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Geospatial Assessment of Soil Erosion Intensity and Sediment Yield Using the Revised Universal Soil Loss Equation (RUSLE) Model

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Abstract: Land degradation caused by soil erosion is considered among the most severe problems of the 21stcentury. It poses serious threats to soil fertility, food availability, human health, and the world ecosystem. The purpose of the study is to make a quantitative mapping of soil loss in the Chitral district, Pakistan. For the estimation of soil loss in the study area, the Revised Universal Soil Loss Equation (RUSLE) model was used in combination with Remote Sensing (RS) and Geographic Information System (GIS). Topographical features of the study area show that the area is more vulnerable to soil loss, having the highest average annual soil loss of 78 ton/ha/year. Maps generated in the study show that the area has the highest sediment yield of 258 tons/ha/year and higher average annual soil loss of 450 tons/ha/year. The very high severity class represents 8%, 16% under high, 21% under moderate, 12% under low, and 13% under very low soil loss in the Chitral district. The above study is helpful to researchers and planners for better planning to control the loss of soil in the high severity zones. Plantation of trees and structures should be built like check dams, which effectively control the soil erosion process.

Keywords: land degradation; soil erosion; RUSLE; GIS; soil loss

1. Introduction

Soil erosion is considered among the major global problems of the nineteenth and twentieth centuries [1]; it directly affects the food, health of human beings, and the world's ecosystem. Soil erosion represents the detachment of soil and its transportation and deposition by different agents [2]. Approximately 84% of soil erosion is caused by two main factors, water and wind, but the average soil loss estimated due to water is more than 2000 t/km^2/year [3]. Loss of soil due to water or tillage removes the upper soil filled with nutrients, so it increases threats to better productivity of land [4]. In soil erosion, sediments are transported from land to rivers and then these transported sediments affect the storage capacity of reservoirs [5].

Land degradation detrimentally affects the rate of crop production. Soil loss is the most severe type of land degradation across the world [6]. It has harmful impacts on crop production by removing topsoil enrich with nutrients. It is also harmful to aquatic animals by polluting water and decreases the storage capacity of reservoirs [7]. Sediment yield is the output of soil erosion that is the transportation process in total area [2]. It is the total amount of sediments yielded in the catchment area per unit of time. It results in the combination of some erosion processes and deposition of sediments in the basin [8].

According to Chuenchum [3], globally, almost 0.5–1% of sedimentation disturbs the yearly loss of storage capacity of reservoirs. It is also predicted that in the 2050s, most dams in the world will be left with 50% of their present volume, which is a highly disturbing figure. Meanwhile in Asia, researchers note that 40% of the total storage of reservoirs is covered with sediments, which show high loss in storage capacity. These factors are responsible for affecting the long-term sustainability of water sources [9]. Previous literature shows that developing countries are at high soil erosion risk, e.g., India has an area of approximately 30 to 32.8 M.ha (Million hectares) affected by water erosion [10]. A recent study in Iran showed that the country is suffering from an average yearly soil loss of 24 tons/ha/year [11]. In Pakistan, approximately 16 M.ha (million hectares) of land, which is about 20 percent of the total land, is affected by the loss of soil; from that, 11.2 M.ha (approximately 70 percent) is soil loss due to water [12]. In the world, sediment yield is approximately 20 billion tons, and 80% of the sediments reach the oceans annually from all major rivers of the world [13].

Soil erosion has serious threats to world food production and, ultimately, to the economy of countries affected by soil loss [14]. The steeper slope lands having higher rainfall rates are more susceptible to soil loss. Annually, about 1 billion tons of productive soils are disintegrated and they are dropped in reservoirs and imported into the Arabian Sea [15]. It has been observed in different studies that soil erosion has seriously affected the storage capacity of reservoirs and dams. According to [5,16], due to sedimentation, the Warsak Dam suffered a 70% decrease in production capacity in Pakistan. Thus, it is important to estimate the quantity of soil erosion to take control measures against the eroded quantity. A decrease in the rate of soil loss in the Warsak Dam increases the power generation capacity of the dam. It will also be helpful in lowering the threats to food production in the agricultural areas.

To mitigate any challenging situation, risk mapping is considered a basic step. Erosion models are basic tools that will be helpful in future planning of soil conservation [14]. GIS and remote sensing technology are considered as the most powerful tools to measure metrological and biophysical constraints at variant spatial scales [17]. It is not possible to calculate the soil loss by using conventional methods due to the high cost, and because they are time consuming [18]. Therefore, the Revised Universal Soil Loss Equation (RUSLE) model is most widely used because it is simple, easy, and requires fewer data and time. The integration of the RUSLE model with GIS and remote sensing data generate more accurate results [6]. This model can easily be implemented, and required data are easily available for most countries. The results generated from this study will be useful to overcome mismanagement issues and well-grounded measures should be taken to control soil loss in areas with higher soil erosion rates [19,20].

