Scientific Research Publishing

Journal of Geoscience and Environment Protection, 2025, 13(2), 215-229
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Estimation of Soil Erosion Dynamics through Rusle Model in Gilgit Baltistan, Pakistan

Nageen Tayyab*, Moazzam Ali Khan, Amir Alamgir, Tariq Masood Ali Khan, Nasir Sulman

Institute of Environmental Studies, University of Karachi, Karachi, Sindh, Pakistan
Email: *nageen5768t@gmail.com

How to cite this paper: Tayyab, N., Khan, M. A., Alamgir, A., Khan, T. M. A., & Sulman, N. (2025). Estimation of Soil Erosion Dynamics through Rusle Model in Gilgit Baltistan, Pakistan. *Journal of Geoscience and Environment Protection, 13,* 215-229.
https://doi.org/10.4236/gep.2025.132014

Received: January 22, 2025
Accepted: February 23, 2025
Published: February 26, 2025

Abstract

Soil integrity and fertility is on high risk due to water erosion, it's not only disturbed cropping practices but also damages the ecosystem of the land. In this study, the combination of GIS and RUSLE modeling are used to compute average yearly soil erosion rate in Baltistan Division of Gilgit. R, K, LS C & P Factors were computed to determine average Annual Soil Loss (ASL) which came out to be 6.68 tons/hectare/year. Higher altitudes, which are primarily covered in glaciers and watersheds, depicts maximum value of ASL when compared with lower altitude. Study area may witness a rise in soil loss due to soil texture and change in rain pattern (due to climate change). The maps developed during the study can also be referred to develop planning of land management strategy against soil erosion.

Keywords

Gilgit Baltistan, Soil Erosion, Rain Erosivity, Soil Erodibility, GIS, RUSLE

1. Introduction

One of the major risks to agricultural land and ecosystem is soil erosion, which negatively impacts the soil texture, soil chemistry, fertility of land, rate of sedimentation in river, water quality and land infrastructure (Zhou et al., 2020). This issue disturbed the food production that causes the habitat destruction of our environment (Gao, 2016). Erosion can be referred as a process in which the soil particles detach from the soil masses and are transported due to the erosive factors like wind and water as rainfall runoff (Abdul Rahaman et al., 2015).

The latest estimates regarding climate change indicates that amount of soil losses because of erosion is going to accelerate due to higher frequency of storms (Shukla et al., 2019). FAO pointed out that modernization of farming techniques and mechanization have led to an increased rate of soil erosion while on the other hand typical traditional practices have led to the sustainability of soils in regards to its fertility.

Assessing the rate of erosion in hydrological basins is somewhat difficult, therefore, numerous models have been designed for in situ estimation including physical models (Nord & Esteves, 2005), & conceptual models (Schuol et al., 2008). However, the methodology used in RUSLE is found more robust for the estimation of land degradation for land and agricultural planning. This model has also been tested in various hydrological basins and can also be used along various geographical equipment.

Soil erosion is depending upon number of factors such as rainfall patterns of the study area (Dissanayake et al., 2019), topographic state (slope, slope length and steepness), soil texture, i.e. physical and chemical states, and its rate of sedimentation (Gupta & Kumar, 2017). Cropping practices and managements procedures also play an important role in soil erosion particularly from agriculture land. Wischmeier and Smith in 1965 proposed Universal Soil Loss Equation (USLE) which was then revised into Revised Universal Soil Loss Equation (RUSLE), and Modified Universal Soil Loss (MUSLE) Equation (Boggs et al., 2001; Van et al., 2001).

At time accessibility to the site is cumbersome, therefore data obtained from satellite can be used to employ above mentioned models more conveniently for further studies (Fernandez et al., 2003, Gitas et al., 2009; Xu et al., 2008). One of most vital information obtained is Digital Elevation Model (DEM). DEM data with grid cell size of 30m can be obtained from SRTM (Kim & Julien, 2006). The RUSLE Model can provide soil erosion on cell by cell basis, (Shinde et al., 2010), which is very useful when working for a large basin. Foregoing into above, the aim of paper is to determine and analyze annual land erosion in selected area of Gilgit Baltistan, showcase maps depicting risk and intensity of soil erosion

1.1. Study Area

The map of Pakistan is located in shown in **Figure 1**. The total area of the country is 881,913 km^2. The Gilgit Baltistan province previously recognized as northern areas of Pakistan comprises of 3 divisions namely Gilgit, Baltistan and Diamer. The Diamer and Baltistan Divisions comprises of nine districts in total. Out of nine districts, three districts i.e. Dareil, Tangir and Roundu have been notified but not functional. Details of remaining six districts are in **Table 1**.

1.2. Data

Altitude, slope angle, land usage and land coverage, soil texture, rainfall, and Normalized Difference Vegetation Index (NDVI) were integrated into current study for calculation of annual average soil. These methodologies of this study involved geospatial datasets that were used for estimating and plotting maps of yearly soil erosion, with a spatial resolution of 1 km. The details of data sets are appended in **Table 2**.

