Journal of Climate and Community Development
A Double-Blind, Peer-Reviewed, HEC recognized Y-category Research Journal
E-ISSN: 3006-7855 P-ISSN: 3006-7847

Risk Assessment of Soil Erosion Under Different Land use Changes Across the Himalayan Ecosystem Using GIS & RS Techniques in the Rusle Model

Urwa Tahir [1] **Arshad Ashraf** [2] **Saleem Arif** [3]

[1] M.Phil, Government College University, Faisalabad, Punjab, Pakistan.
[2] PhD, Climate, Energy and Water Research Institute (CEWRI), National Agricultural Research Centre (NARC), Park Road, Chak Shahzad, Islamabad, Pakistan.
[3] PhD, Government College University, Faisalabad, Punjab, Pakistan.

Corresponding Author: urwatahiruaf@gmail.com

Vol. *4*, ***Issue*** *1, 2025*

Article Information

Received:
2025-02-02

Revised:
2025-04-21

Accepted:
2025-04-29

ABSTRACT

Soil erosion poses a significant risk to agricultural production, especially in mountainous areas with weak geology and widespread deforestation. This research evaluated soil erosion dynamics in Mansehra District, Pakistan, for 2000 and 2023 by applying the Revised Universal Soil Loss Equation (RUSLE) model. Five major parameters rainfall erosivity (R), soil erodibility (K), slope steepness and length (LS), cover management (C), and conservation practices (P) were obtained from meteorological, soil, and remote sensing data. Results indicated that average soil erosion had risen from 26.5 tons/ha/year in 2000 to 33.7 tons/ha/year in 2023, an increase of 26.6% during the study period. Risk of soil erosion was classified into very low, low, moderate, high, and very high classes, with steep slopes and greater rainfall being most susceptible. Land cover and land use changes, fueled by population expansion and infrastructure development, greatly exacerbated erosion, especially in regions where rangelands were being cleared to agricultural land. The results underscore the critical necessity for particular methods for preventing erosion and environmentally friendly land management techniques. This research offers a useful framework for the formulation of conservation measures to reduce soil erosion on varied landscapes in Pakistan.

Keywords: *Rusle, GIS & RS, Himalayan Region, Geology and Widespread, Mansehra District.*

Citation: APA
Tahir, U., Ashraf, A & Arif, S. (2025). Risk assessment of soil erosion under different land use changes across the Himalayan ecosystem using GIS & RS techniques in the Rusle model, Journal of Climate and Community Development, 4(1), 139-156.

1. Introduction

A fundamental part of the earth's crust is soil, which is loose natural material formed from the weathering of minerals and rocks. It can or cannot have organic matter that supports plant life (Blum et al., 2017). Soil erosion is a problem globally, especially in areas where there are anthropogenic environmental changes (Rozos et al., 2013). Erosion is actually brought about by many natural processes such as heavy rain, running water, forest clearance and vegetation cover, soil disconnection and transport of soil by a number of forces (Finlayson et al., 2003). The two primary reasons for soil erosion are water and wind, both of which lead to an extensive annual loss of soil. Lower agricultural productivity capacity, reduced value of groundwater, and requirement for drainage networks are among some signs of lost cultivated soil (Berthelin et al., 2018). Some geospatial technologies that have shown promise in monitoring natural resources and evaluating soil risks like erosion are geographic information systems (GIS) and satellite remote sensing (RS) (Lambin et al., 2011). Knowledge of the underlying causes of deterioration and identifying areas more prone to it can enable local government agencies and other stakeholders to develop more effective conservation programs. Soil erosion and environmental deterioration are exacerbated by human-induced activities like felling of trees, overgrazing, construction, and large-scale farming. It is mainly due to a variety of natural processes like heavy rainfalls, running water, deforestation and plant cover, separation of soil and soil transport by multiple forces (Finlayson et al., 2003). In addition to this, identification of a solution to soil degradation is vital to the welfare of the people residing in Mansehra district.

Study area: In the Khyber Pakhtunkhwa region of Pakistan, the research site of Mansehra district covers a distance of around 4579 km2 in between the longitudes 72.81oE-74.13oE and latitudes 34.18oN-35.18oN (Figure 1). Mansehra district is surrounded by lush valleys, great mountains, and splendid landscapes. It is also abundant in biological resources and has extensive cultural heritage. It is the seventh most populous city of the KPK province and the 71st most populous city in Pakistan, with a population of more than 300,000 people.

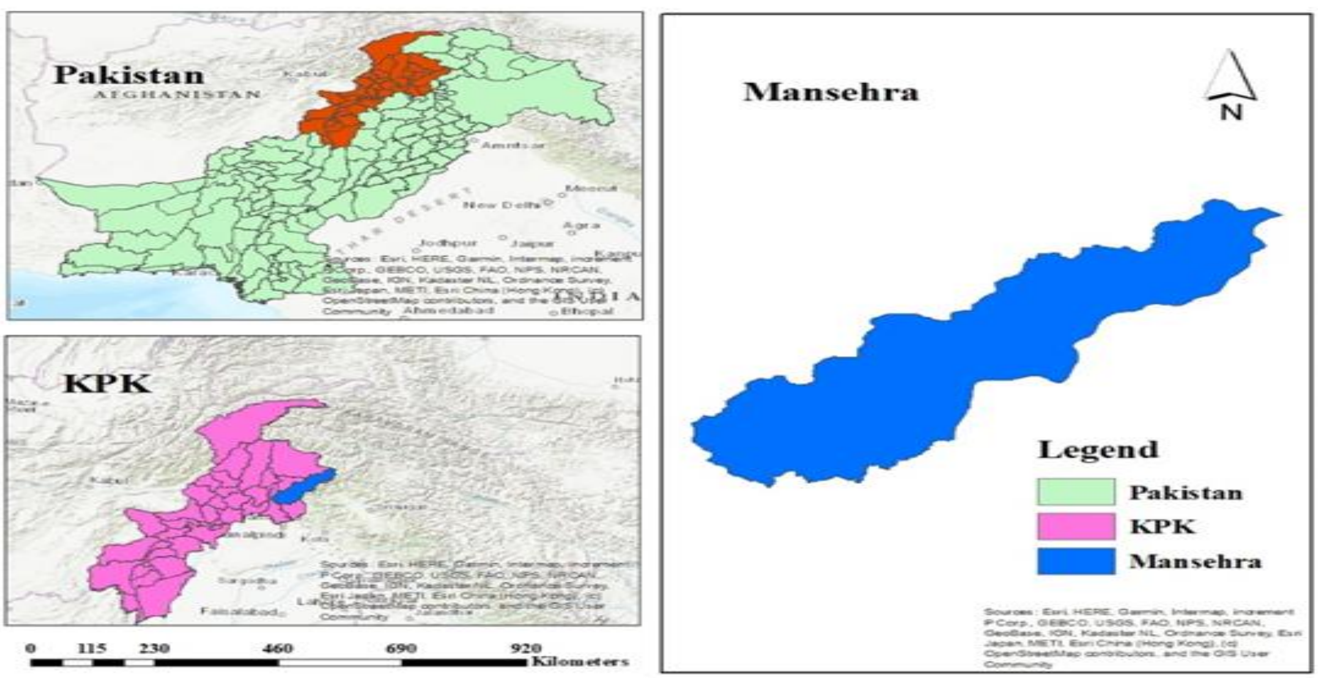

Figure 1: *Research Area map*

2. Materials and Methods

2.1. Dataset Used:

The analysis makes use of the following datasets: All Landsat satellite series data are available for free download from the United States Geological Survey (USGS). With a temporal resolution of 16 days, these satellites are able to capture the whole planet, including the atmosphere, land, and ocean. Applications include detecting forest fires, analyzing vegetation, predicting the weather and climate, measuring the global sea surface temperature, studying ocean dynamics, and research (Chopra et al., 2006).

2.2. Satellite Data

To calculate soil erosion, satellite imagery is necessary. LULC is determined using Sentinel-2 imagery with a 10m resolution, while the slope map is derived from Digital Elevation Model (DEM) data at a resolution of 30 meters from the Shuttle Radar Topography Mission (SRTM).

