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SOIL EROSION MODELLING THROUGH COHESIVE USE OF RUSLE AND GIS IN RAMGANGA RIVER BASIN, INDIA

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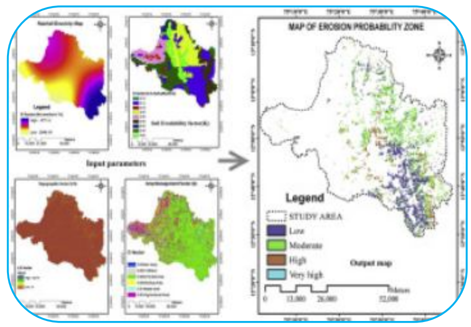
ABSTRACT:

Soil erosion is a major concern of land degradation that impedes adequate agricultural production, soil quality, soil compaction, water quality, environments, and hydrological systems, and has long been recognised as a major issue for human sustainability. This study is evaluated in the context of the Ramganga river basin, which has an astounding soil erosion rate that impedes annual crop production and the area's hydrological functioning. Based on the Revised Universal Soil Loss Equation (RUSLE) and GIS, this paper investigates the amount of soil erosion rate and depicts the erosion over the Ramganga river basin. The piedmont region and lower portion of the basin (152.41 -ton ha^{-1} year^{-1}) has been identified as a hotspot of soil erosion probability and erosion rate due to deep alluvial loamy soil and cultivated area. This study provides a detailed identification of the large magnitude of soil erosion as well as suggestions for long-term soil conservation and protection.



KEY WORDS: *Soil Erosion, Revised Universal Soil Loss Equation (RUSLE), Remote Sensing, GIS, Sediment Delivery Ratio (SDR), Ramganga River Basin.*

1.INTRODUCTION:

Soil erosion is the process of separating soil particles from the earth's surface and transporting them via erosive agents such as floating water and wind or forces linked to human disturbance (Morgan, 2005). Soil erosion causes the decay of high organic matter and nutrients, insufficient food supply, the decay of edaphic properties, fertility, and soil life, increased surface runoff, and accelerated deposition (Clark, 1985; Crosson 1997; Lal, 1998; Verstraeten and Poesen, 1999; Lal, 2001; Stocking, 2003; Haregeweyn et al., 2006; Boardman and Poesen, 2006; Pimentel, 2006; Demirci and Karaburun, 2012; Imamoglu and Dengiz, 2016). Soil erosion studies are relevant in the appropriate strategies of soil and water conservation, as well as the prevention of surface water pollution from contaminated soil (Onori et al., 2006). Soil erosion affects approximately 56 percent of the terrestrial surface globally (Gabriels and Cornelis, 2009), which implies each year soil erosion succeeds 0.90-0.95 mm of soil (FAO, 2015), and approximately 20 Mha year^{-1} crop productivity is reduced and becomes uneconomic due to soil erosion and degradation (UNEP, 1991).

Soil erosion is more common in mountainous areas, and it is increasingly recognised as a threat to ecosystem and land degradation assessment strategies for sustainable farming and economic development (Millward and Mersey, 1999; Dabral et al., 2008; Sharma, 2010; Prasannakumar et al., 2012). Multiple drivers, such as soil physiognomies, rainfall regimes, hydrographic systems, land use and land cover, land - use practices, and topographic slope gradient, increase the possibility of potentially slack changes in the spatiotemporal pattern of soil loss within the catchment (Morgan, 2005). Humans are responsible for significant causes such as irresponsible agriculture, deforestation, overgrazing, and construction activities. Furthermore, pulverised sediment reduces infiltration and increases turbidity, lowering sunlight penetration and water temperature, and causative drivers, such as various types of contaminants immersed in fine particles degrading water quality, become affected (Toy et al., 2002). Because of its ability to wipe out and expose vast portions of the messy terrain in a relatively short period of time, mass movement will have a greater impact on soil erosion (Van Beek, 2002; Bosco and Sander, 2014).

The river basin is experiencing severe land degradation as a magnitude of the complex landscape, soil, and climate regime, and the recent deforestation activities, thus, resulting in accelerated soil erosion and a prolonged and massive impact on the environment. Soil productivity declines as a result of soil erosion, resulting in insufficient crop production to meet the world's growing population. The identification and assessment of erosion-prone areas improves soil conservation and river ecosystem management. As a result, using the Revised Universal Soil Loss Equation (RUSLE) in conjunction with GIS and remote sensing, this study estimates the likely amount of soil erosion rate and depicts soil erosion and sediment delivery pattern over Ramganga River basin for soil conservation planning for their venerability.