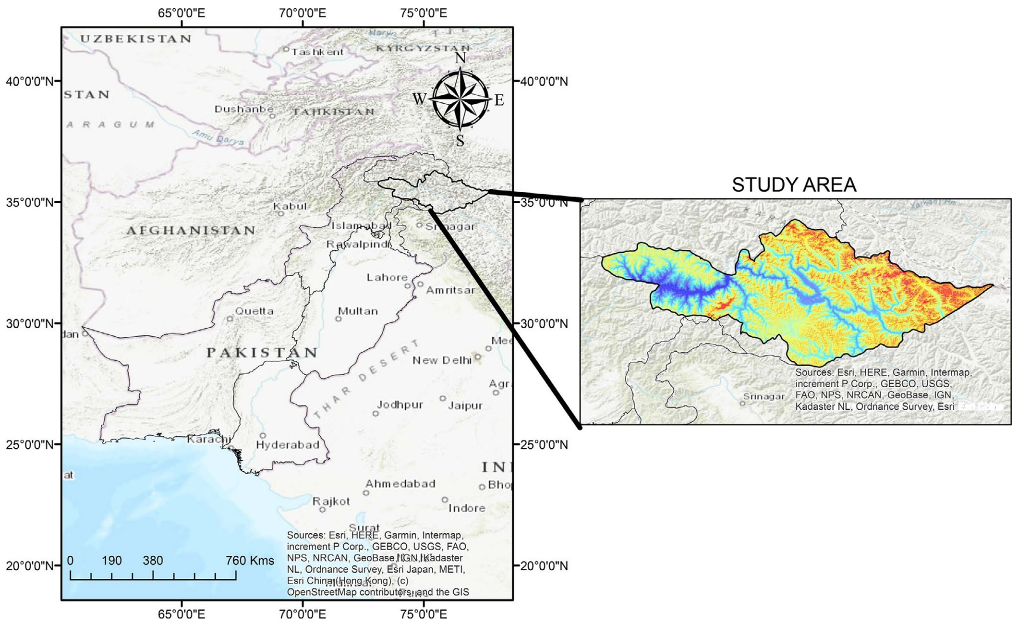

Figure 1. Study area.

Table 1. Districts of Diamer and Baltistan, Gilgit Baltistan, Pakistan.

Divisions	District	Area (km^2)	Population (in million)
Diamer and Baltistan	Diamer	7234	323,643
	Skardu	10,168	312,875
	Ghanche	8531	181,610
	Astore	5411	102,738
	Shigar	4173	84,662
	Kharmang	6144	58,303

Source: Data taken from report "Gilgit Baltistan at a Glance-2022" uploaded on official website of Planning and Development Department, Gilgit Baltistan

Table 2. Dataset & source.

Datasets	Source/Website
Annual rainfall	Pakistan Meteorological Department
Digital Soil Data	Harmonized World Soil Database Viewer version 2.0
Digital Elevation Model (DEM)	Open Topography (https://portal.opentopography.org/datasets)
Normalized Difference Vegetation Index (NDVI)	USGS (https://earthexplorer.usgs.gov/)

2. Methodology

The annual soil erosion can be assessed by computing average rainfall, R, K, LS, C and P factors and using Equation 1:

$$\text{Annual Soil Loss} = R \times K \times LS \times C \times P \quad (1)$$

Factor details in above formula are depicted in below mentioned table (Table 3):

Table 3. RUSLE factors & their units.

Factor	Description	Unit
	Annual soil loss	tons/ha/year
R	Rainfall erosivity	MJ mm/ha/h/year
K	Soil erodibility	tons/ha/h/ha/MJ mm
LS	Topographic (Slope Length and Slope Steepness)	dimensionless
C	Crop Management	dimensionless
P	Conservation Practices	dimensionless

In order to calculate Rainfall Erosivity (*R* Factor), annual average rainfall data is used which was obtained from three meteorological stations (Chilas, Astore and Skardu) situated in Gilgit working under Pakistan Metrology Department. The point data was further computed by Inverse Distance Weighted (IDW) of ArcGIS. To calculate *R*-Factor, we used Lambordi methodology, which is as follows:

$$R = 1.03 \times P \quad (2)$$

here '*R*' indicates rainfall erosivity (MJ mm/ha/h/year) & '*P*' represent annual rainfall (mm).

With regards to soil erodibility, there are various geological factors i.e. soil texture, organic matter content of soil, partical permeability, and soil size as described by Renard and Ferreira (1993). For calculating *K*-Factor, world soil data was taken from "Harmonized World Soil Database Viewer version 2.0" collaboratively created by Food and Agriculture Organization of the United Nations (FAO) and International Institute for Applied Systems Analysis (IIASA). Thereafter, *K* factor of each above mentioned soils were computed through following Equations (3) to (7) as suggested by Williams et al., (1995):

$$K_{usle} = f_{csand} \times f_{cl\text{-}si} \times f_{orgc} \times f_{hisand} \quad (3)$$

$$f_{csand} = \left(0.2 + 0.3 \times \exp\left(-0.256 \times m_s\left(1 - \frac{m_{silt}}{100}\right)\right)\right) \quad (4)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \quad (5)$$

$$f_{orgc} = \left(1 - \frac{0.25 \times orgc}{orgc + \exp(3.72 - 2.95 \times orgc)}\right) \quad (6)$$

$$f_{hisand} = \left(1 - \frac{0.7 \times \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left(-5.51 + 22.9 \times \left(1 - \frac{m_s}{100}\right)\right)}\right) \quad (7)$$

In this framework,

K_{usle} indicates the amount of erodibility,

m_s indicates the percentage of sand,

m_{silt} indicates the percentage of silt,

m_c indicates the percentage of clay,

f_{orgc} is a factor that declines the K values with high organic carbon content in soil,

$orgc$ indicates the organic carbon content,

f_{csand} is a factor that decreases the K indicator with high coarse-sand content and proliferations it for soils with little sand, in soils,

$f_{cl\text{-}si}$ gives little soil erodibility factors with high clay-to-silt ratios, and,

f_{hisand} declines the K value for soils with tremendously high sand content.

The topographic factor (LS Factor) comprises of two factors slope length and steepness. These factors are calculated individually first DEM data which was taken from Open Topography (https://portal.opentopography.org/datasets). DEM is then utilized to calculate flow accumulation. The data is then inserted in Raster Calculation function of ArcGIS using Equation (8) as recommended by Moore and Burch (1986) to calculate LS Factor.

$$LS = \left(\frac{\text{Flow accumulation} \times \text{Cell size}}{22.13}\right)^{0.4} \times \left(\frac{\text{Sin Slope} \varnothing \times 0.01745}{0.0896}\right)^{1.3} \tag{8}$$

For crop management factor (C Factor), NDVI is used (Ahmad et al., 1988). NDVI shows a relationship among parts having specific type of vegetation and those which are barren. NDVI data is taken through Landsat-8 data which was taken from USGS website (https://earthexplorer.usgs.gov/). Bands 4 and 5 of LANDSAT 8 data are then used to calculate NDVI and consequent C Factor through Equations (9) and (10) (Durigon et al., 2014).