Soil erosion has created a challenging situation for humans due to its complexity and variable factors influencing its rate [21]. Many factors influence the rate of soil erosion, such as slope, rainfall, land use, elevation, and vegetation. These factors cause severe damage, individually or in combination to agricultural lands, and reduce the carrying capacity of reservoirs. Several studies justified that land cover changes significantly affect soil loss [22,23]. Due to changes in climate, rainfall intensity increases, so ultimately soil erosion also increases in that area [24]. To overcome the impact of these factors, soil erosion estimation is necessary. Soil degradation caused by soil erosion is due to different erosion factors, such as surface erosion and rainfall erosion. Soil erosion is a major problem in rivers as it removes minerals that are necessary for vegetation and increases sedimentation of the reservoirs. Measures to control soil erosion can be possible after the risk mapping of that area, in which the quantity of erosion is calculated in terms of tons per hectare per year. Different types of models have been used by different scholars across different regions of the world.

In previous studies, various field and empirical methods were used to estimate the loss, but they were time consuming and costly [25]. Estimation of soil erosion can be done by the integration of GIS and the RUSLE model. The analytical functions of GIS were used to find different factors of the RUSLE that were finally used to calculate total soil erosion in the region [12]. According to Prem Rangsiwanichpong [26], the RUSLE model in combination with GIS can generate long-term results of soil erosion estimation, even for the steep slope regions when the physical parameters are known. RUSLE model is an extension of the Universal Soil Loss Equation (USLE) model and Modified Universal Soil Loss Equation (MUSLE) model, and it has been widely used due to its simplicity, feasibility, and efficiency in results. This method is based on observations, so it may not give the real picture of the results, but due to easy availability of data, it is a commonly used method [27]. It generates meaningful results in agricultural lands and reservoirs [28,29]. Reference [30] assessed the soil erosion rate based on the USLE model on the reservoirs of the Yunnan province. Saleem Ullah [6] used the RUSLE model with GIS in the Potohar region of Pakistan. There are many other similar studies on land degradation due to soil erosion [31–36].

The above-mentioned studies show the limitations of the RUSLE model. The estimation of potential soil erosion is improved by the development of the RUSLE model. The RUSLE model has different input factors that can be taken from literature or from statistical and empirical data by integration with GIS. Results generated by RUSLE are valid for the estimation of soil erosion due to water. Estimation of the quantity of soil erosion is important because the results of this study will be beneficial for researchers and engineers to plan for control of soil loss in the future. The RUSLE model based on GIS was also used in similar studies [3,6,26,37] and provides quantitative data of soil erosion.

The study aims to estimate the quantity of eroded soil by making a profile of soil loss in the Chitral district. The maps will be generated with the integration of Remote Sensing data and GIS using the RUSLE model. Maps will identify the intensity of erosion in different parts and their influencing factors in more concrete standings. Areas with the highest values of soil erosion will be useful after this research work, which should be the sole focus of agencies and planners. It could aid in the sustainability of dams, ecosystems, and better agriculture production.

2. Methods and Materials

2.1. Study Area

The Chitral River is a 480km long tributary of the Kabul River, which is, in turn, a subordinate of the River Indus, located in the Khyber Pakhtunkhwa province of Pakistan. It is located in eastern Afghanistan and northern Khyber Pakhtunkhwa. The Chitral River is situated between 35°50′46″ N and 71°47′09″ E. Figure 1 shows the map of the Chitral District. Different valleys of the district merge together to form 36 tributaries; the Chitral River is a combination of these tributaries. The Digital Elevation Model (DEM) (Figure 2) shows, in the map, that it is a highly elevated area with the highest elevation (7965m). From the extreme north in Baroghil—the Chitral River starts from the Chiantar glacier and re-enters Warsak in Peshawar Valley before entering Afghanistan in the Kunar province, and traverses a 496 km distance. The highest peak of the Hindukush Mountains, Tirch Mir, the surrounding glaciers form the second major tributary of the river. Hindu Kush Mountain's snow and melting glaciers feed the river system, so its flow remains throughout the year. The Warsak Dam is located 30km west of Peshawar, having a maximum output of 250,000 K-Watts, and was constructed on the Chitral River for irrigation and hydropower generation purposes. The Dam is suffering from silting issues. Due to silting, its reservoir almost became full. Now, the power generation capacity of the Dam has dropped to 64,000–20,000 kW throughout summer and winter seasons, correspondingly.

2.2. Methodology

To survey the various territories of soil erosion through several models, different techniques are used. In this study, with help from the Revised Universal Soil Loss Equation (RUSLE) model, theestimation of soil erosion is made [29]. Due to the improved nature, the RUSLE model has been utilized and that replica is the modified shape of the Universal Soil loss equation (USLE) and MUSEL [38]. The structure of RUSLE has greater adaptability in displaying disintegration in new conditions and generates more productive results than USLE. The RUSLE model has some additional flexibility in modeling erosion in new conditions and has further economic edge over the USLE model. There is an advantage of using the RUSLE technique because it can be a combination of empirical and process-based styles, and use optimum information as compared to the Universal Soil Loss Equation model. RUSLE factors enable additional adaptability in scheming soil loss by figuring exactly into the sub-factors. This permits the gauge by separating the substance into more substances, from the original substance, through the transportation of deposit [28]. The RUSLEmodel has been utilized to identify the soil erosion in this study, which is based on GIS. The RUSLE model equation (Equation (1)) is used to estimate the average annual soil loss.