2.3. Sentinel-2 for LULC

Sentinel-2 image data of 2000 and 2023 (Path 150, Row 037) were used as primary data to study land-use/land-cover of Mansehra district of Pakistan. From USGS Earth Explorer, the photos were obtained. All the classification samples were taken through training samples, which include water, built-up, barren land, agriculture land, snow cover, rangeland and forest. The selected classifier was trained by using the training samples and extracted features along with parameters adjusted as needed to optimize classification accuracy. The trained model was applied to the entire Sentinel-2 image to classify each pixel into one of the predefined land cover classes. Accuracy assessment was performed to evaluate the quality of the classification. Map was generated showing the classified land cover classes. Regression analysis was applied to relate the DEM data and the rainfall data in order to represent the spatial variation of rainfall. Land use and degraded areas in the study area were confirmed by field surveys that used the Global Positioning System (GPS) to obtain ground control points.

Table 1: *RUSLE input data types and sources utilized in this research area*

Input Parameters	Data Sources	Spatial Resolution	Purpose
Image Data	USGS	30m	LULC & C-factor
Soil Data	OWWDSE	1:1,000,000	To drive K-factor
DEM Data	ASTER DEM	30m	To drive LS-factor
Rainfall Data	PMD	20 years monthly data	To drive R-factor

2.4. Geographic Information System and Remote Sensing

A geographic information system (GIS) is an entity that gathers, stores, integrates, analyzes, organizes, and presents data related to coordinates or locations. Using GIS, geographic information, correlations, patterns, and trends can be identified. Statistical analysis, databases, and mapping are integrated through GIS (Omar et al., 2010). ArcGIS version 10.5 was employed in this inquiry. Figure 2 illustrates the integrated processes of the RUSLE model with ArcGIS. Since the 1970s, GIS has been applied in environmental management (Kim et al., 2006). First, by incorporating GIS functionalities with RUSLE, it is possible to visualize and analyze the likelihood of soil erosion in a very short time (Blaszczynski et al., 2001). This is useful as it will permit large-scale research simulations with a little processing time demand by employing massive amounts of data (Blaszczynski et al., 2001). Furthermore, by presenting animated sequences of model output images across time and space, GIS is a sophisticated tool that makes it possible to see model output from external perspectives (Tim et al., 1996). This is beneficial because it will allow large-scale simulation research with minimal processing time requirement by using enormous amounts of data (Blaszczynski et al., 2001). In addition, by showing animated series of model output images over space and time, GIS is an advanced tool that allows one to visualize model output from outside viewpoints (Tim et al., 1996).

2.5. GIS and RUSLE Modeling

Traditional methods are unsuitable for performing an efficient assessment of soil erosion in Himalaya regions. Existing methods for identifying areas of soil erosion depend on physical surveys, which are costly and labor-intensive to perform for small-scale projects. The "Universal Soil Loss Equation" (USLE) is the most popular empirical equation for assessing soil erosion from drainage basins, even though numerous parametric models have been developed globally (Wischmeier and Smith, 1978). The RUSLE model was chosen because of its scalability to GIS-based workflows, best fit accommodation of the RS data available, and relatively low input data requirements. The model is used in the world mostly to predict the levels of rill and gully erosion from the fields that are cultivated using diverse means. RUSLE attains these needs through the implementation of five essential components, which assess an area's soil loss: conservation practices (P factor), rainfall-runoff erosivity (R factor), cover management (C factor), soil erodibility (K factor), and length-slope (LS factor).

2.6. Assessment of Soil Erosion

On slope fields, the RUSLE model (Renard et al., 1997) was employed to estimate the annual loss of soil. The estimation of average annual soil loss worldwide has been carried out extensively with the help of this model (Renard et al., 1997; Kidane et al., 2019; Yesuph & Dagnaw et al., 2019; Woldemariam & Harka et al., 2020). Six parameter raster spatial analysis was employed to calculate the total annual loss of soil (Wischmeier & Smith et al., 1978; Hurni et al., 1985; Renard et al., 1997). The RUSLE model was developed by the US Department of Agriculture based on the USLE model. The RUSLE empirical model of soil erosion is the accepted method for calculating the average risk of soil erosion in a country. A correct assessment of the erosion problem is dependent on the geographical, economic, environmental, and cultural setting of the problem.

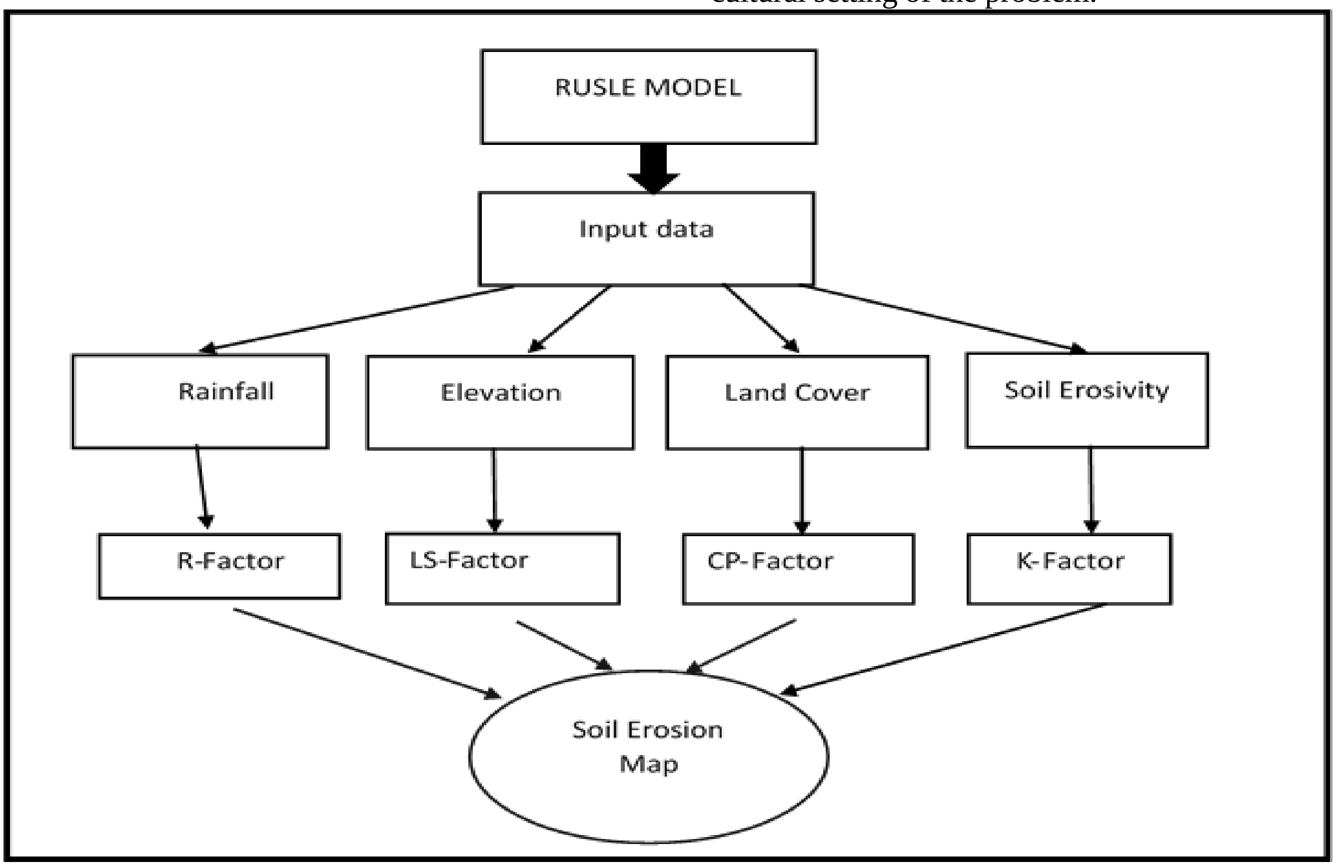

Figure 2: *Flowchart showing the study's methodology*

The most effective erosion prediction model now in use is RUSLE, which is simple to use at the local or regional level. Additionally, it is simple to incorporate numerous factors obtained from DEM and LULC (land use land cover) from satellite pictures into RUSLE, such as slope, aspect, accumulation, etc. The inability of RUSLE to channel sediment limits its application to small regions, which is a drawback (Nearing et al., 2005). An expression for the RUSLE model is as follows:

A is equal to $R \times K \times LS \times C \times P$ (1)

Rainfall Erosivity (R) Factor

The R factor was calculated using information from four meteorological stations in the research area: Muzzarabad, Balakot, Kakul, and Chillas.

The change in precipitation according to elevation was then calculated using the technique (provided in Equation 2).

Rainfall erosivity factor (R), which measures how much rainfall affects soil erosion, is calculated using comprehensive, continuous rainfall data (Wischmeier and Smith et al., 1978). The two main determinants of the erosivity of a storm, the precipitation amount and the peak intensity which lasts for a longer duration, are both denoted by the letter R.