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} \tag{9}$$

$$C \text{ factor} = \frac{-\text{NDVI} + 1}{2} \tag{10}$$

The last factor i.e. Conservation practice Factor (P Factor) is calculated based on types of cropping technique dominant in the study area (Wischmeier & Smith, 1978; Renard et al., 1993).

3. Results and Discussion

The analysis of the data of the present study depicts the risk of erosion due to climatic conditions, topographic conditions & land cover system, using the methodology designed by Renard (1997). For the valuation of data, data analysis, and computation of RUSLE model, all the data sets obtained for R, K, LS, C and P Factors were assimilated in the raster calculator of the ArcGIS spatial analyst.

3.1. Rainfall Erosivity Factor (R)

The mean annual rainfall in study region is between 698 - 1331 mm per year as shown in **Figure 2.** This data was taken from Pakistan Meteorological Department stations (Chilas, Astore and Skardu) situated in the study area. This data was then inserted in the Lambordi equation (Equation (2)) (Isikwue et al., 2015) in the raster calculator and *R* Factor map (**Figure 3**) was generated that shows wide variation in the study region ranging from 1371.96 MJ mm/ha/h/year – 718.949 MJ mm/ha/h/year. The central and eastern region exhibit highest values whereas the western region shows the lowest value of *R* Factor.

Related study area conducted by Ganasri et al. (2016) in Nethravathi Basin, projected rainfall erosivity factor from 2948.16 to 4711.4 expressed as MJ mm/ha/h/year. Another paper by Sidi Almouctar et al. (2021) in Niger (Maradi Region) stated that the average rainfall-erosivity value was 822.3 MJ mm/ha/h/year. Khan et al. (2023) reported the values of *R* ranging from 456 to 695 MJ mm/ha/h/year in District Swat of Khyber Pakhtunkhwa province of Pakistan.

It has been observed that soil erosion rate is highly controlled by precipitation cycle received in the study area, meaning that area having higher precipitation cycle will have higher soil erosion and vice versa (Jain et al., 2001; Dabral et al., 2008). Therefore, it can be seen that areas mentioned in **Table 4** and study area i.e. Baltistan Division, Pakistan have relatively high *R* factor. Lower *R* factor value in Maradi Region i.e. 0.011 is due to the fact that Northern part of the area is dry and has lower annual average rainfall compared to south Maradi Region. Variation in R factor values in different parts of the world has linkages with inconsistent soil erosion rate observed across the globe.

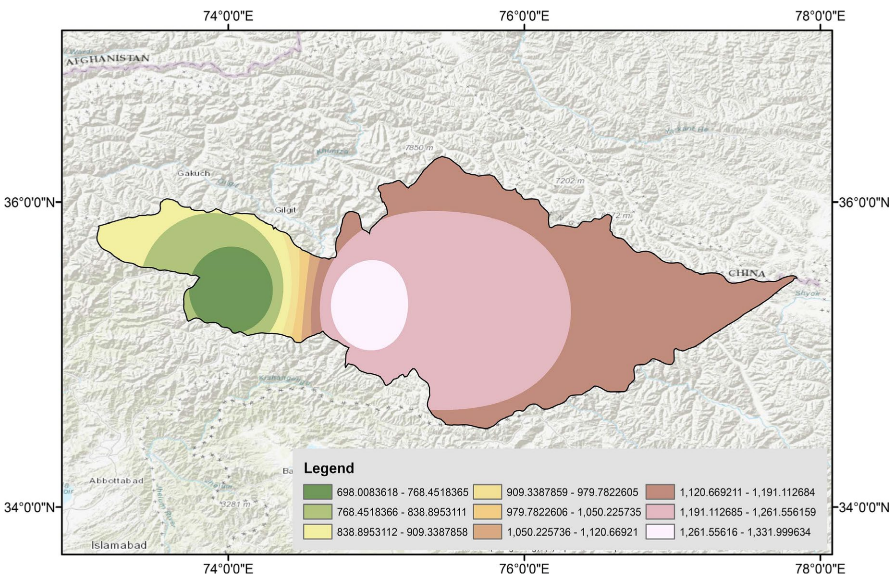

Figure 2. Mean annual rainfall.

3.2. Soil Erodibility Factor (*K*)

Data from world soil data base was inserted in ArcGIS and study area was clipped, wherein following three types of soils along with thick sheets of Glaciers were

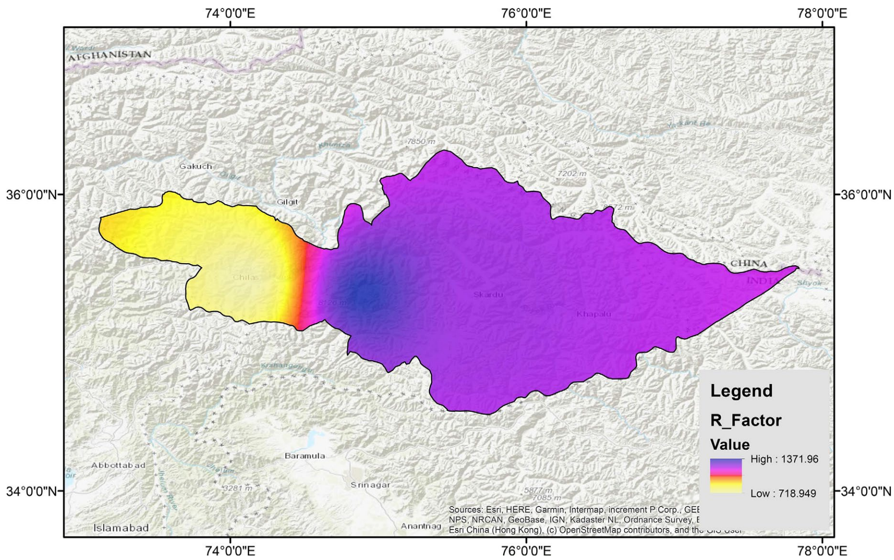

Figure 3. *R* factor.