$$A = R \times K \times LS \times C \times P \tag{1}$$

where, A = yearly mean soil loss (t ha^{-1} every year), R = precipitation erosivity factor (MJ ha^{-1} every year), K = soil erodibility factor (t ha h MJ^{-1} mm^{-1}), C = cover management factor (dimensionless), LS = slope length and slope steepness factor (dimensionless), and P = support practices factor (dimensionless). The raster calculator tool was used to multiply the parameters given above for the estimation of annual average soil loss of the region. The multiplication of isolated factors generated a combined map of soil loss. Quantity of eroded soil was taken from that final in terms of tons/ha/year. The outputs maps have a 90m resolution, which is acceptable for a regional study. The information elements of the exploration strategy came from different origins. The R-factor [33], K-factor [39], and P-factor [6] were recovered from the investigations including the high goals of (100 meter). Through a correlation of the ongoing, the topographic factor (LS)-factor has been determined by comparing the Digital Elevation Model (DEM) data, as well as data that are analyzed from this current investigation. The information that is obtained from the present study has been compared to the information that was obtained through the Advanced Elevation Model (DEM) [40]. The methodology chart of study is shown in Figure 3.

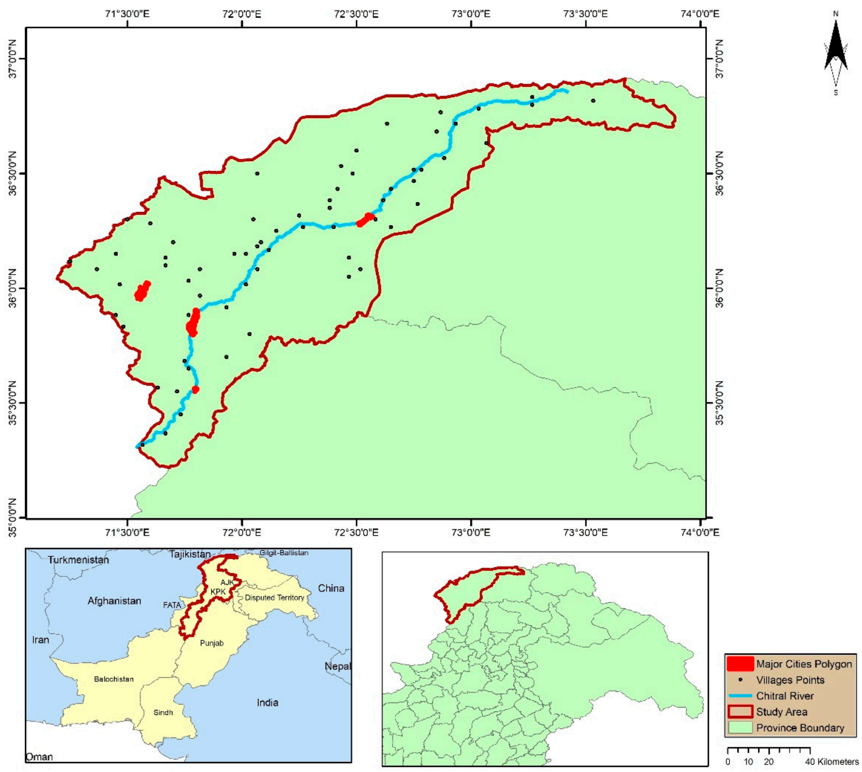

Figure 1. Map of Chitral district.

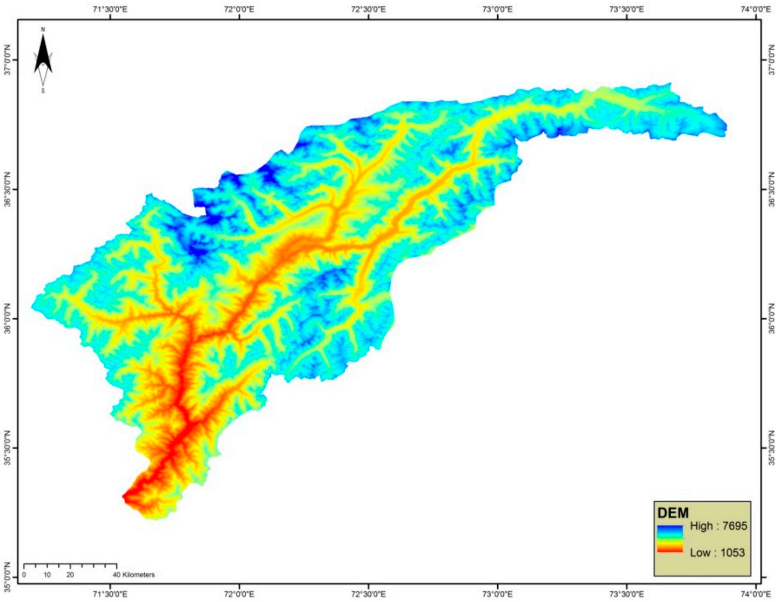

Figure 2. Digital Elevation Model (DEM) of the study area.

Figure 3. Workflow chart of the study. (DEM(Digital Elevation Model),C Factor(Cover management), R Factor(Rainfall erosivity), LS Factor(Slope length-gradient), K Factor(Soil erodibility), RUSLE(Revised Universal Soil Loss Equation)).

2.3. RUSLE Model Factor

2.3.1. Topographic (LS) Factor

The required model is calculated through the combined topographic factor LS-factor by utilizing the Global Digital Elevation Model (GDEM). The Shuttle Radar Topography Mission (SRTM) Dem data is used in this study. SRTM has 90m resolution and very good accuracy. The procedure involves the steps for the creation of the slope, such as the angle of the slope, length of slope, and joined LS factor that is given as under:

Usage of DEM to identify and fill the reservoir.