2. THE STUDY AREA

The Ramganga river is the left tributary of the Ganges river system, with a geographical extent of 27°10'23.65"N to 30°6'9.73"N and 78°12'56.98"E to 79°51'11.55"E and an area of approximately 22691.22 km^2 spread across the Indian states of Uttarakhand and Uttar Pradesh. The basin's altitudinal variations range from 120 to 3,098 metres above mean sea level (Fig.1). The northern subsurface is mostly composed of metamorphic rock with limestone bands interspersed. Alluvium in the form of fluvial, sand, and silt deposits is found in the central and lower portions. Throughout the catchment, sandy loams, sandy clay loams (coarse to fine texture), loamy fragmental, reddish clay, silty loams, sandy, clayey soils, rocky, and stratified soils can be found. The climate of the basin is variable, with summer temperatures in the foothills and freezing temperatures in the high mountains. It has been classified as tropical, temperate, and alpine, with a widespread monsoon regime of the Great alluvial plains. The annual precipitation ranges from 429 to 2322 mm on average. Summer and post-monsoon seasons are mild with little rain, whereas monsoon seasons are extremely wet. The average annual temperature in the region is ~ 23°C, with highs of ~ 45°C in the summer and lows of ~ -3°C in the winter.

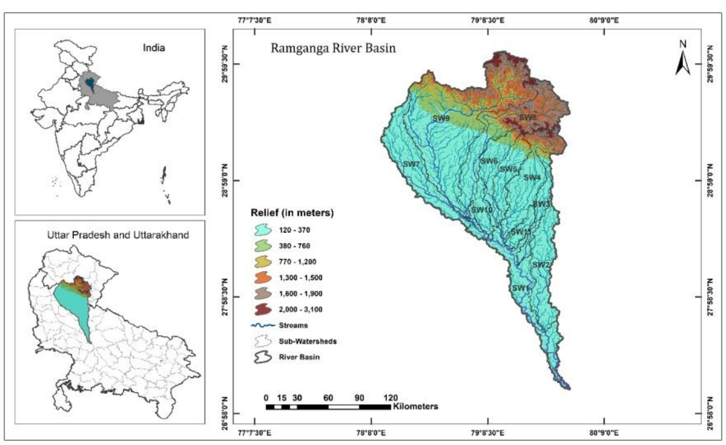


Fig. 1. Location map of the study area, exhibiting the Digital Elevation Model with 30-meter spatial resolution and stream network.

3. MATERIALS AND METHODS

Soil loss prediction in a hydrologic outlet or field can be estimated using different models on various platforms, which is critical for soil management practises. The RUSLE model was used in this study to analyse soil erosion in the Ramganga river basin. Land use/land cover, slope length/steepness, rainfall pattern, edaphic characteristics, and management practises are significant contributing factors for simulating soil erosion, which are then integrated with the RUSLE model. The RUSLE model is widely used due to its simplicity and data availability of various factors (Williams and Berndt, 1972; Wischmeier and Smith, 1978; Desmet and Govers, 1996; Jain and Kothyari, 2000; Bonilla et al., 2010; Jiang et al., 2015). Despite the fact that RUSLE is an empirical model that not only presents spatial heterogeneity of soil erosion instigated by surface runoff using necessary covariates specifying basin physical characteristics, it also predicts erosion rates at a reasonable cost, time, and accuracy (Balasubramani et al., 2015).

3.1 Generation of various factors of RUSLE model

The RUSLE model needs several factors in assessing soil erosion. The equation of RUSLE method (1) is given as follows (Renard et al., 1997):

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

Where, A is the annual average soil loss per unit area (tons/ha^{-1}),
R is rainfall-runoff erosivity factor (MJ mm ha^{-1} hr^{-1}),
K is soil erodibility factor (ton ha hr MJ^{-1} mm^{-1}),
L is slope length factor, S is slope steepness factor (dimensionless),
C is cover and management factor (dimensionless),
P is support and conservation practices factor (dimensionless) (Fig. 2).
These factors have been generated using several equations and assigning weight.