found: Orthic Acrisols, Lithosols, Eutric Cambisols. f_{orgc}, f_{csand}, $f_{cl\text{-}si}$ and f_{hisand} of each soil type was calculated through the Equations (4) to (7) and *K* Factor then calculated from Equation (3). Accordingly, *K* Factor was then inserted in ArcGIS and relevant map was generated which is at **Figure 4**. Details of the soil are also given in **Table 4**.

Table 4. Soil erodibility (*K*).

Soil	sand % topsoil	silt % topsoil	clay % topsoil	OC % topsoil	f_{csand}	$f_{cl\text{-}si}$	f_{orgc}	f_{hisand}	*K* Factor
Lithosols	58.9	16.2	24.9	0.97	0.2	0.756	0.9272	0.994	0.1394
Orthic Acrisols	53.6	15.8	30.6	2.25	0.2	0.723	0.7559	0.998	0.1092
Glacier	-	-	-	-	-	-	-	-	1
Eutric Cambisols	36.4	37.2	26.4	1.07	0.2	0.8513	0.9054	0.999	0.1555

This corroborates the findings of Waseem et al. (2023) who have calculated the rate of erosion of the soil in the Jhelum River watershed (Azad Jammu and Kashmir, AJ&K, Pakistan). They suggested that heavy rainfall and steep slopes together results in significant erosion runoff. Ganasri et al. (2016) also reported that if the steepness increases the erosion also increases. *K* values ranging from 0.131 to 0.156 in Jhelum area of Pakistan.

3.3. Topographic Factor (*LS*)

LS Factor can be determined by slope length and its steepness. These factors directly impact the rate of erosion of the soil. If the steepness increases the erosion also increases (Ganasri & Ramesh, 2016). For *LS*, we first used Digital Elevation Model (DEM) data to determine slope length and then steepness was calculated. Topographic Factor was then calculated by inserting both these factors in

Equation 8(Moore & Burch, 1986). The values lf *LS* factor computed were in the range of 0 to 176.998 (**Figure 5**).

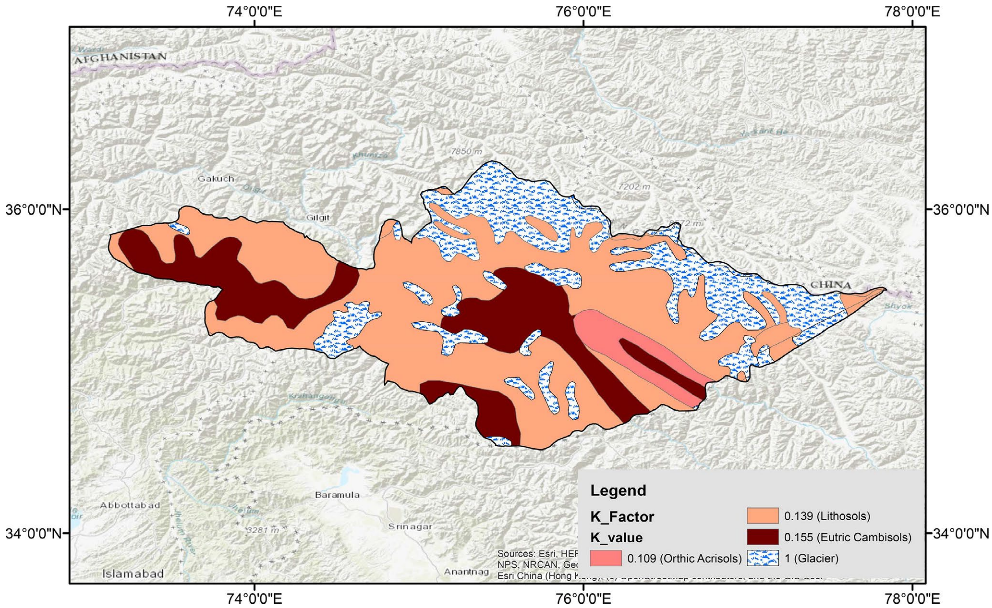

Figure 4. *K* factor.

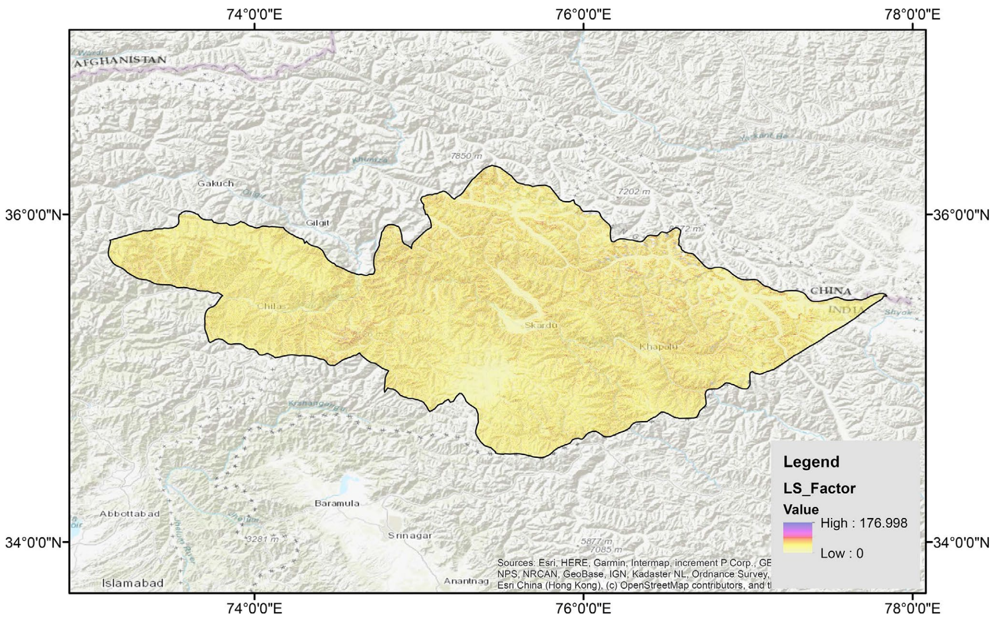

Figure 5. LS factor.