- By using filled DEM as input to find the way of the flow.
- By using the direction of flow as an input grid derived the flow assemblage.
- Flow assemblage is used as an input grid for the extraction of the stream network.
- Using the extraction of drainage for the ordering of stream network
- Using ordering map of stream network for the derivation of water basin flow length.
- Slope derivation through DEM.

With the help of incline maps and stream length, the LS-factor can be derived.

Morgan and Davidson [41] recommended the equation (Equation (2)) for the determination of the LS factor,

$$LS = \sqrt{(L/22\ (0.065 + 0.0450.\ \llbracket 0.45 \rrbracket \hat{}{*} + \llbracket 0.0065 \rrbracket \hat{}{*}\ S\hat{}2))} \tag{2}$$

where L = length of slope in meters and S = percentage of slope (%).

2.3.2. Cover (C) Factor

The C-factor helped to calculate the land cover of the study area map. Land cover impact on soil erosion is estimated land cover calculations, with the support of the C-factor. Different seasonal variations were observed in the C-factor depending upon the crop's production type and rainfall intensity. For the spatial location of land cover, a detailed inspection study was conducted to get the categorized and confirmed solution FAO (Food and Agriculture Organization) land cover data were used in this research, which has good accuracy. According to current cogitation, land use gave distinct behavior by the numerical values assigned to the C-factor [6].

2.3.3. Soil Erodibility (K) Factor

The K-factor explains the different types of soil of varying susceptibility to eroding and its participation in the rate of runoff. One of the major soil erodibility factors is the texture of soil; soil aggregation is dependent on these factors [42]. These data are acquired from the Soil Survey of Pakistan. Pertaining to soil erosion, the impacted behavior of the soil is readily explained with the help of the K-factor.

2.3.4. Rainfall Erosivity (R) Factor

The extent and intensity of every single rainfall throughout a year are justified by this factor. Satellite Rainfall Data of GPM (Global Precipitation Measurement) were used in this study. This satellite data is the product of NASA (National Aeronautics and Space Administration) and is widely used because of its enhanced accuracy. The annual rainfall data for the two meteorological stations situated in the study area were obtained from the Pakistan Meteorological Department; it was integrated with the satellite data to validate the results. The need for specific data generally makes it difficult to estimate this factor to a certain degree. This uncertainty and ambiguity has led to the origin of easy procedures. In this study, the R-factor was calculated using the proposed model of [41] by utilizing the given equation from the interpolated map of rainfall. The same equation was used by Saleem

Ullah [6] in his research in the Potohar region, adjacent, and having the same topographic conditions as our study area.

$$R = 0.05 \times P \tag{3}$$

where P shows average annual rainfall (mm).

2.3.5. Erosion Control Practice (P) Factor

The ratio of soil loss, with a given surface condition to soil loss with up-and-down-hill plowing, is termed as the erosion control practice factor (P-factor). Steps, such as treatments and precautionary measures taken to retain free particles near the source and prevention of further transport of particles, are involved to determine the value of the P-factor. The precautionary measures were taken against erosion, such as land treatments in the form of contouring, compaction, the establishment of sediment basins, building other structures to monitor, and control soil erosion, account for the P-factor. The practices for minimizing the effect of various significant factors on erosion generally assist in the calculation of this factor. This region has never been studied for this issue before. Thus, no resistance practices and techniques are in use in the region; therefore, the value of '1' was given to the P-factor for this whole region [43].

2.3.6. Sediment Yield (Y)

The number of sediments passing or reaching a point of interest in a given period is sediment yield. The estimates are normally calculated in terms of kilograms per year or tons per year. It shows the total amount of sediments that are washed away by the flow to the exit point of the watershed [44]. The sediment delivery ratio (SDR) was obtained by the distribution of sediment yield "Y" by the drainage area of drainage "A" of that specific watershed, as indicated in Equations (4) and (5), respectively. Thus,

$$SDR = Y/A \tag{4}$$

It can also be expressed as

$$Y = SDR \times A \tag{5}$$

where, SDR shows sediment delivery ratio, Y represents sediment yield ratio, and A is used for the drainage area.

3. Results

3.1. C-factor

There are various types of land cover; different values of C-factor are assigned to those land covers according to their condition. The different C-factor values are represented in the map and their spatial distribution. The values of the C-factor are given according to the different types of land use. For bare area 1, for natural shrubs, the value is 0.70, for the crop in flood plain, 0.28, and 0.004 for the forest, as shown in Figure 4a. Higher values of the C-factor show more vulnerability to erosion. In general, the rate of soil erosion decreases with more vegetation by providing a barrier to eroded soil. It improves the physical and chemical properties of soil and maintains the coarseness of the surface of the soil. Table 1 represents the values in between 0.004 to 1; high values of the C-factor show that area is more susceptible to soil loss.

