves particularly useful for accurately assessing neo-tectonic activity in the region. The T-index, represented by the equation $T = Da/Dd$, is employed to calculate the distances from the basin midline and the basin margin to the basin midline. To generate a T-index map of the Bannu Depression, we utilize data from the 5th, 6th, and 7th Strahler stream orders, employing SRTM DEM in MATLAB. The resulting T-index map showcases arrows depicting the direction of river midline migration. It is evident that streams are migrating in a downward tilt direction due to uplift, indicating active tectonic processes in the area. This map provides valuable insights into the region's geomorphic dynamics, offering significant information for the assessment and understanding of neo-tectonic activity in the Bannu Depression.

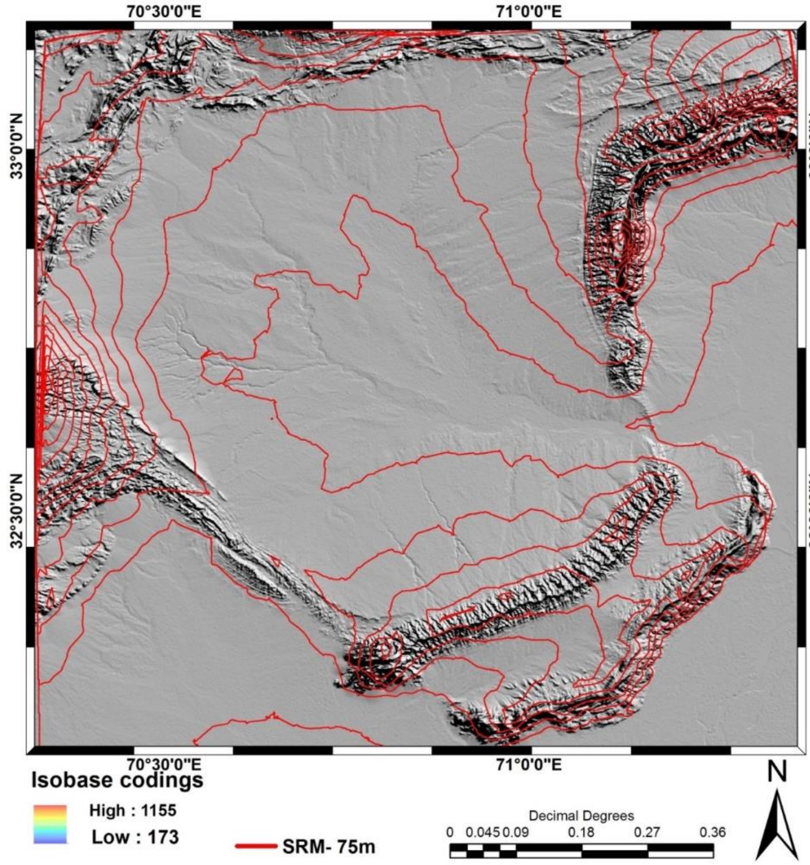

Figure 6: SRM of Bannu Depression

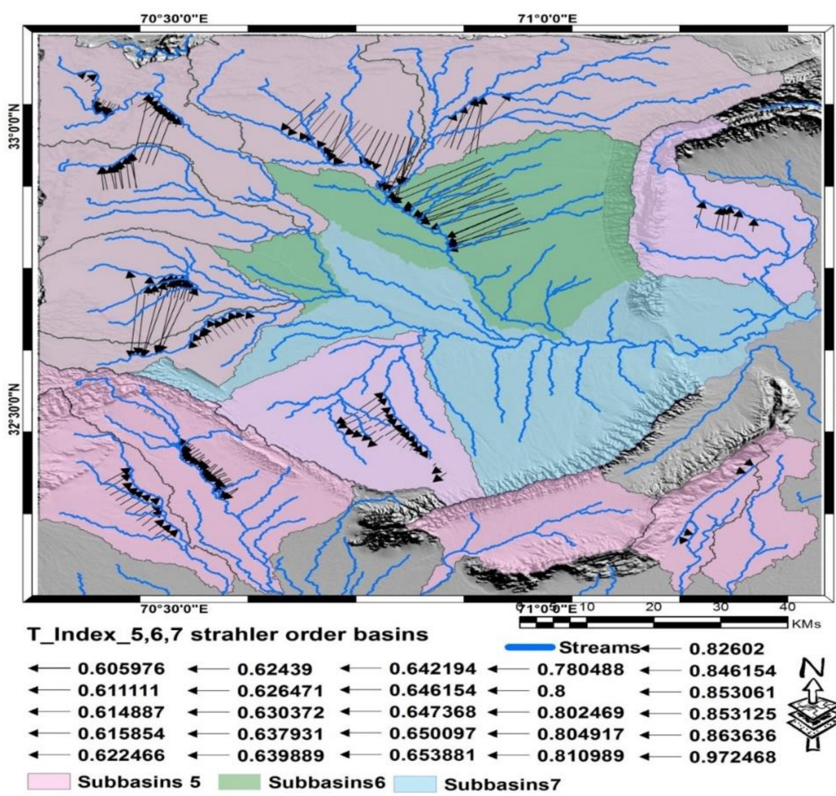

Figure 17: T-Index map of bannu basin

Conclusion:

In conclusion, the Revised Universal Soil Loss Equation (RUSLE) model has proven to be a valuable and cost-effective tool for estimating soil erosion rates in various regions. Its ability to incorporate multiple factors, such as rainfall intensity, soil erodibility, slope, land cover, and land management practices, allows for a comprehensive assessment of soil erosion risk. By integrating RUSLE parameters into GIS software, like ArcGIS, researchers and land managers can generate soil erosion risk maps, providing critical information for soil conservation and land management strategies. Hypsometry, the study of elevation distribution within a geographic area, plays a significant role in understanding the landscape's topographical characteristics. Hypsometric data and maps provide valuable insights into the elevation ranges, identifying low-lying areas and highland regions within a landscape. ISO base maps, which conform to the International Organization for Standardization (ISO) standards, serve as fundamental