Ganasri et al. (2016) reported LS values ranged from 0 - 1240 in the Nethravathi Basin which is quite higher than the present values. Similarly, during estimation of soil erosion risk in Kerala, India Prasannakumar et al. (2012) reported LS Factor values ranged from 0 - 22.90 which is much lower than the present value. In the present study high LS Value (47.199 - 176.997) were observed in higher altitude mostly covered with glaciers. These areas experienced high rate of soil erosion by water due to abrupt slope gradient and high precipitation rate (Ansari & Tayfur, 2023). Lower LS values were found in areas around water bodies.

3.4. Crop Management Factor (*C*)

In order to calculate NDVI, LANDSAT 8 data of area was acquired from (https://earthexplorer.usgs.gov/). Data was then inserted in ARCGIS and NDVI was calculated by using Equation (9). NDVI values ranged from 1.0 to 0.414068 (**Figure 6**). *C* Factor was calculated through Equation (10), where values ranging from 0.0 - 0.707034 were obtained (**Figure 7**).

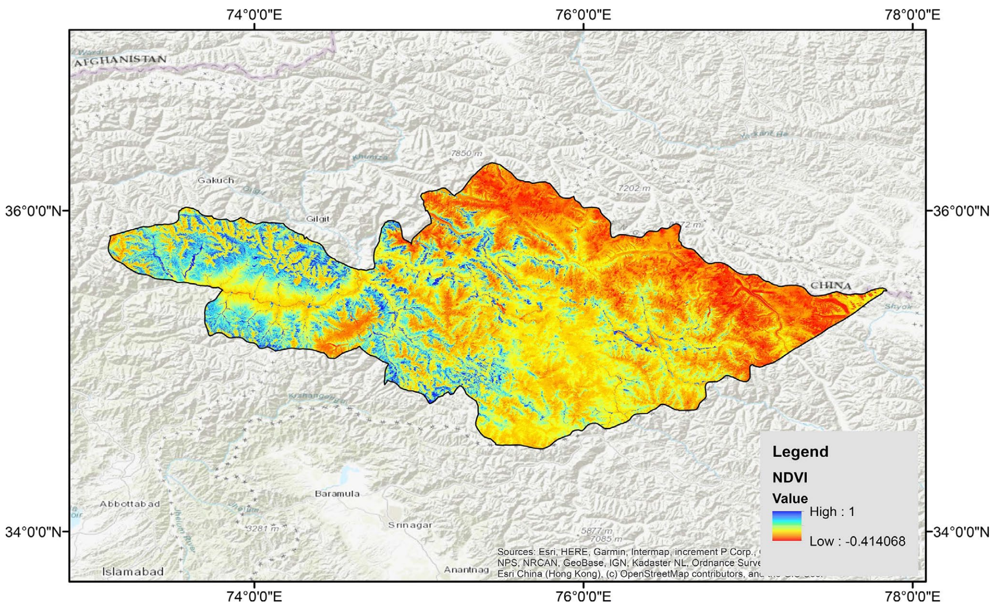

Figure 6. NDVI.

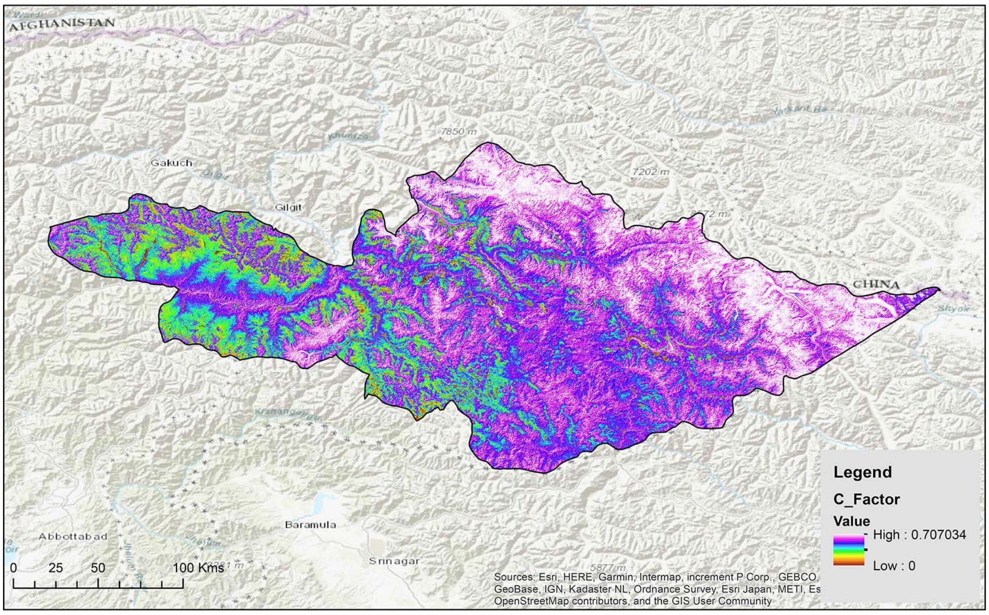

Figure 7. *C* factor.