3.2. K-Factor

In this study area, the K-factor has different values according to various types of land cover (Table 2). In this region, the lower value for calcareous clayey soil is 0.1, because soil aggregation and water diffusivity are higher, so it is less susceptible to soil loss. When clay amount is high, the value of K is lower because this soil is easily diffusible. The soil with a high amount of silt is easily removable from all types of soil. The value of the K-factor is 0.4 for water and seasonally flooded type of soil, because it can be sprinkled easily, and runoff rates are high due to a large amount of silt. For non-calcareous soil, the value is 0.33, which is greater than the mountainous land, which is 0.2 for neighboring areas. The soils have a moderate value of K for calcareous loamy soil, and they are moderately detached, and produce moderate runoff. Figure 4b shows the Chitral district map for K-factor.

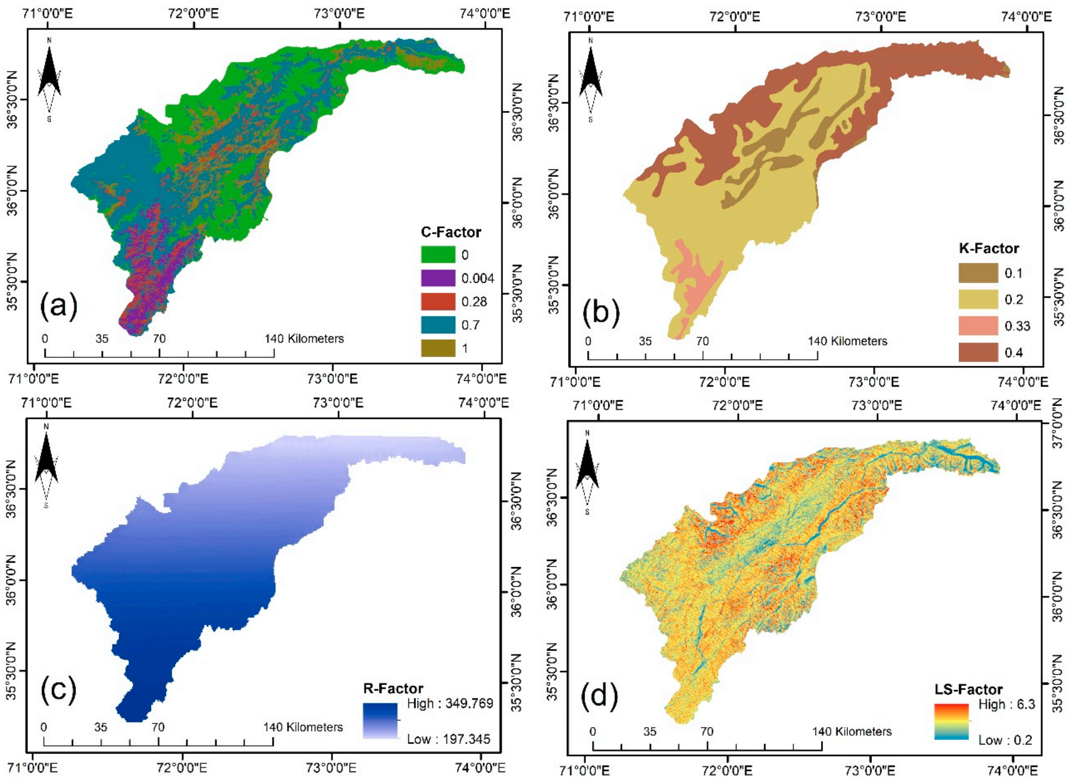

Figure 4. District Map for (**a**) C-Factor, (**b**) K-Factor, (**c**) R-Factor, (**d**) LS-Factor.

Table 1. C-factor in the Chitral district.

Sr. No	Land Cover	C-factor
1	Bare area	1
2	Rangeland/natural herbs and shrubs	0.7
3	Crop in the flood plain	0.28
4	Forest natural trees	0.004
5	Built-up areas	0
6	Wet areas	0

Table 2. K-factor in the Chitral district.

Sr. No	Soil Type	K-Factor
1	Calcareous clayey soil	0.1
2	Calcareous loamy and clayey soil	0.2
3	Mountainous land with nearly continuous	0.2
4	Non-calcareous loamy soil	0.33
5	Rough broken land	0.4
6	Water and seasonally flooded soil	0.4
7	Calcareous silty soil–gullied land complex	0.4

3.3. R-Factor

The areas with high altitude, and higher from the surface of the sea, have the highest rate of rainfall. The rainfall erosivity, the R-factor map shows that the rate of rainfall is higher in high altitude areas and adjacent areas with it (that increases the rate of soil erosion). The value ranges from 197.345 to 349.769, from low to high, respectively. High rainfall values show higher erosivity in the southwestern part of the Chitral district. The northern and western portion of the Chitral district is less prone to erosion due to low values of rainfall, as shown in Figure 4c.

3.4. LS-Factor

The map of the LS factor (Slope Length-gradient) shows the influence of length and slope on soil erosion. Due to the mountainous nature of the region, high LS values are observed in northeast (Bandok) and some parts of the southwest (Harchin) of the study area, which are leading factors toward final soil loss. Topographical features, as shown in Figure 4d, indicate that elevation values range from 1053 to 7695. Most of the area includes moderate and high slope or moderate to high values of the LS factor, and show that the area is susceptible to moderate and high soil loss. The distribution of the LS factor in the map shows that the maximum part of the study area has values between 0.2 and 6.3, and near 6.3, which is an indicator of moderate and high erosivity in the region.