Past studies have revealed that the energy and intensity of each rainstorm occurrence are directly related to the quantity of soil lost from cultivated land. The value of the rainfall erosivity factor employed by RUSLE needs to consider the quantity and intensity of runoff likely to be correlated with rainfall and the effect of raindrops. When rainfall intensity statistics are available, they are frequently used to calculate the rainfall erosivity factor. Rainfall intensity is often used to determine R, if such data is available. Equation (2) was utilized in this investigation to get the R factor. Using monthly precipitation data spanning 20 years (2000–2019) (Wischmeier and Smith 1978):

Table 2. *Average yearly precipitation and R-value (calculated from 20 years of data) for 2000–2019*

S. No	Stations	Location		Elevation (m)	Rainfall (mm)	R-Value
		Longitude (X)	Latitude (Y)			
1	Balakot	73.33635	34.55819	995	1410.23	909.62
2	Kakul	73.19619	34.19697	1225	1234.59	627.11
3	Muzaffarabad	73.45035	34.38779	732	1388.09	817.58
4	Chillas	74.09455	35.42433	1265	175.77	30.87

$$\boldsymbol{LogR = 1.93\ log \sum \frac{Pi2}{Pi} - 1.52} \qquad \textbf{(2)}$$

Where R is the rainfall erosivity factor (MJ mm t. ha−1.year−1), Pi is the monthly rainfall (mm), and P is the annual rainfall (mm).

Soil Erodibility (K) Factor

The soil erodibility factor (K) indicates how soil and soil profile typically respond to erosion caused by rainfall and runoff. It is also believed to function as a gauge of the rate of soil loss per unit of the rainwater erosion index in a specific kind of soil. The RUSLE model makes use of the method suggested by Gabriels (1998) to calculate a soil type's K factor. The methodology being discussed involves integrating several measurable soil parameters into the top five most strongly linked to soil erodibility. These features include the proportions of sand, silt, organic matter, permeability, and soil structure. Each zone yielded three to five samples, which were then pooled to create a single representative sample for that specific zone. The K-factor values were computed following the determination of the proportions of silt, sand, organic matter, and clay in the soil samples. By allocating the K factor values to the appropriate zones or soil mapping units, the final erodibility map was produced (Wischmeier et al., 1999).

$$\boldsymbol{K = Fc_{sand} * Fcl_{silt} * ForgC * Fhi.sand}$$

Where K represents the soil erodibility factor, fcsand is the soil's very coarse sand content, fcl−si is the soil's clay and silt content, and forgC is the soil's organic carbon content, fhi.

Table 3: *K-values according to the classes of soil textural characteristics*

S.No.	Longitude	Latitude	Texture class	K-Factor
1	73.296944	34.422222	Sandy Loam	0.16
2	73.296944	34.623056	Sandy Loam	0.16
3	73.341111	34.400833	Loam	0.18
4	73.256111	34.358611	Sandy Loam	0.09
5	73.258294	34.455199	Sandy Loam	0.17

Table 4: Soil Id assigns to soil texture classes

Soil-id	Area (%)	Land types/ Geomorphology	Soil characteristics
1	84.34	Mountain-Valley Systems	Shallow and medium textured in the valleys
2	0.10	Gravelly Fans	Soils with a medium to coarse texture
3	4.16	Loess deposits	Gently sloping, moderately deep,
4	6.33	(Gently sloping, locally dissected)	Coarse textured soil in Alluvial basin
5	4.44	Miscellaneous areas	Area comprising snow or large mass of ice mixed with earthy materials.
6	0.64	(Water body/ River course)	Lakes, river course comprising area

In the research region, six soil mapping units were identified. Ranging between 1 and 20. The soil unit 1 lie in mountainous valley which covers 84.34 %. Soil unit 2 and 3 lies in Gravelly fans and Loess deposits respectively. Soil unit 4 is mostly dominant in gentle sloping areas that mainly lie and consist of coarse textured soil covering 6.33% area. Soil Id 5 and 6 are present in miscellaneous area and water bodies and river course 4.44% and 0.64 % area respectively.

Slope Length and Steepness (LS) Factor

The length (L) and steepness (S) of the slope are directly related to soil erosion. These are significant topographic markers that have impact on soil erosion (Datta & Schack-Kirchner et al., 2010). Soil erosion typically affects places with steeper slopes more than those with gentler slopes. In a similar vein, a longer slope makes erosion more likely. Since the topographic element affects erosion in a very unpredictable way, accurate estimation of it is crucial (Renard et al., 2011). The LS factor in this study was determined using SRTM DEM 30m. The selection of the SRTM DEM was based on its high accuracy, extensive coverage, and lack of cloud cover (Farr & Kobrick et al., 2000). With the help of slope and flow accumulation LS-Factor can be generated for RUSLE. The raster calculator tool included in the Spatial Analyst extension was then used to determine the LS factor using equation **(Equation 3).** Schmidt et al. (2003) developed the "Spatial Analyst Extension" component of "ArcGIS" to compute the length slope factor map using the DEM and comparisons from Moore et al. (1993). The results were as follows for estimation of the steepness and length in slope:

$$\boldsymbol{LS = \text{POW}([\text{flowacc}] * \text{resolution} / 22.1, 0.4) * 0.0065 + 0.045*[\text{slope}] + 0.0065\text{\textasciicircum}2} \quad (3)$$

Where, Flowacc is equal to flow accumulation; Resolution is equal to pixel size of the image used i.e., 30m and Slope is equal to Slope % and POW is equal to power

Management (support) Practice (P) Factor

The ratio of soil loss resulting from a certain support technique to the comparable soil loss following up-and down-cultivation is known as the practice factor (P). Expert appraisal of present farming practices, either by field observations or aerial picture analysis, is one of the most popular methods for calculating a particular factor (Strand et al., 2002). A land use map cannot accurately depict the variations in support techniques, such as contour tillage and terracing, at the scale of a catchment area (Fu et al., 2005). The P value may gradually rise with increased terracing area, suggesting that terraces are less effective in reducing runoff and erosion (Foster et al., 2002; Hammad et al., 2011).

Land Use Land Cover (Supervised Classification)

To determine the LULC of the Mansehra region, Landsat satellite images of 2000 and 2023 were used. The USGS website, earthexplorer.usgs.gov, is a free website from which these images were downloaded. Multivariate supervised classification was done using ArcGIS10.5 to generate LULC maps of the study area. The classification of these images led to the development of seven LULC categories: built-up areas, water bodies, forests, snow cover, and bare ground. A rigorous error evaluation was done for the purpose of validating the accuracy of the classification. An accuracy assessment was performed using ground truth points and high-resolution Google Earth images to determine the accuracy of picture classification.

Table: 5 *Analysis of Land Use Land Cover*

LAND USE LAND COVER ANALYSIS		
Year	**2000**	**2023**
Satellite	Landsat 5	Landsat 8
Data	21/05/2000	21/05/2023
Path	150	150
Row	36	36
Bands	5	7
Methodology	Supervised Classification	Supervised Classification
Resolution	30m	30m

Cover Management (C) Factor (2000-2023)

The cover and management factor (C), considered to be the second most important factor controlling soil erosion (following topography), shows how cropping and management operations influence runoff and the intensity of soil erosion (Wischmeier and Smith 1978; Renard et al., 1997). Raindrop kinetic energy is typically lost by vegetation cover before it hits the soil surface. The runoff and erosion rates are, therefore, significantly impacted by cropping and plant cover. Consequently, soil erosion can be minimized with effective vegetation management, plant residue, and tillage (Lee et al., 2004). The plant cover, the production level of such cover, and the corresponding cropping practices are grouped to constitute the C-factor. With supervised classification and Landsat ETM 5 and 7 images having a resolution of 30 meters, land use/cover maps for the years 2000 and 2023 were developed.

The land use/cover map was recoded using Look up Tool in Arc GIS according to its C values, which were calculated using Wischmeier and Smith (1978) and other researches that have been carried out in similar circumstances in the north (Al-Zitawi et al., 2006). The C-factor represents the influence of management on soil loss. It is primarily associated with the percentage of vegetation cover. It is the ratio of loss of soil from specific crops to the equivalent loss from tilled, infertile test-plots.