Belasri and Lakhouili (2016) reported *C*-Factor ranged from 0.0 to 1.0 in Morocco, Prasannakumar et al. (2012) suggested *C* factor ranged from 0.3 to 1.5 in Kerala, India. The values of *C* in the present study was little higher as compared to other studies.

High value of *C* factor has been observed on the northern part of study area which is on high altitude and mostly covered with glaciers (Waseem et al., 2023). Furthermore, due to high altitude and land steepness, crop management and agricultural practice is difficult in said area. According to different reports variable C-Factors were reported. The studies mentioned above depicted that high values have been observed in areas having high altitude and water bodies.

3.5. Conservation Practice Factor (*P*)

Table 5 was taken as reference in order to calculate *P* Factor. Values normally obtained varies from zero to one, where zero represents area where low soil erosion rate will be observed and one denotes area having high rate of soil erosion rate. *P* factor also depends upon type of cropping practice being followed in the study area. Using slope data calculated earlier during LS, *P*-factor ranging from 0.10 to 0.20 was obtained (**Figure 8**). High *P* factor shows that area needs good cropping practices in order to reduce the risk of soil erosion (Joshi et al., 2023).

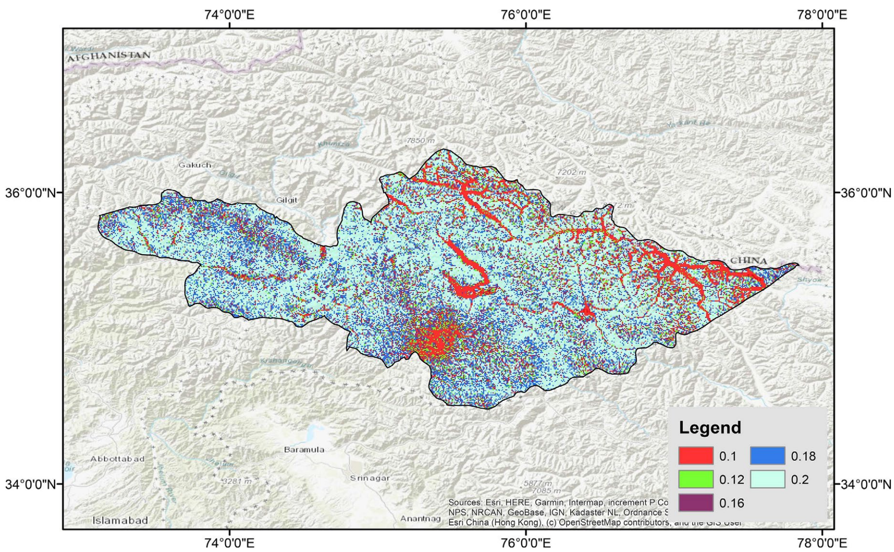

Figure 8. *P* factor.

Table 5. Conservation factor (*P*).

Slope	Contouring	Stripping	Terracing
0.0 - 7.00	0.55	0.27	0.10
7.00 - 11.3	0.60	0.30	0.12
11.3 - 17.6	0.80	0.40	0.16
17.6 - 26.8	0.90	0.45	0.18
>26.8	1.00	0.50	0.20

Source: Korean Institute of Construction Technology, 1992.

Research papers similar to same region has also observed various that is 0.1 to 1 in Minab, Iran (Azimi Sardari et al., 2019) and 0.55 to 1 in Nepal (Joshi et al., 2023).

3.6. Annual Soil Loss

After obtaining all the factors, annual soil erosion was calculated on ARCGIS using RUSLE Model equation and annual average value of 6.68279 tons/hectare/year was obtained. Classification Statistics is shown in **Table 6**.

Table 6. Annual soil loss classification statistics.

Classification Statistics	
Min	0
Max	634.8497
Mean	6.68279
Standard Deviation	15.823

The ASL values was classified (**Table 7**) depending on erosion intensity (low to high) and map was generated which is at **Figure 9**.

Table 7. Level of soil erosion and its corresponding ranges.

Level of soil erosion	Tons/hectare/year
Very low	<5
Low	5.1 - 25
Moderate	25.1 - 50
High	50.1 - 75
Very High	>75

Milentijević et al. (2021) reported ASL in Bačka ranges situated in Serbia from 0.0 - 28.6 tons/hectare/year, with an average value of 0.007022 tons/hectare/year. Further, ASL from 0.0 - 38.09 tons/hectare/year and average annual soil loss rate of 2.2 tons/hectare/year was observed in Dijo watershed area, Ethiopia (Bekele & Gemi, 2021).

4. Conclusion

The study depicts the risk of soil loss in the Baltistan division of the Gilgit-Baltistan province of Pakistan. The results indicate that the precipitation pattern, slope and steepness of the land are the main contributor of erosion. The intensity of the erosion will increase with the passage of time **due to unexpected disturbance in rainfall and long summer**. Increase in rate of rainfall cycle can directly increase the loss of top soil from the high slope length area. Whilst, long summer will cause risk of glacier melting which will in return increase the area of