3.5. Sediment Yield

The quantity of soil eroded from the reservoir due to rainfall is termed as sediment yield. The areas with a steep slope, scrubland, and sandy soil have the highest sediment yield, as shown in the map. Figure 5 shows the capacity of sediment yield in the Chitral district. The map shows that these areas have as high sediment yields as 258 tons/ha/year. In the downward portion of the study area, there is more sediment yield while the northwestern portion shows the low sediment yield.

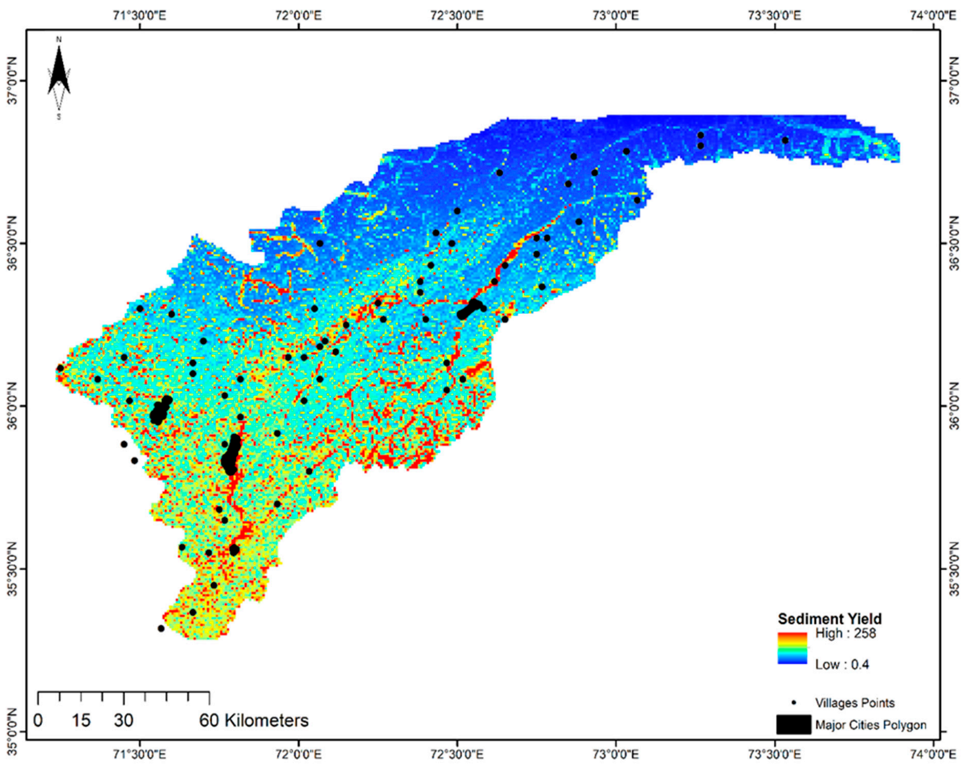

Figure 5. District map for sediment yield.

3.6. Soil Loss

Figure 6 shows the average yearly soil loss in the area ranges from 0 to 450 tons/ha/year, showing low and high values, respectively. Bare areas and highlands with steep slopes are more vulnerable to soil loss as shown in the map. The soil erosion estimation map is further explained in Figure 7 by using GIS techniques. The map of the study area represents the severity of soil loss. In the map, the Chitral district is further classified into five sub-classes, defined as very high, high, moderate, low, and very low, according to the severity of erosion. This classification has been carried out after Saleem Ullah et al. [6]. The area in this study is different, thus, changes in classification are made accordingly. The percentages of the area lie under soil loss, concerning its severity, are 43% in very low, 12% in low, 21% in moderate, 16% in high, and 8% in the very high severity zone of the study area, as shown in Table 3.

Table 3. Severity classes and area covered by these classes in the Chitral district.

Soil Erosion Severity Class	Soil Loss (tons/h/year)	Total Area (ha)	Area (%)
Very Low	<5	648,159	43
Low	5–10	180,882	12
Moderate	10–20	316,543	21
High	20–50	241,175	16
Very High	>50	120,588	8