reference maps for various applications. These maps provide consistent and reliable geospatial data, such as administrative boundaries, transportation networks, hydrography, and elevation contours. In summary, the integration of the RUSLE model, hypsometry, and ISO base maps offers a powerful approach for understanding and managing soil erosion risks. Together, these tools facilitate a comprehensive analysis of soil loss potential, landscape characteristics, and geographic context, aiding in the development of targeted soil conservation strategies and sustainable land management practices. With increasing concerns about soil degradation and environmental resilience, the application of these tools is becoming ever more critical for safeguarding our natural resources and promoting long-term ecological stability.

References

[1] D. A. Robinson *et al.*, “Soil natural capital in Europe; A framework for state and change assessment,” *Sci. Rep.*, vol. 7, no. 1, pp. 1–14, 2017, doi: 10.1038/s41598-017-06819-3.

[2] S. D. Keesstra *et al.*, “The significance of soils and soil science towards realization of the United Nations sustainable development goals,” *Soil*, vol. 2, no. 2, pp. 111–128, 2016, doi: 10.5194/soil-2-111-2016.

[3] A. Gayen and S. Saha, “Application of weights-of-evidence (WoE) and evidential belief function (EBF) models for the delineation of soil erosion vulnerable zones: a study on Pathro river basin, Jharkhand, India,” *Model. Earth Syst. Environ.*, vol. 3, no. 3, pp. 1123–1139, 2017, doi: 10.1007/s40808-017-0362-4.

[4] A. El Jazouli, A. Barakat, A. Ghafiri, S. El Moutaki, A. Ettaqy, and R. Khellouk, “Soil erosion modeled with USLE, GIS, and remote sensing: a case study of Ikkour watershed in Middle Atlas (Morocco),” *Geosci. Lett.*, vol. 4, no. 1, 2017, doi: 10.1186/s40562-017-0091-6.

[5] P. Borrelli *et al.*, “An assessment of the global impact of 21st century land use change on soil erosion,” *Nat. Commun.*, vol. 8, no. 1, 2017, doi: 10.1038/s41467-017-02142-7.