3. Results and Discussions

In this research, the percentage of soil loss was estimated utilizing the RUSLE model within the GIS platform. This research is the pioneer in quantifying soil loss and partitioning the study area into different erosion-vulnerable zones. The RUSLE method employs five parameters to predict the rate of soil loss on a bare slope at any time scale: The R factor, the K factor, the LS factor, the C factor, and the P factor (Gashaw et al., 2018). The steep slopes of the study area, susceptibility to erosion, and regular rains render it susceptible to loss. One of the most effective models for predicting soil loss is RUSLE. Many studies have employed the same model, which has the same environmental and geographic variables.

3.1. Rainfall Erosivity (R) Factor

For 20 years (2000-2019), the Pakistan Metrology Department (PMD) has provided in Excel format the annual rainfall records of four meteorological stations: Balakot, Kakul, Muzaffarabad, and Chillas. The data were geographically linked using MET stations' shapefile. Since the data were point-based, a continuous raster grid was created using ArcGIS's inverse distance-weighted (IDW) technique.

The average yearly precipitation (P) in the studied region was computed using a straightforward kriging interpolation approach. During the interpolation technique, rainfall data from four distinct rain gauge stations **(Table 2)** around the research region were taken into account. Twenty years were spent watching the stations.The region of Chillas had the lowest R-factor values, while the greatest values were found between Balakot and Kakul. The four weather stations' average annual precipitation factor of erosivity (R) was determined to range from 1410.23 to 193.40 MJ mm ha-1 h-1 year-1, while the value of R was found to range from 909.62 to 42.67 MJ mm ha-1 h-1 year-1.

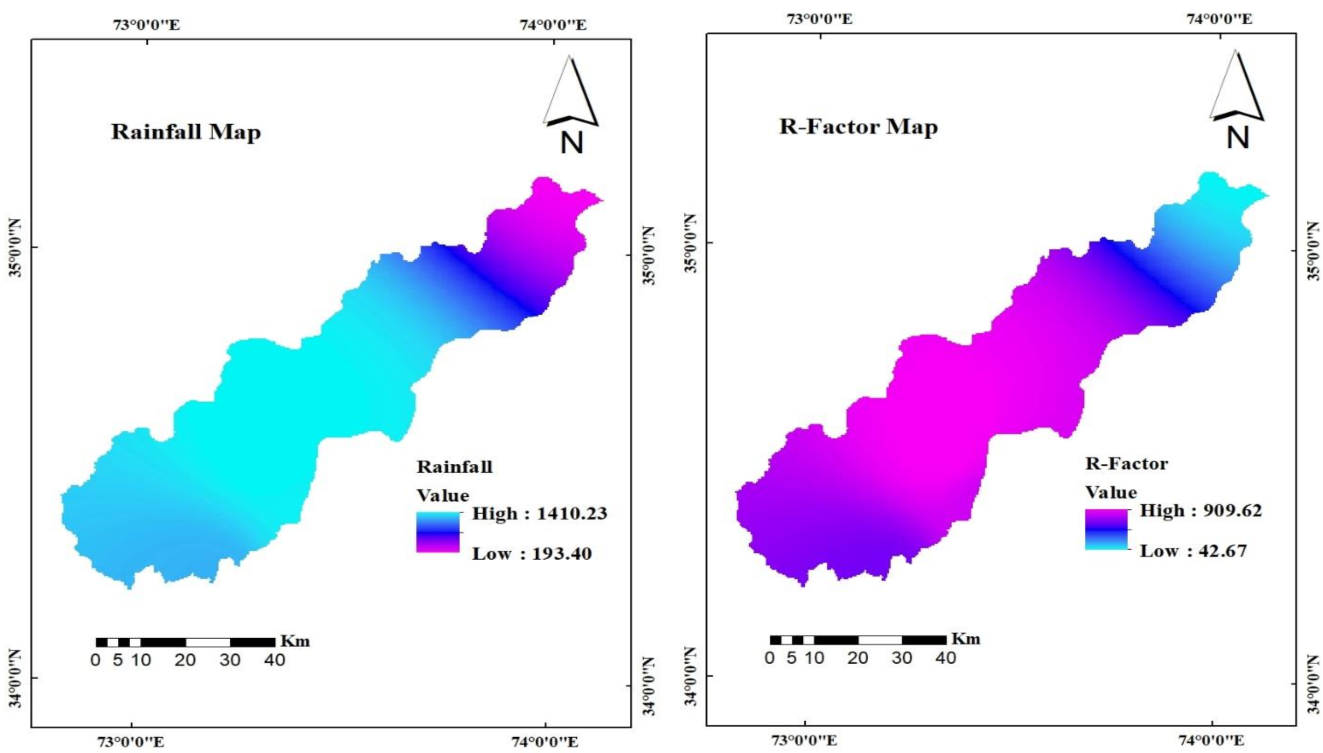

Figure 4: *Map of the research area's mean annual rainfall and R-factor*

3.2. Soil Erodibility (K) Factor

The vulnerability of different types of soil to erosion varies. The K factor, also known as soil erodibility, measures the soil's natural vulnerability to erosion caused by precipitation and water runoff. Various physical and chemical attributes influence its erodibility. The RUSLE model brings out some fundamental physical attributes influencing soil erodibility, including particle size distribution, organic content, soil structure, and soil permeability. The used soil map in calculating the K factor was provided by the

Pakistan Soil Survey. The computed K factor values for Mansehra indicate that the soil erodibility varies between 0.09 and 0.18 tons/ha/year. The Mansehra soil erodibility factor map, shown in Figure 5, indicates that the research area's minimal soil erodibility value is around 0.09 tons/ha/year and its maximum value is 0.18 tons/ha/year. The Mansehra soil erodibility factor map is depicted in **Figure 5**, with lowest and highest values of 0.09 and 0.18 tons/ha/year, respectively, indicated. The majority of the research area is impacted by moderate to high levels of soil erosion, whereas the majority of the region has low values of soil erodibility.