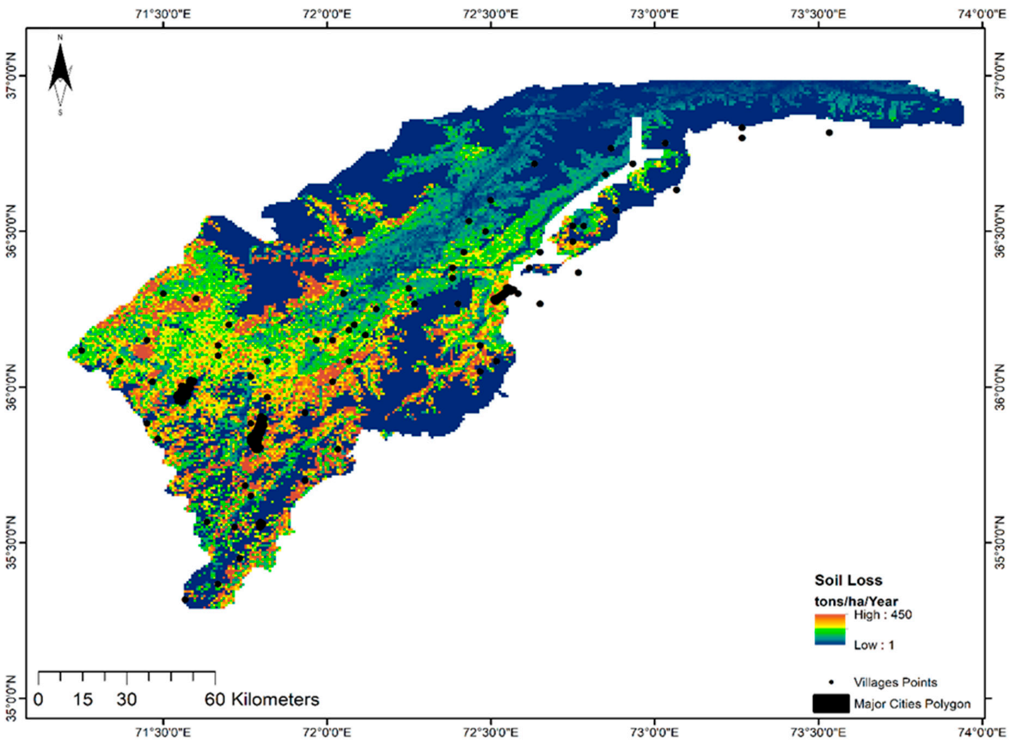

Figure 6. District map for soil loss.

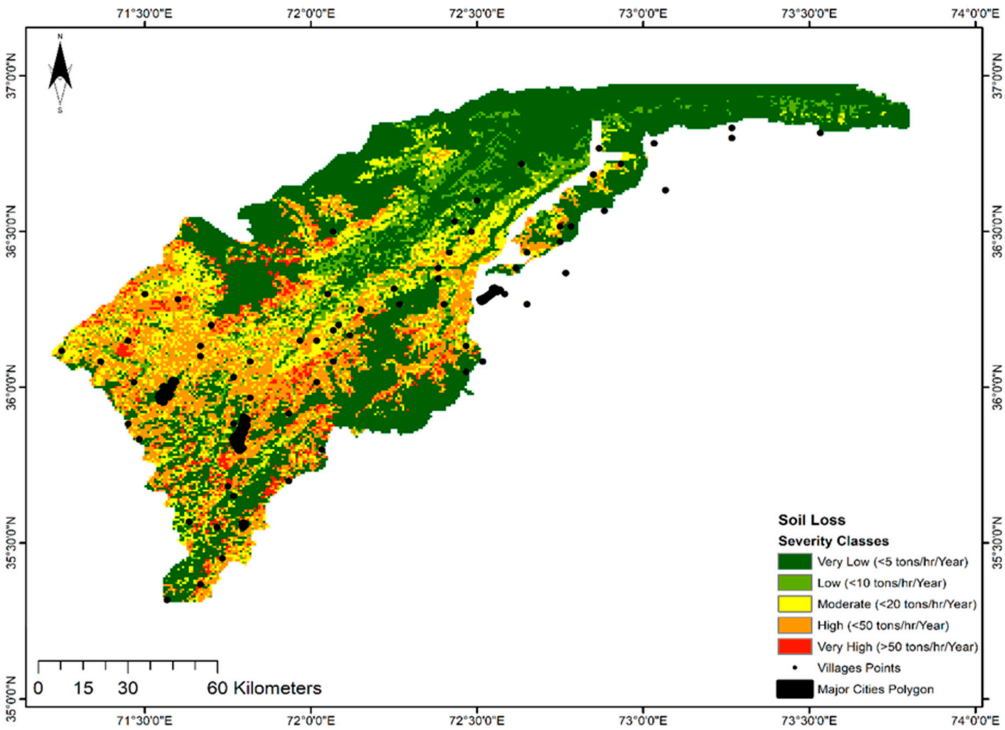

Figure 7. District map for severity classes.

4. Discussion

Soil erosion is an alarming and very serious problem, especially in the study area where different factors contribute to the rapid erosion of soil and sedimentation. Factors, such as steep slope of the region, climate, velocity of flowing water, and environmental conditions accelerate the rate of runoff and sedimentation. The study area is fed by melting glaciers. This rapid melting of glaciers, due to increased global warming, causes the issue of soil erosion. There is a dam located on the path of the Chitral River in this area. Ignoring the phenomena can lead to reduced power generation from the dam and water distribution, which will consequently affect the agriculture and land use of this region. Severe sedimentation caused by soil erosion has already affected the output power generation capacity of the dam to a very large extent. It was designed to have a maximum output of 250,000 k-Watts. The dam has reached a state of less power generation capacity due to extensive silting. Now, the power generation capacity of the dam has dropped to 64,000–20,000 kW in summers and winters, respectively.