[6] A. Gayen, S. Saha, and H. R. Pourghasemi, “Soil erosion assessment using RUSLE model and its validation by FR probability model,” *Geocarto Int.*, vol. 35, no. 15, pp. 1750–1768, 2020, doi: 10.1080/10106049.2019.1581272.

[7] H. Allafta and C. Opp, “Soil Erosion Assessment Using the RUSLE Model, Remote Sensing, and GIS in the Shatt Al-Arab Basin (Iraq-Iran),” *Appl. Sci.*, vol. 12, no. 15, 2022, doi: 10.3390/app12157776.

[8] P. Chuenchum, M. Xu, and W. Tang, “Estimation of soil erosion and sediment yield in the lancang-mekong river using the modified revised universal soil loss equation and GIS techniques,” *Water (Switzerland)*, vol. 12, no. 1, 2020, doi: 10.3390/w12010135.

[9] D. E. Walling, “Human impact on the sediment loads of Asian rivers,” *IAHS-AISH Publ.*, vol. 349, no. September 2009, pp. 37–51, 2011.

[10] A. Maqsoom *et al.*, “Geospatial Assessment of Soil Erosion Intensity and Sediment

Yield Using the Revised Universal Soil Loss Equation (RUSLE) Model," *ISPRS Int. J. Geo-Information 2020, Vol. 9, Page 356*, vol. 9, no. 6, p. 356, May 2020, doi: 10.3390/IJGI9060356.
[11] T. Khatoon and A. Javed, "Morphometric Behavior of Shahzad Watershed, Lalitpur District, Uttar Pradesh, India: A Geospatial Approach," *J. Geogr. Inf. Syst.*, vol. 14, no. 03, pp. 193–220, 2022, doi: 10.4236/jgis.2022.143011.
[12] A. Ashraf, M. K. Abuzar, B. Ahmad, M. M. Ahmad, and Q. Hussain, "Modeling risk of soil erosion in high and medium rainfall zones of pothwar region, Pakistan," *Proc. Pakistan Acad. Sci. Part B*, vol. 54, no. 2, pp. 67–77, 2017.
[13] P. Thapa, "Spatial Estimation of Soil Erosion Using RUSLE Modeling: A case study of Dolakha District, Nepal," Jul. 2020, doi: 10.21203/RS.3.RS-25478/V4.
[14] H. Atoma, K. V Suryabhagavan, and M. Balakrishnan, "Soil erosion assessment using RUSLE model and GIS in Huluka watershed, Central Ethiopia," *Sustain. Water Resour. Manag.*, vol. 6, no. 1, p. 12, 2020, doi: 10.1007/s40899-020-00365-z.
[15] A. R. Vaezi, M. Abbasi, S. Keesstra, and A. Cerdà, "Assessment of soil particle erodibility and sediment trapping using check dams in small semi-arid catchments," *CATENA*, vol. 157, pp. 227–240, 2017, doi: https://doi.org/10.1016/j.catena.2017.05.021.
[16] X. Wang *et al.*, "Assessment of soil erosion change and its relationships with land use/cover change in China from the end of the 1980s to 2010," *CATENA*, vol. 137, pp. 256–268, 2016, doi: https://doi.org/10.1016/j.catena.2015.10.004.
[17] M. Zare, T. Panagopoulos, and L. Loures, "Simulating the impacts of future land use change on soil erosion in the Kasilian watershed, Iran," *Land use policy*, vol. 67, pp. 558–572, 2017, doi: https://doi.org/10.1016/j.landusepol.2017.06.028.
[18] S. Altaf, G. Meraj, and S. A. Romshoo, "Morphometry and land cover based multi-criteria analysis for assessing the soil erosion susceptibility of the western Himalayan watershed," *Environ. Monit. Assess.*, vol. 186, no. 12, pp. 8391–8412, 2014, doi: 10.1007/s10661-014-4012-2.
[19] M. Amin and S. A. Romshoo, "Comparative assessment of soil erosion modelling approaches in a Himalayan watershed," *Model. Earth Syst. Environ.*, vol. 5, no. 1, pp. 175–192, 2019, doi: 10.1007/s40808-018-0526-x.
[20] H. Abdo and J. Salloum, "Mapping the soil loss in Marqya basin: Syria using RUSLE model in GIS and RS techniques," *Environ. Earth Sci.*, vol. 76, no. 3, p. 114, 2017, doi: 10.1007/s12665-017-6424-0.
[21] O. Djoukbala, M. Mazour, M. Hasbaia, and O. Benselama, "Estimating of water erosion in semiarid regions using RUSLE equation under GIS environment," *Environ. Earth Sci.*, vol. 77, no. 9, p. 345, 2018, doi: 10.1007/s12665-018-7532-1.
[22] H. S. Gelagay and A. S. Minale, "Soil loss estimation using GIS and Remote sensing techniques: A case of Koga watershed, Northwestern Ethiopia," *Int. Soil Water Conserv. Res.*, vol. 4, no. 2, pp. 126–136, 2016, doi: 10.1016/j.iswcr.2016.01.002.
[23] P. Rangsiwanichpong, S. Kazama, and L. Gunawardhana, "Assessment of sediment yield in Thailand using revised universal soil loss equation and geographic information system techniques," *River Res. Appl.*, vol. 34, no. 9, pp. 1113–1122, 2018, doi: https://doi.org/10.1002/rra.3351.
[24] S. S. Biswas and P. Pani, "Estimation of soil erosion using RUSLE and GIS techniques: a case study of Barakar River basin, Jharkhand, India," *Model. Earth Syst. Environ.*, vol. 1, no. 4, pp. 1–13, 2015, doi: 10.1007/s40808-015-0040-3.
[25] K. Balasubramani, M. Veena, K. Kumaraswamy, and V. Saravanabavan, "Estimation of soil erosion in a semi-arid watershed of Tamil Nadu (India) using revised universal soil loss equation (rusle) model through GIS," *Model. Earth Syst. Environ.*, vol. 1, no. 3, pp.