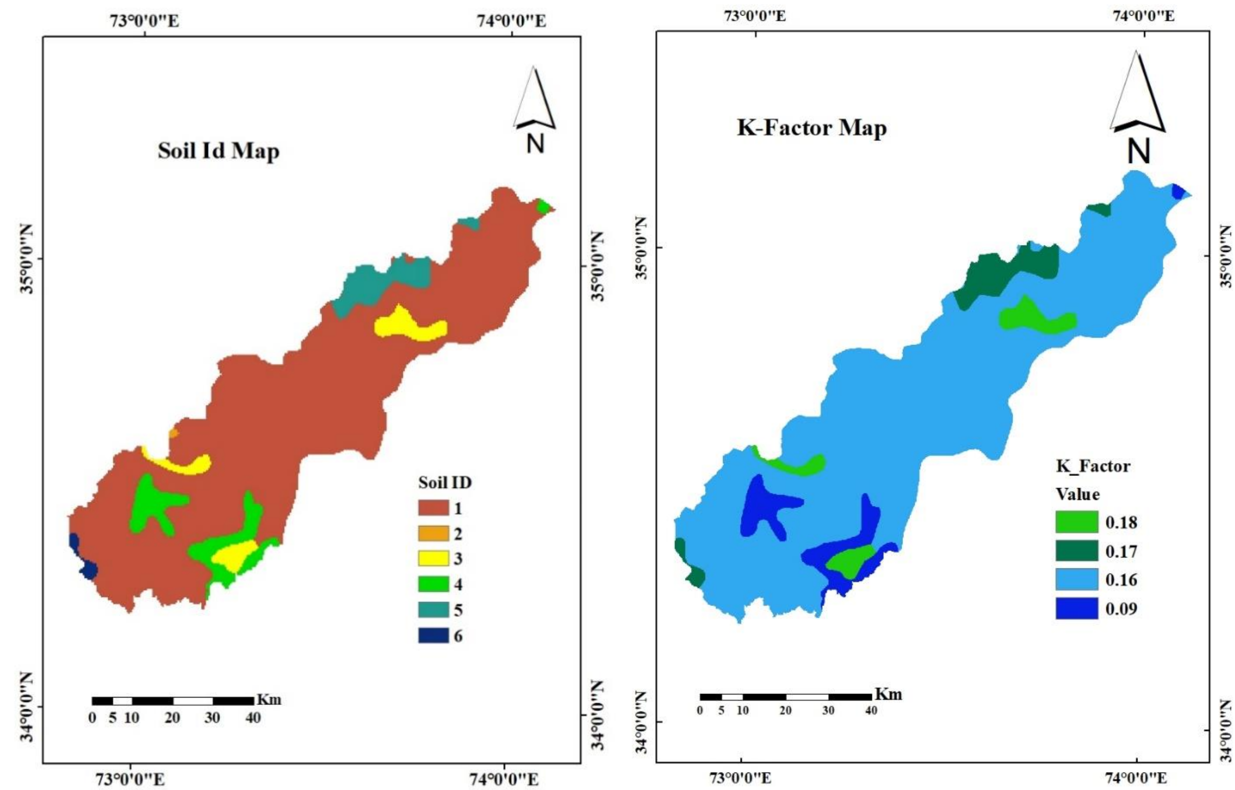

Figure 5: *Map of the research area's K factor and Soil Id*

3.3. Slope Length and Steepness (LS) Factor

Soil erosion and the LS factor are closely related. Erosion is frequently more likely to occur on longer, steeper slopes. The research region is characterized by high, steep hills. Because it is widely accessible and free of cost, the LS factor—which is obtained from the SRTM DEM—is frequently employed in soil erosion research. The 30m SRTM DEM was used to compute the LS factor for this research region, and the results ranged from 0 to 1561.68. Figure 11 displays the Mansehra's LS map. The ranges of LS values shown in this map are between 0 and 1561.68, indicating that northern parts of the study area have higher elevations, making erosion more pronounced at higher elevatations and LS having higher values in the upper part of the region. Due to the extremely high slope, the southern portion of the region has the highest values of LS factor. Since the northern part of the district also has the highest LS values, places with severe soil erosion are primarily found there.

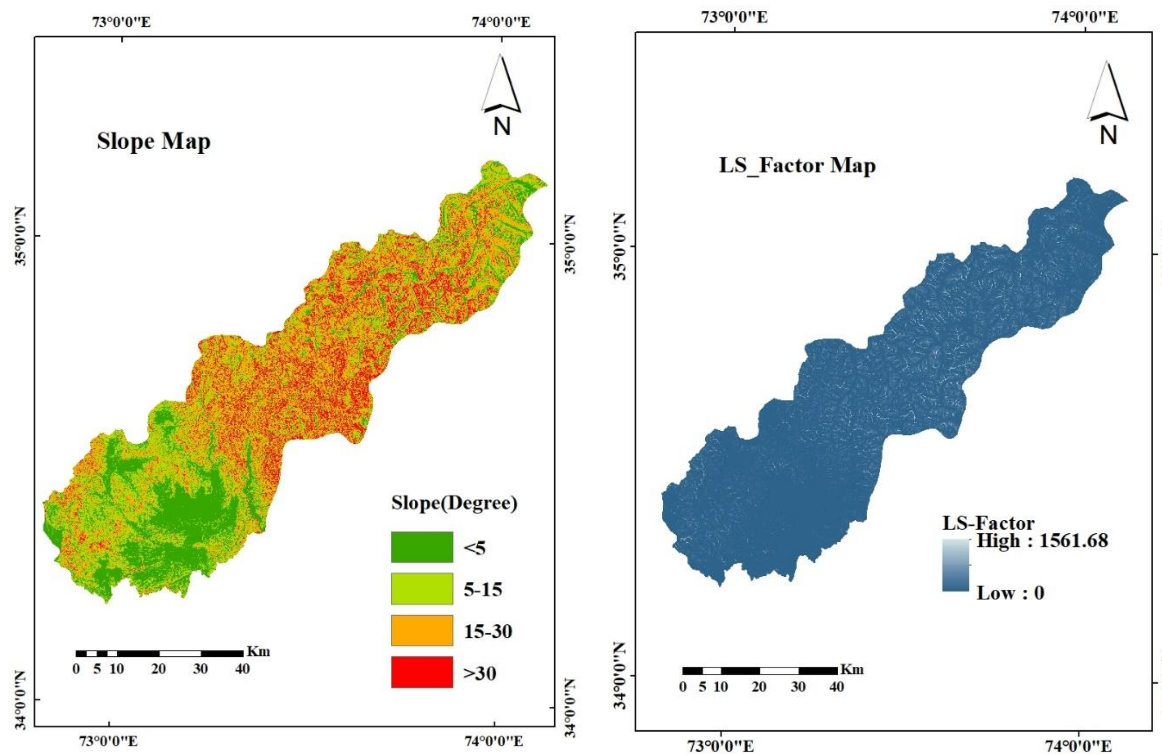

Figure 6: *Slope (%) and LS factor map of the study area*

3.4.Land Use and Land Cover

The primary kinds of LULC consist of the proportion of built-up and urban regions to the overall land cover is 3.47%. Towns, major metropolitan centers, and infrastructure development fall under this category. A glaring sign of the district's urbanization patterns is the growth of built-up areas. Cropland makes up about 31.21% of the whole region, suggesting a heavy reliance on agriculture for subsistence. The lush plains and valleys include the majority of the area used for agriculture. Forest makes up 22.68% of the total area, they represent the highest LULC category after cropland. The forests, which offer essential ecosystem services including carbon sequestration, wildlife habitat, and soil erosion prevention, are mostly found in steep and mountainous areas. 20.72% of the region is made up of barren ground, which is characterized by rocky outcrops, conditions akin to a desert, and little to no flora. Rangeland (grazing areas of the rural public) about 17.98% includes regions where grasses and shrubs predominate. These areas sustain a variety of species and are frequently utilized for the grazing of animals. The district is covered in water bodies, such as lakes and rivers that make up 1.63%. These are essential for maintaining aquatic habitats, drinking water, and irrigation. Snow/glaciers cover over 2.31% of the area in district Mansehra.

Table 6: *Comparative Analysis of LULC 2000-2023*

Analysis LULC 2000-2023(%)				
Sr. No.	**Land cover Classes**	**Area % (2000)**	**Area % (2023)**	**Change% (2000-2023)**
1	Water	5.6	5.6	0
2	Snow Cover	16.3	27.5	11.2
3	Forest	29.6	18.4	-11.2
4	Built up	3.6	7.9	3.6
5	Agriculture Land	5.1	8.8	3.6
6	Rangeland	28.9	21.6	-7.3
7	Barren Land	10.6	9.9	-0.7
	Total	100.0	100.0	

Table 7: *Risk of erosion in relation to different land use scenarios (tons/ha/yr)*

Scenarios	**Descriptions**	**(tons/ha/year)**
1	Convert all forest to rangeland class (Deforestation Case)	38.5
2	Convert all rangeland to forest (Afforestation Case)	33.5
3	Convert all rangeland to built-up land (Urbanization Case)	41.5
4	Convert all rangeland to agriculture land (Cultivation Case)	56.5

Table 8: *Soil Loss Severity classes with area percentage distribution of 2000-2023.*

		Area in percentage	
		2000	**2023**
Very low	<5	51.6	57.8
Low	5-25	31.3	22.6
Moderate	25-50	7.2	7.7
High	50-100	4.0	7.0
Very High	>100	5.9	4.8