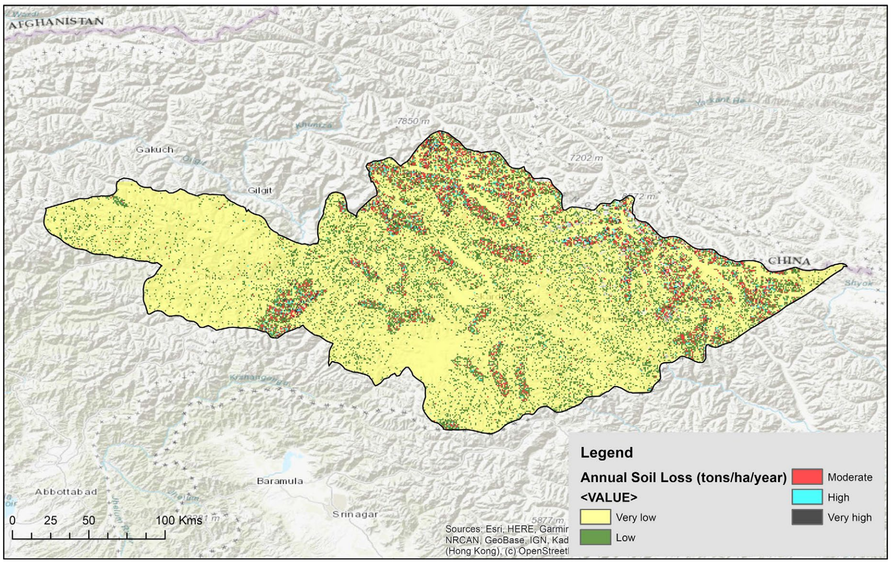

Figure 9. Annual soil loss of study area.

barren land to be eroded. Further, frozen soil under the glacier also prone to erosion when thaw will increase soil loss. It is pertinent to mention here that RUSLE is a theoretical calculation undertaken using data from GIS, World Soil Database etc., therefore cross-verification through field measurements is recommended for further research. Till that time, maps generated during the course of this study can be used as a reference by the federal and provincial agencies during town planning to ensure that construction of infrastructures are not carried out in the vicinity of area which lies in moderate to very high levels of soil erosion.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Abdul Rahaman, S., Aruchamy, S., Jegankumar, R., & Abdul Ajeez, S. (2015). Estimation of Annual Average Soil Loss, Based on RUSLE Model in Kallar Watershed, Bhavani Basin, Tamil Nadu, India. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2,* 207-214. https://doi.org/10.5194/isprsannals-ii-2-w2-207-2015

Ansari, A., & Tayfur, G. (2023). Comparative Analysis of Estimation of Slope-Length Gradient (LS) Factor for Entire Afghanistan. *Geomatics, Natural Hazards and Risk, 14,* Article ID: 2200890. https://doi.org/10.1080/19475705.2023.2200890

Azimi Sardari, M. R., Bazrafshan, O., Panagopoulos, T., & Sardooi, E. R. (2019). Modeling the Impact of Climate Change and Land Use Change Scenarios on Soil Erosion at the Minab Dam Watershed. *Sustainability, 11,* Article 3353. https://doi.org/10.3390/su11123353

Bekele, B., & Gemi, Y. (2021). Soil Erosion Risk and Sediment Yield Assessment with Universal Soil Loss Equation and GIS: In Dijo Watershed, Rift Valley Basin of Ethiopia. *Modeling Earth Systems and Environment, 7,* 273-291. https://doi.org/10.1007/s40808-020-01017-z

Belasri, A., & Lakhouili, A. (2016). Estimation of Soil Erosion Risk Using the Universal Soil Loss Equation (USLE) and Geo-Information Technology in Oued El Makhazine Watershed, Morocco. *Journal of Geographic Information System, 8,* 98-107. https://doi.org/10.4236/jgis.2016.81010

Boggs, G., Devonport, C., Evans, K., & Puig, P. (2001). GIS-Based Rapid Assessment of Erosion Risk in a Small Catchment in the Wet/Dry Tropics of Australia. *Land Degradation & Development, 12,* 417-434. https://doi.org/10.1002/ldr.457

Dabral, P. P., Baithuri, N., & Pandey, A. (2008). Soil Erosion Assessment in a Hilly Catchment of North Eastern India Using USLE, GIS and Remote Sensing. *Water Resources Management, 22,* 1783-1798. https://doi.org/10.1007/s11269-008-9253-9

Dissanayake, D., Morimoto, T., & Ranagalage, M. (2019). Accessing the Soil Erosion Rate Based on RUSLE Model for Sustainable Land Use Management: A Case Study of the Kotmale Watershed, Sri Lanka. *Modeling Earth Systems and Environment, 5,* 291-306. https://doi.org/10.1007/s40808-018-0534-x

Durigon, V. L., Carvalho, D. F., Antunes, M. A. H., Oliveira, P. T. S., & Fernandes, M. M. (2014). NDVI Time Series for Monitoring RUSLE Cover Management Factor in a Tropical Watershed. *International Journal of Remote Sensing, 35,* 441-453. https://doi.org/10.1080/01431161.2013.871081

Fernandez, C., Wu, J. Q., McCool, D. Q., & Stockle, C. O. (2003). Estimating Water Erosion and Sediment Yield with GIS, RUSLE and SEDD. *Journal of Soil and Water Conservation, 58,* 128-136.

Ganasri, B. P., & Ramesh, H. (2016). Assessment of Soil Erosion by RUSLE Model Using Remote Sensing and GIS—A Case Study of Nethravathi Basin. *Geoscience Frontiers, 7,* 953-961. https://doi.org/10.1016/j.gsf.2015.10.007

Gao, J. (2016). Wetland and Its Degradation in the Yellow River Source Zone. In G. J. Brierley, *et al.* (Eds.), *Landscape and Ecosystem Diversity, Dynamics and Management in the Yellow River Source Zone* (pp. 209-232). Springer International Publishing. https://doi.org/10.1007/978-3-319-30475-5_10

Gitas, I. Z., Douros, K., Minakou, C., Silleos, G. N., & Karydas, C. G. (2009). Multi-Temporal Soil Erosion Risk Assessment in N. Chalkidiki Using a Modified USLE Raster Model. *EARSeL eProceedings, 8,* 40-52. http://www.eproceedings.org/static/vol08_1/08_1_gitas1.pdf

Gupta, S., & Kumar, S. (2017). Simulating Climate Change Impact on Soil Erosion Using RUSLE Model—A Case Study in a Watershed of Mid-Himalayan Landscape. *Journal of Earth System Science, 126,* Article No. 43. https://doi.org/10.1007/s12040-017-0823-1