1–17, 2015, doi: 10.1007/s40808-015-0015-4.

[26] L. Jiang, Z. Yao, Z. Liu, S. Wu, R. Wang, and L. Wang, "Estimation of soil erosion in some sections of Lower Jinsha River based on RUSLE," *Nat. Hazards*, vol. 76, no. 3, pp. 1831–1847, 2015, doi: 10.1007/s11069-014-1569-6.

[27] Q. Zhou, S. Yang, C. Zhao, M. Cai, and L. Ya, "A Soil Erosion Assessment of the Upper Mekong River in Yunnan Province, China," *Mt. Res. Dev.*, vol. 34, no. 1, pp. 36–47, 2014, doi: 10.1659/MRD-JOURNAL-D-13-00027.1.

[28] S. Ullah, A. Ali, M. Iqbal, M. Javid, and M. Imran, "Geospatial assessment of soil erosion intensity and sediment yield: a case study of Potohar Region, Pakistan," *Environ. Earth Sci.*, vol. 77, no. 19, pp. 1–13, Oct. 2018, doi: 10.1007/S12665-018-7867-7/METRICS.

[29] H. Xie, Y. Zhang, Z. Wu, and T. Lv, "A bibliometric analysis on land degradation: Current status, development, and future directions," *Land*, vol. 9, no. 1, 2020, doi: 10.3390/LAND9010028.

[30] X. Chen, Z. Liang, Z. Zhang, and L. Zhang, "Effects of soil and water conservation measures on runoff and sediment yield in red soil slope farmland under natural rainfall," *Sustain.*, vol. 12, no. 8, 2020, doi: 10.3390/SU12083417.

[31] I. C. Nicu, "Is overgrazing really influencing soil erosion?," *Water (Switzerland)*, vol. 10, no. 8, pp. 1–16, 2018, doi: 10.3390/w10081077.

[32] R. U. Khan, T. Bannu, and T. Bannu, "Ethnobotanical Study of Food Value Flora of District Bannu Khyber Journal of Medicinal Plants Studies Ethnobotanical Study of Food Value Flora of District Bannu Khyber Pakhtunkhwa , Pakistan," no. June 2015, 2013.

[33] K. Pakhtunkhwa, M. Rooman, Y. Assad, S. Tabassum, S. Sultan, and S. Ayaz, "A cross-sectional survey of hard ticks and molecular characterization of Rhipicephalus microplus parasitizing domestic animals of," no. August, 2021, doi: 10.1371/journal.pone.0255138.