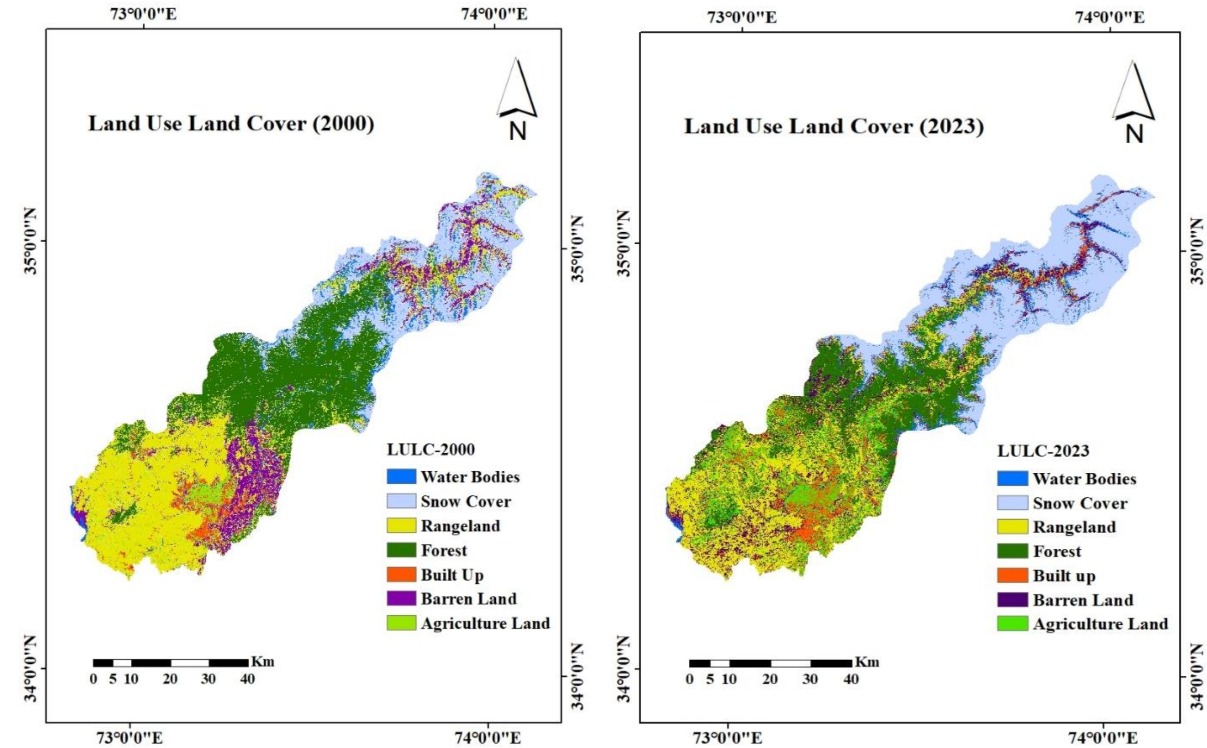

Figure 7: *LULC-2000and 2023 Map of study area*

3.5.Cover Management (C) Factor (2000-2023)

The LULC map for this research shows that the selected area is made up of different land cover classes, including built-up (3.47%), grassland (17.98%), water bodies (1.63%) and cropland (31.21%)), forest (22.68%), snow (2.31%) and barren land (20.72%). According to the accuracy evaluation, the overall accuracy is 91.19%. It was observed that the C-factor values varied from 0.001 to 0.2 in both the years 2000 and 2023. Figures (8) shows that the C-factor values. It shows the soil vegetation index that controls soil loss. As vegetation grows, soil loss decreases. (Jiang et al., 2015; Prasanna kumar et al., 2011; Shit et al., 2015).

As a resultIt is critical to manage soil erosion and lower the rate of runoff. Landsat satellite imagery in 2000 and 2023 with a resolution of 30 m were used in this study to determine the C factor. Different LULCs are produced after categorizing the photos utilized in this study, which were retrieved from the USGS Earth Explorer website. Seven land use classifications were applied to the study region. Tables 5 and 6 were used to apply the crop management factor to the various land use patterns. The land cover map and the C factor value were used to create a C factor map. According to Fernandez et al. (2003) and Ashraf (2020), the C-factor values assigned to the different LULC classifications were as follows: 0.05 for built-up land, 0.001 for water bodies and snow/glacier, 0.02 for grassland, 0.13 for arable land, 0.2 for bare land/barren land, and 0.008 for forest cover.

Soil erosion is more likely in areas with higher C factor values.

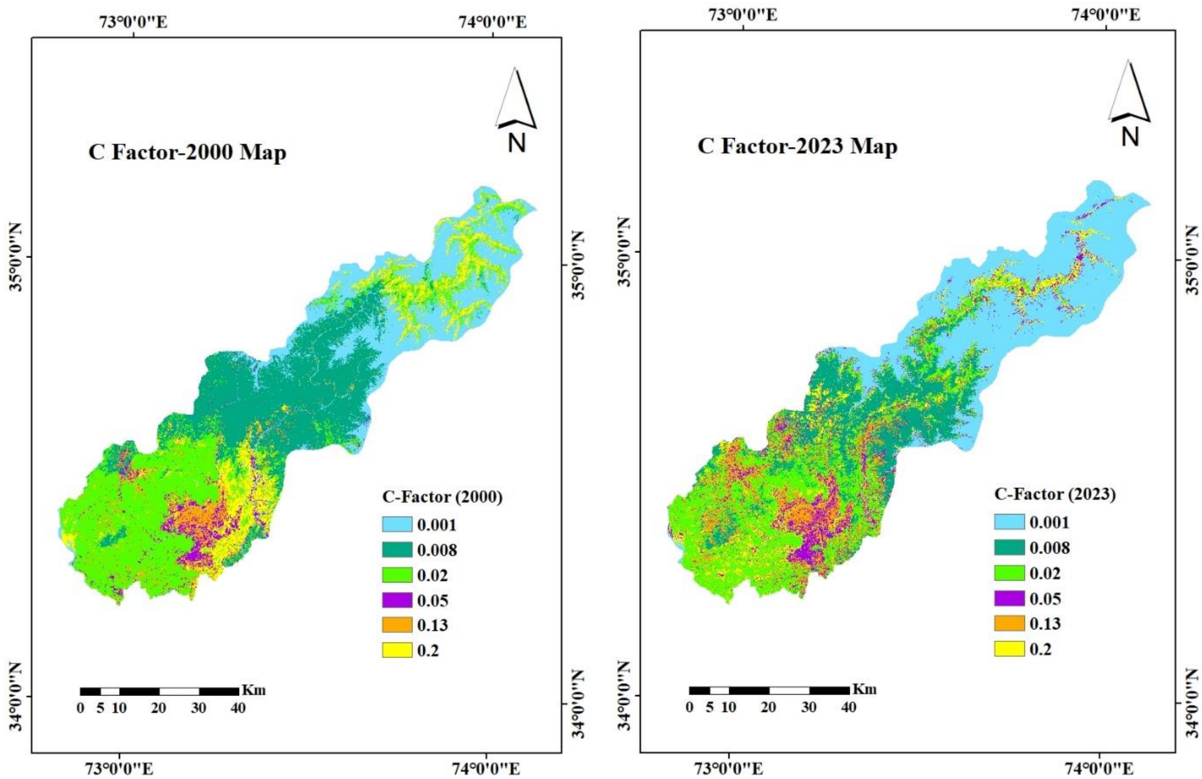

Figure 8: *C-Factor_2000-2023 map of the study area*

3.6. The Land Use Nexus Loss of soil and land cover

Based on a comparison of the Mansehra district's trends in LULC and land loss. It also draws attention to the elements that contribute to soil erosion. After being examined using the hotspot method, the data was shown on ArcGIS software-created maps. The research area's mean annual soil loss in 2000 was 26.5 tons per hectare; by 2023, that amount had risen to 33.7 tons per hectare. The areas of woods, built-up areas, and bare ground all saw considerable changes during this time; the area covered in snow cover rose from 16.31% in 2000 to 27.53% in 2023. During the study period, there were drastic changes in the four main classes of land cover, i.e. forest, snow cover, built-up area and meadows. The built up area gradually increased from 150.8 to 332.5 km2. The rate of soil loss rose by 11.84 tons per hectare per year, from 26.5 to 33.7 tons per hectare per year, in the same time between 2000 and 2023. The primary LULC classes that changed between 2000 and 2023 according to the LULC research were snow cover, built-up area, forest, and barren terrain. The rate of soil erosion rose throughout this time, rising from 26.5 tons per hectare year in 2000 to 33.7 tons per hectare annually in 2023. The extremely high land area grew between 2000 and 2023 as well. The majority of the snow-covered region in the area has turned into bare ground, which increases its susceptibility to weathering and soil erosion, according to a LULC study conducted there. In the study region, the area covered by snow cover has grown dramatically and quickly in tandem with the expansion of agricultural and built-up areas, while the area covered by barren ground has also expanded. Following the measurement of soil loss for the years 2000 and 2023, five zones were identified from the maps of the Mansehra region: very low, low, moderate, high, and very high (Figures 8).