Isikwue, M., Ocheme, J., & Aho, M. (2015). Evaluation of Rainfall Erosivity Index for Abuja, Nigeria Using Lombardi Method. *Nigerian Journal of Technology, 34,* Article No. 56. https://doi.org/10.4314/njt.v34i1.7

Jain, S. K., Kumar, S., & Varghese, J. (2001). Estimation of Soil Erosion for a Himalayan Watershed Using GIS Technique. *Water Resources Management, 15,* 41-54. https://doi.org/10.1023/a:1012246029263

Joshi, P., Adhikari, R., Bhandari, R., Shrestha, B., Shrestha, N., Chhetri, S. et al. (2023). Himalayan Watersheds in Nepal Record High Soil Erosion Rates Estimated Using the RUSLE Model and Experimental Erosion Plots. *Heliyon, 9,* e15800. https://doi.org/10.1016/j.heliyon.2023.e15800

Khan, A., Rahman, A., & Mahmood, S. (2023). Spatial Estimation of Soil Erosion Risk Using RUSLE Model in District Swat, Eastern Hindu Kush, Pakistan. *Journal of Water and Climate Change, 14,* 1881-1899. https://doi.org/10.2166/wcc.2023.495

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

Milentijević, N., Ostojić, M., Fekete, R., Kalkan, K., Ristić, D., Bačević, N. et al. (2021). Assessment of Soil Erosion Rates Using Revised Universal Soil Loss Equation (RUSLE) and GIS in Bačka (Serbia). *Polish Journal of Environmental Studies, 30,* 5175-5184. https://doi.org/10.15244/pjoes/135617

Moore, I. D., & Burch, G. J. (1986). Physical Basis of the Length-Slope Factor in the Universal Soil Loss Equation. *Soil Science Society of America Journal, 50,* 1294-1298. https://doi.org/10.2136/sssaj1986.03615995005000050042x

Nord, G., & Esteves, M. (2005). PSEM_2D: A Physically Based Model of Erosion Processes at the Plot Scale. *Water Resources Research, 41,* W08407. https://doi.org/10.1029/2004wr003690

Prasannakumar, V., Vijith, H., Abinod, S., & Geetha, N. (2012). Estimation of Soil Erosion Risk within a Small Mountainous Sub-Watershed in Kerala, India, Using Revised Universal Soil Loss Equation (RUSLE) and Geo-Information Technology. *Geoscience Frontiers, 3,* 209-215. https://doi.org/10.1016/j.gsf.2011.11.003

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.

Renard, K. G., & Ferreira, V. A. (1993). RUSLE Model Description and Database Sensitivity. *Journal of Environmental Quality, 22,* 458-466. https://doi.org/10.2134/jeq1993.00472425002200030009x

Renard, K. G., Lane, L. J., Simanton, J. R., Emmerich, W. E., Stone, J. J., Weltz, M. A., & Yakowitz, D. S. (1993). Agricultural Impacts in an Arid Environment: Walnut Gulch Studies. *Hydrological Science and Technology, 9,* 145-190.

Schuol, J., Abbaspour, K. C., Srinivasan, R., & Yang, H. (2008). Estimation of Freshwater Availability in the West African Sub-Continent Using the SWAT Hydrologic Model. *Journal of Hydrology, 352,* 30-49. https://doi.org/10.1016/j.jhydrol.2007.12.025

Shinde, V., Tiwari, K. N., & Singh, M. (2010). Prioritization of Micro Watersheds on the Basis of Soil Erosion Hazard Using Remote Sensing and Geographic Information System. *International Journal of Water Resources and Environmental Engineering, 2,* 130-136.

Shukla, P. R., Skeg, J., Buendia, E. C., Masson-Delmotte, V., Pörtner, H. O., Roberts, D. C., Zhai, P., Slade, R., Connors, S., Van Diemen, S., Ferrat, M., Haughey, E., Luz, S., Pathak, M., Petzold, J., Pereira, J. P., Vyas, P., Huntley, E., Kissick, K., & Malley, J. (2019). *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. https://philpapers.org/rec/SHUCCA-2

Sidi Almouctar, M. A., Wu, Y., Zhao, F., & Dossou, J. F. (2021). Soil Erosion Assessment Using the RUSLE Model and Geospatial Techniques (Remote Sensing and GIS) in South-Central Niger (Maradi Region). *Water, 13,* Article No. 3511. https://doi.org/10.3390/w13243511

Van Remortel, R. D., Hamilton, M. E., & Hickey, R. J. (2001). Estimating the LS Factor for RUSLE through Iterative Slope Length Processing of Digital Elevation Data within Arclnfo Grid. *Cartography, 30,* 27-35. https://doi.org/10.1080/00690805.2001.9714133

Waseem, M., Iqbal, F., Humayun, M., Umais Latif, M., Javed, T., & Kebede Leta, M. (2023). Spatial Assessment of Soil Erosion Risk Using RUSLE Embedded in GIS Environment: A Case Study of Jhelum River Watershed. *Applied Sciences, 13,* Article No. 3775.

https://doi.org/10.3390/app13063775

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.

Xu, Y.-Q., Peng, J., & Shao, X.-M. (2008). Retracted Article: Assessment of Soil Erosion Using RUSLE and GIS: A Case Study of the Maotiao River Watershed, Guizhou Province, China. *Environmental Geology, 56,* 1643-1652. https://doi.org/10.1007/s00254-008-1261-9

Zhou, P., Ge, Y., Jiang, Y., Xie, Y., Si, Z., Yang, H., Huo, H.-Y., Yu, J., & Wei, G. (2020). *Assessment of Soil Erosion by the RUSLE Model Using Remote Sensing and GIS: A Case Study of Jilin Province of China*. https://doi.org/10.20944/preprints202011.0435.v1