The five parameters involved in the RUSLE model are rainfall–runoff erosivity (R), soil erodibility (K) factor, slope length and steepness (LS) factor, land cover management (C) factor, and support practice (P) factor. These factors are used to estimate the annual average soil loss rate. The maps of these factors were generated separately, and value ranges were obtained from generated maps. The high value of rainfall–runoff erosivity factor (R) indicates that the lower part of the Chitral receives more rainfall, including the areas of Shoghar, Chitral, and Kalash, as indicated in the results. The topography and high elevation of this region is the major reason for the excessive rains. The soil erodibility (K) factor ranges between 0.1 and 0.4. The soil erodibility map was generated by assigning the K-factor values to the respective soil types in the soil map. The soils, having low permeability, low antecedent moisture content, etc., are represented by the lower values of the K-factor (0.1). The slope length (LS) factor has a range of 0.2 to 6.3. The higher value represents flow accumulation and an increase of slope. Land Cover management (C) factor lies in the range of 0 and 1. Maximum land cover is indicated by assigning it the value of 1, whereas the least land cover is represented by 0. The value of the support practice (P) factor is taken as 1.0 because of the ignorance of authorities on conservation, and the deficiency of data on conservation practices. This value is also taken as 1.0 in many previous studies. The above values are used by Saleem Ullah, et al. [6] in research similar to the presented study. The annual average rate of soil loss of the study area is about 58 tons/ ha/year, and the overall annual soil loss from this region is nearly 31 million tons/year. The results and the generated map of severity classification of soil erosion determined that 43% area of Chitral region falls in the category of the very low zone, which indicates soil erosion of fewer than 5 tons/ha/year, which is contradictory to the tolerable limit of fewer than 2 tons /ha/year [45]. This clearly shows that this region needs to be addressed properly in this regard. Moreover, 5–10% of the area falls in the low-erosion zone, 21% of the area in the region lies in the moderate zone, 16% lies in high-erosion zones, whereas 8% of the total study area is occupied by the severe erosion zone. The areas with less vegetation and steep slopes are more vulnerable to high erosion. Many land use activities, such as urbanization and deforestation, significantly add to erosion, and make it extreme in areas with steep slopes [46].

Many research organizations and researchers have been adopting RUSLE as a very effective and valid method for soil loss calculation, and it has been accepted worldwide. It has been widely accepted due to its good prediction and high reliability in studies related to soil erosion [6]. However, the analysis for practical validation was not performed due to a lack of resources. The implication of many difficulties in the evaluation of erosion soil and the unavailability of required data are the reasons behind the lack of practical validation of the results [47]. The final results of the conducted study are similar to previously conducted studies in the adjacent regions at the watershed level. The results of a study conducted in the watershed of Fateh Jang showed that rate of soil loss was 17–41 tons/ha/year for slopes of about 1–10% in the area for uncultivated land, while the rate was comparatively lower (9–26 tons ha/year) for vegetative land [6]. The results of another study conducted for assessment of soil loss for plain area soils by [43] for a small hilly watershed by using RUSLE, showed that the rate of soil loss was 0.1–8 tons/ha/year. The mean soil loss rate of the watershed of the total area of 13 ha was 19.1 tons/ ha/year. About 74% of soil loss was generated by steep slopes [6]. Results of the study presented above showed that the Chitral district is at more risk to soil erosion than the Potohar region of Pakistan.

The results obtained from the study are significant in recognizing, and having, a complete understanding of risks related to the erosion of soil for the study area. Not only the risks, but also to figure out the dominant and significant factors contributing to soil erosion. The factors, such as land use, soil type, land cover, and topography of the area, and their contribution to soil erosion, can be analyzed. The management of natural resources and planning/policymaking can use the outputs of this study to minimize the degradation of land and sediment transportation in water storing structures, especially for the Warsak Dam in this region. The assessment of potential risk can be done in the regions of complex topography and high precipitation/rainfall rates. This will assist in recognizing priority areas for imposing plans and precautionary measures to resolve the conflict of erosion and other issues related to land degradation [48]. The assessment of soil erosion is very beneficial to deal with the issue of severe sedimentation in the Warsak Dam, as well as the conversion of land use patterns. Deforestation also enhances the severity of soil erosion. This assessment of quantities of losses due to erosion in the Chitral region would be valuable in building suitable and permanent structures for the harvesting of natural water that would be a source of water supply in the lean season. It can also help in the prevention of soil erosion in the study area. As the KPK (Khyber Pakhtunkhwa) government focuses on planting trees and strip cropping as conservation practices, these practices most likely prevent soil loss in this region.

5. Conclusions

The results of this investigation indicate that the Chitral district is highly prone and severely affected by soil erosion, especially the southwestern part of this district, including the areas of Asfik, Ispheru Arkari, Shoghar, Harchin, and Kalash. If rates of soil erosion continue at the same rate, it will probably cause severe land degradation. The estimated soil loss was 19 tons/ha/year and maximum soil erosion (moderate, high, and very high) was observed in the areas mentioned above. The percentage of the area under the influence of very high soil erosion (i.e., 8%) is an alarming indicator that this region needs to be addressed properly in the matter of soil erosion. If not addressed properly, it will alter the land use patterns and may affect the lives of people living in this region. The maximum sediment yield caused by soil erosion is 258 tons/ha/year. The topography and soil type of the more effected area is the major cause of their high susceptibility to soil erosion. The huge production of sediment quantities badly affects the drainage paths already located in the region. The results generated from this study include sediment yield, erosion severity classes, and erosion intensity. This information could assist the planners, and policymakers can use the results of this study to take precautionary measures according to the obtained values of soil erosion. It helps the institutes related to soil conservation to pay more attention to the areas highly prone to erosion. It is recommended to find the impact of individual contributing factors, such as land use, rainfall, vegetation on soil erosion in previous years. This technique of integration of GIS with the RUSLE model can be used in other areas of Pakistan to estimate and control soil erosion on wider scales.

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