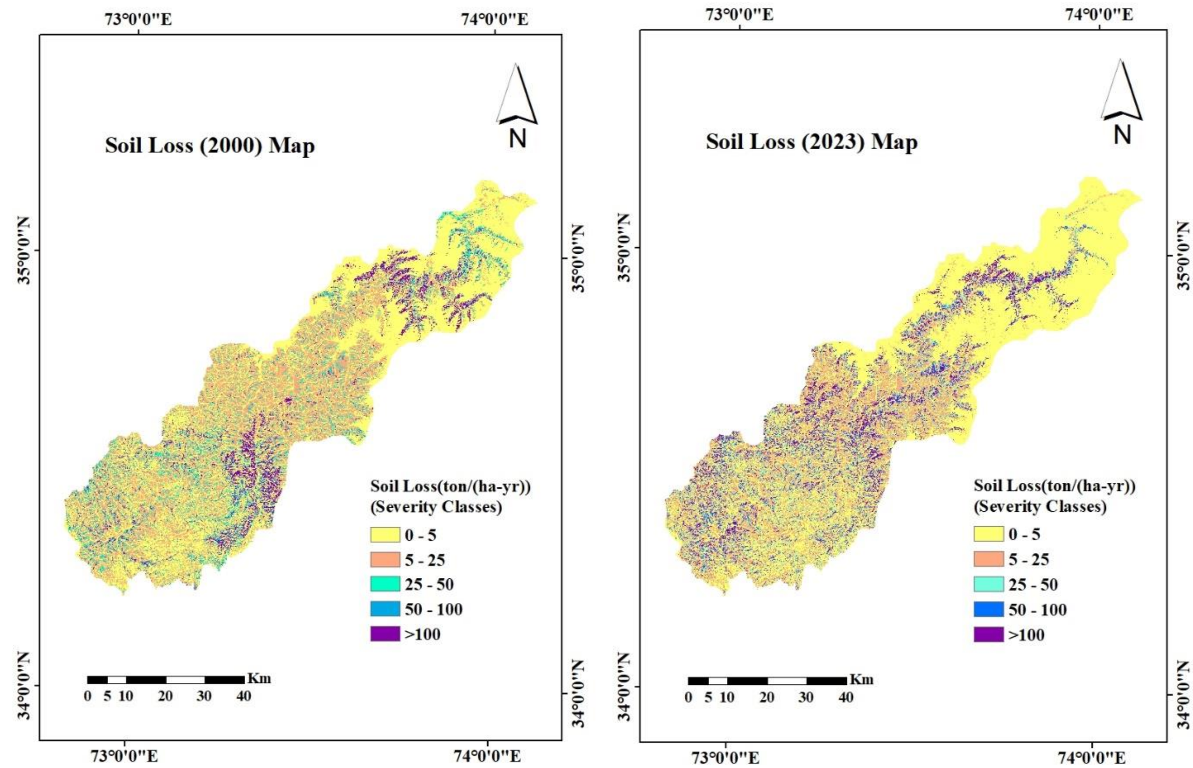

Figure 9: *Annual Soil Loss during 2000 and 2023 in the study area*

4. Scenarios of Different Land Use

To advance and implement future risk mitigation strategies and actions, the response of soil erosion was evaluated under several scenarios of change in land use circumstances. These four options have to do with the conditions around land usage.

Forest to Rangeland The average erosion rate in scenario 1, when all forest is converted to rangeland, is 38.5 tons/ha/year, which is somewhat higher than in the base condition (Table 12). **Rangeland to Forest** in scenario 2 assumes that all rangeland (about 21.66%) is turned into forest. Soil erosion occurred at a rate of around 33.5 tons per hectare per year. **Rangeland to Built-up land** in scenario 3 assumes conversion of rangeland to built-up land and scrub forest to rangeland, reflecting ongoing urbanization in the region. The study area is experiencing erosion at a rate of around 41.5 tons per hectare per year. **Range land to Agriculture land** in scenario 4 assumes that all rangeland and open soil have been converted to farm land, indicating a cultivation situation. The research region saw an average erosion rate of 56.5 tons/ha/year.

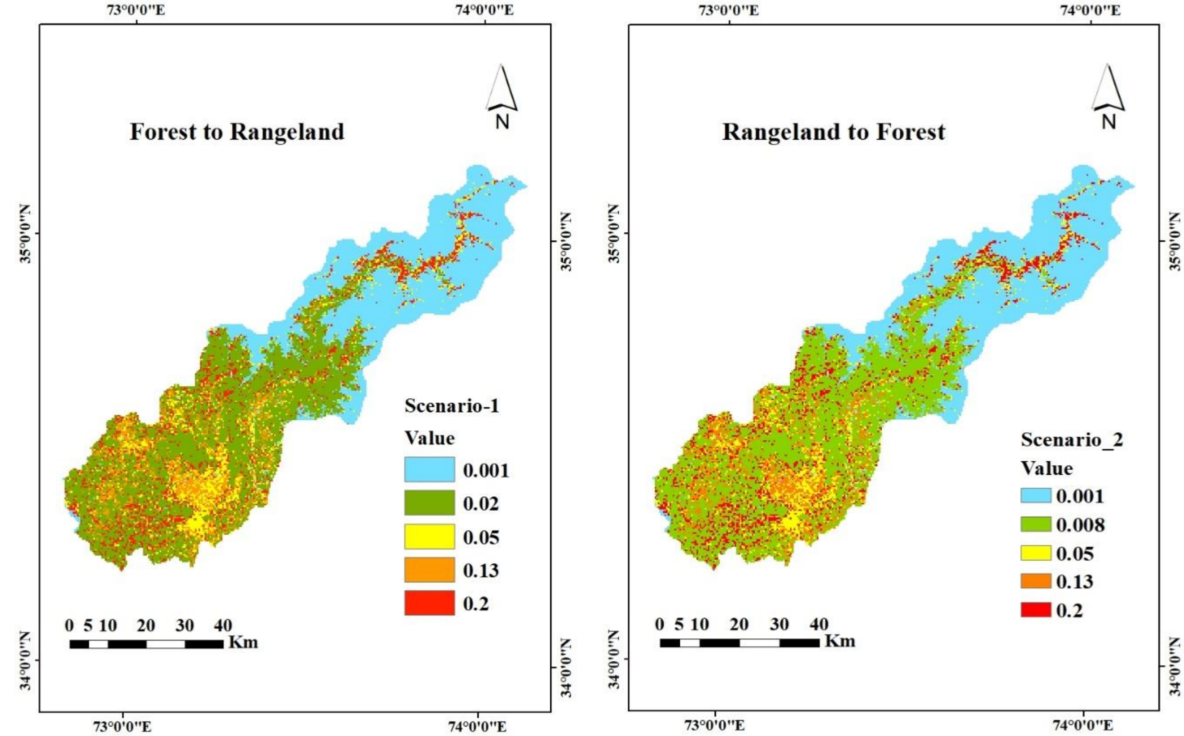

Figure 10: *Convert all forest to rangeland class and rangeland to forest*

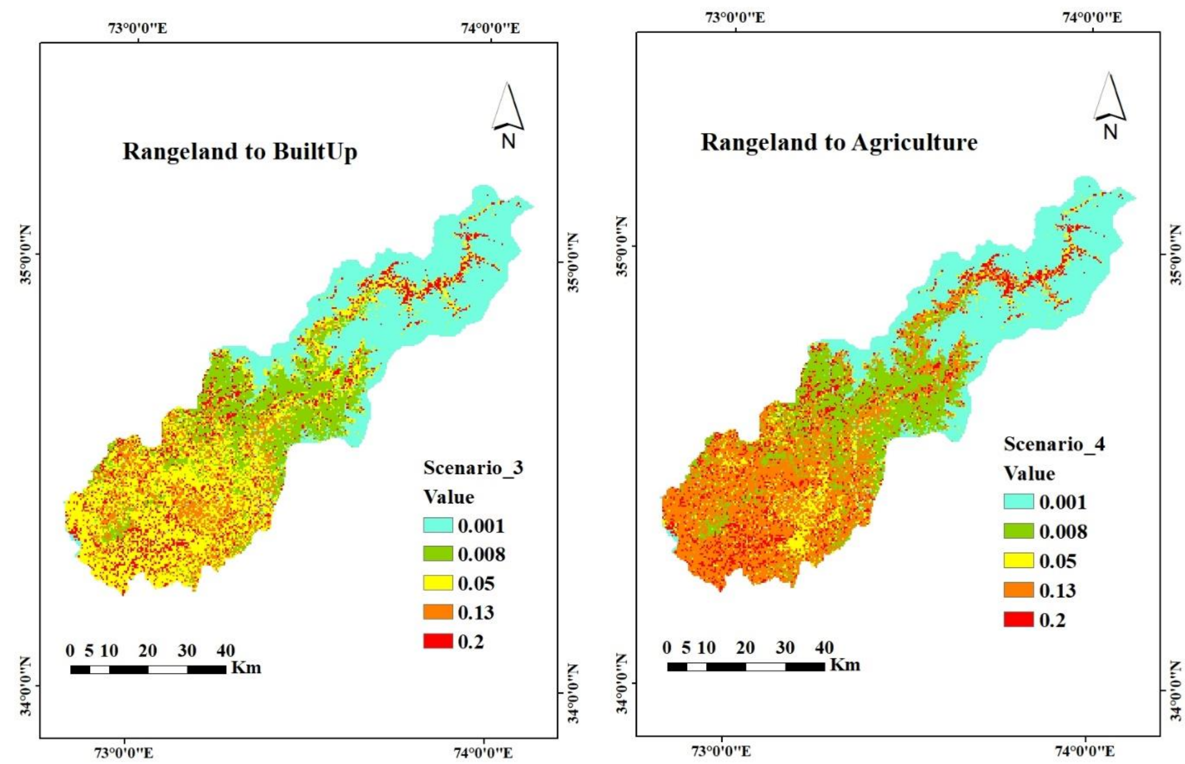

Figure 11: *Convert all rangeland to built-up land and rangeland to agriculture land*