[34] T. S. Abdulkadir *et al.*, "Quantitative analysis of soil erosion causative factors for susceptibility assessment in a complex watershed," *Cogent Eng.*, vol. 6, no. 1, Jan. 2019, doi: 10.1080/23311916.2019.1594506.

[35] L. Tsegaye and R. Bharti, "Soil erosion and sediment yield assessment using RUSLE and GIS-based approach in Anjeb watershed, Northwest Ethiopia," *SN Appl. Sci.*, vol. 3, no. 5, pp. 1–19, 2021, doi: 10.1007/s42452-021-04564-x.

[36] W. Maleika, "Inverse distance weighting method optimization in the process of digital terrain model creation based on data collected from a multibeam echosounder," *Appl. Geomatics*, vol. 12, no. 4, pp. 397–407, 2020, doi: 10.1007/s12518-020-00307-6.

[37] D. Liu, Q. Zhao, D. Fu, S. Guo, P. Liu, and Y. Zeng, "Comparison of spatial interpolation methods for the estimation of precipitation patterns at different time scales to improve the accuracy of discharge simulations," *Hydrol. Res.*, vol. 51, no. 4, pp. 583–601, 2020, doi: 10.2166/NH.2020.146.

[38] N. Ejaz, M. Elhag, J. Bahrawi, L. Zhang, H. F. Gabriel, and K. U. Rahman, "Soil Erosion Modelling and Accumulation Using RUSLE and Remote Sensing Techniques: Case Study Wadi Baysh, Kingdom of Saudi Arabia," *Sustain.*, vol. 15, no. 4, pp. 1–14, 2023, doi: 10.3390/su15043218.

[39] S. Y. Siswanto and M. I. S. Sule, "The Impact of slope steepness and land use type on soil properties in Cirandu Sub-Sub Catchment, Citarum Watershed," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 393, no. 1, 2019, doi: 10.1088/1755-1315/393/1/012059.

[40] I. A. N. D. Moore and G. J. Burch, "DIVISION S-6-SOIL AND WATER MANAGEMENT Physical Basis of the Length-slope Factor in the Universal Soil Loss Equation 1," *Soil Conserv.*, vol. 50, no. 1986, pp. 1294–1298, 1986.

[41] I. D. Moore and G. J. Burch, "Modelling Erosion and Deposition: Topographic Effects.," *Trans. Am. Soc. Agric. Eng.*, vol. 29, no. 6, pp. 1624–1630, 1986, doi: 10.13031/2013.30363.
[42] B. P. Ganasri and H. Ramesh, "Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin," *Geosci. Front.*, vol. 7, no. 6, pp. 953–961, 2016, doi: 10.1016/j.gsf.2015.10.007.
[43] Y. Farhan and S. Nawaiseh, "Spatial assessment of soil erosion risk using RUSLE and GIS techniques," *Environ. Earth Sci.*, vol. 74, no. 6, pp. 4649–4669, 2015, doi: 10.1007/s12665-015-4430-7.
[44] A. Y. Yesuph and A. B. Dagnew, "Soil erosion mapping and severity analysis based on RUSLE model and local perception in the Beshillo Catchment of the Blue Nile Basin, Ethiopia," *Environ. Syst. Res.*, vol. 8, no. 1, pp. 1–21, 2019, doi: 10.1186/s40068-019-0145-1.
[45] C. M. Fayas, N. S. Abeysingha, K. G. S. Nirmanee, D. Samaratunga, and A. Mallawatantri, "Soil loss estimation using rusle model to prioritize erosion control in KELANI river basin in Sri Lanka," *Int. Soil Water Conserv. Res.*, vol. 7, no. 2, pp. 130–137, 2019, doi: 10.1016/j.iswcr.2019.01.003.
[46] S. Batool, S. A. Shirazi, and S. A. Mahmood, "Research Article Appraisal of Soil Erosion through RUSLE Model and Hypsometry in Chakwal Watershed (Potwar-Pakistan)," 2021.
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