5. Conclusion

In the current study, the risk of soil erosion in the Mansehra area of Pakistan's Himalaya region was estimated using the RUSLE model in conjunction with RS and GIS. The study provides a thorough insight of the intensity and temporal distribution of soil erosion. The RUSLE and GIS method performed effectively in mapping and measuring the erosion risk in the area. In the Mansehra district, factors like as topography, precipitation, and urbanization affect soil erosion. In the research region, annual rainfall was predicted to be between 193 and 1410 mm. The soil erodibility value were found within range of 0.09-0.18 in the area. The steeper slope areas are more prone to risk of soil erosion. The slope length and steepness LS values were observed within range of 0-1344.54 in the study area. The soil loss was calculated using all factors (R, K, LS, C and P) showing an average annual rate of about 25.5 ton/ha/year during 2000 and 30.7 ton/ha/year during 2023 period in the Mansehra district. Overall the soil loss indicated 26.6% increase during the twenty-three-year period (2000-2023). The primary LULC change found in the region was the conversion of vegetated land to built-up areas. According to the estimate, the annual rate of soil loss would rise in tandem with the expansion in barren regions between 2000 and 2023. If the current trend persists, it is anticipated that there would be an even greater loss of productive soils, which will have detrimental effects on the region's socioeconomic structure and mountain ecology.

6. Recommendations

To successfully combat soil erosion, a number of recommendations are put forth based on the findings of this thesis. Conservation tillage helps preserve soil organic matter and structure by causing the least amount of soil disturbance possible. Encourage farmers to use reduced or no-till farming methods. To assist with the changeover, provide cash incentives and training. Enhanced water infiltration, enhanced soil health, and decreased soil erosion. By sowing cover crops in the off-season, you may improve soil fertility, prevent soil erosion, and hold onto more water. Create initiatives to provide technical guidance and seeds for cover crops. Emphasize the farmers' long-term financial gains. Enhanced biodiversity, better soil structure, and decreased rates of erosion. The suggestions put forth aim to avoid soil erosion by combining practical farming practices, structural interventions, government support, and public education. By using these strategies, it is possible to ensure sustainable land use, protect the quality of the water, and enhance soil health. Future research has to focus on how these acts will affect the environment in the long run as well as how to come up with innovative solutions to reduce soil erosion even further.

7. Statements and Declarations

Acknowledgement

The authors gratefully acknowledge the support of the technical staff of the Climate Energy and Water Research Institute, NARC, Islamabad for weather data collection, compilation and reporting during the twenty three-year period.

Funding Sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' Contribution

Urwa Tahir: Conceived the idea, conducted a literature review, synthesised the data, wrote the paper and presented the results, discussions and conclusions while utilizing his field experience and research background. Dr Arshad Ashraf provided insight into data analysis, review and presentation.

References

Al-Zitawi, F. (2006). Using RUSLE in prediction of soil loss for selected sites in north and northwest of Jordan. Irbid: Jordan University of Science and Technology.

Berthelin, J., Valentin, C., & Munch, J. C. (Eds.). (2018). Soils as a Key Component of the Critical Zone 1: Functions and Services. John Wiley & Sons.

Blaszczynski, J. (2001). Regional Sheet and Rill Soil Erosion Prediction with the Revised Universal Soil Loss Equation (RUSLE)-GIS Interface. US Department of the Interior, Bureau of Land Management, National Science & Technology Center.

Blum, A. (2017). Osmotic adjustment is a prime drought stress adaptive engine in support of plant production. *Plant, cell & environment*, *40*(1), 4-10.

Datta, P. S., & Schack-Kirchner, H. (2010). Erosion relevant topographical parameters derived from different DEMs—A comparative study from the Indian Lesser Himalayas. *Remote Sensing*, *2*(8), 1941-1961.

Farr, T. G., & Kobrick, M. (2000). Shuttle Radar Topography Mission produces a wealth of data. Eos, Transactions American Geophysical Union, *81*(48), 583-585.

Fernández, G., Weis, S., Stoffel-Wagner, B., Tendolkar, I., Reuber, M., Beyenburg, S., & Elger, C. E. (2003). Menstrual cycle-dependent neural plasticity in the adult human brain is hormone, task, and region specific. *Journal of Neuroscience*, *23*(9), 3790-3795.

Foster, J. C., & Vo, H. B. (2002). Average characteristics and activity dependence of the subauroral polarization stream. *Journal of Geophysical Research: Space Physics*, *107*(A12), SIA-16.

Fu, B. J., Zhao, W. W., Chen, L. D., Zhang, Q. J., Lü, Y. H., Gulinck, H., & Poesen, J. (2005). Assessment of soil erosion at large watershed scale using RUSLE and GIS: a case study in the Loess Plateau of China. *Land degradation & development*, *16*(1), 73-85.

Hurni, H. (1988). Degradation and conservation of the resources in the Ethiopian highlands. *Mountain research and development*, 123-130.

Jiang, H., Ling, Z., Zhang, Y., Mao, H., Ma, Z., Yin, Y., & Ruan, B. (2015). Altered fecal microbiota composition in patients with major depressive disorder. *Brain, behavior, and immunity*, *48*, 186-194.

Kidane, M., Bezie, A., Kesete, N., & Tolessa, T. (2019). The impact of land use and land cover (LULC) dynamics on soil erosion and sediment yield in Ethiopia. *Heliyon*, *5*(12).

Kim, H. S., & Julien Pierre, Y. (2006). Soil erosion modeling using RUSLE and GIS on the IMHA Watershed. *Water Engineering Research*, *7*(1), 29-41.

Lambin, E. F., & Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the national academy of sciences*, *108*(9), 3465-3472.

Lee, S. (2004). Soil erosion assessment and its verification using the universal soil loss equation and geographic information system: a case study at Boun, Korea. *Environmental Geology*, *45*, 457-465.

Nearing, M. A., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., & Van Oost, K. (2005). Modeling response of soil erosion and runoff to changes in precipitation and cover. *Catena*, *61*(2-3), 131-154.

Omar, S. H. (2010). Oleuropein in olive and its pharmacological effects. *Scientia pharmaceutica*, *78*(2), 133-154.

Prasannakumar, V., Vijith, H., Charutha, R., & Geetha, N. (2011). Spatio-temporal clustering of road accidents: GIS based analysis and assessment. *Procedia-social and behavioral sciences*, *21*, 317-325.

Renard, K. G. (1997). Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). *US Department of Agriculture, Agricultural Research Service*.

Rozos, D., Skilodimou, H. D., Loupasakis, C., & Bathrellos, G. D. (2013). Application of the revised universal soil loss equation model on landslide prevention. An example from N. Euboea (Evia) Island, Greece. *Environmental Earth Sciences*, 70, 3255-3266.

Shit, P. K., Nandi, A. S., & Bhunia, G. S. (2015). Soil erosion risk mapping using RUSLE model on Jhargram sub-division at West Bengal in India. *Modeling Earth Systems and Environment*, *1*, 1-12.

Strand, G. H., Dramstad, W., & Engan, G. (2002). The effect of field experience on the accuracy of identifying land cover types in aerial photographs. *International Journal of Applied Earth Observation and Geoinformation*, *4*(2), 137-146.

Tim, U. S. (1996). Emerging technologies for hydrologic and water quality modeling research. *Transactions of the Asae*, *39*(2), 465-476.

Weldu Woldemariam, G., & Edo Harka, A. (2020). Effect of land use and land cover change on soil erosion in erer sub-basin, Northeast Wabi Shebelle Basin, Ethiopia. *Land*, *9*(4), 111.

Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses: a guide to conservation planning (No. 537). Department of Agriculture, Science and Education Administration.

Yesuph, A. Y., & Dagnew, A. B. (2019). Land use/cover spatiotemporal dynamics, driving forces and implications at the Beshillo catchment of the Blue Nile Basin, North Eastern Highlands of Ethiopia. *Environmental Systems Research*, *8*(1), 1- 30.