3.1.1 Rainfall erosivity factor (R)

The rainfall erosivity factor (R) denotes the proclivity of rainfall and runoff to detach and transport soil, as determined by rainfall intensity in millimetres per hour (maximum 30 minutes) and sporadic rainfall kinetic energy (Wischmeier and Smith, 1978; Wu et al., 2013). The rainfall erosivity, which is closely related to the intensity of rainfall or the force to erode soil, is a critical factor in understanding the geomorphological and hydrological processes at work in a given area (Thomas et al., 2018). Rainfall data for 30 years (1988-2018) was obtained from the India Meteorological Department, with eight rainfall stations. R-factor has been generated applying the equation developed by Wischmeier and Smith, (1978) and later this equation is further modified by Arnoldus et al., (1980). This equation is also used by Prasannakumar et al., (2012), Magesh and Chandrasekhar, (2016) and Mondal et al., (2016). The Eq. is as follows:

$$\boldsymbol{R} = \sum_{i=1}^{12} \mathbf{1.735} \times \mathbf{10}^{\left(\mathbf{1.5} \boldsymbol{log_{10}}\left(\frac{P_i^2}{\mathrm{P}}\right) - \mathbf{0.08188}\right)} \tag{2}$$

where R is the rainfall erosivity factor (MJ mm ha^{-1}h^{-1}year^{-1}, P_i is the monthly rainfall (mm), and P is the annual rainfall (mm).

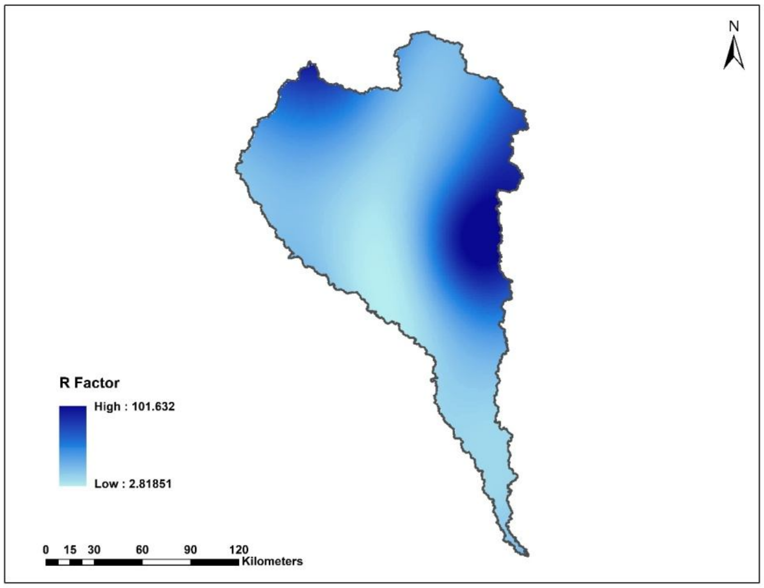


Fig. 2. Rainfall erosivity (R) factor map of the Ramganga river basin

3.1.2 Soil erodibility factor (K)

The K factor is the amount of soil loss per unit of rainfall erosivity from a specific surface soil at a slope of 9% and a length of 22 m. (Renard et al., 1997; Brady & Weil, 2012). Soil texture, organic matter content, aggregate stability, shear strength, permeability, and the nature of clay minerals are all intrinsic physiochemical properties that influence soil erodibility (Moges and Bhat, 2017). The basin's soil categories were vectorized using a soil map obtained from the National Bureau of Soil Survey and Land Utilization Planning (NBSS & LUP). Following that, the percentages of clay, silt, sand, and organic matter were used to calculate the K factor for various soil categories using Eqs. 3-7 (Wiliams, 1995) (Fig. 3). The derived values of K factors were multiplied by 0.1317 to contended with the International System of Units (table 1).

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

where f_{csand} (Equation-4) is a factor which provides low soil erodibility factors for soils with high coarse sand contents and high values for soils with little sand, f_{cl-si} (Equation-5) is a factor that gives low soil erodibility factors for soils with high clay-to-silt ratios, f_{orgc} (Equation-6) is a factor that decreases soil erodibility for soils with high organic matters content, and f_{hisand} (Equation-7) is a factor that decreases soil erodibility for soils with colossally high sand content.

$$\boldsymbol{f_{csand} = \left(0.2 + 0.3 \times exp^{-0.256 \times ms(1 - msilt/100)}\right)} \quad \textbf{(4)}$$

$$\boldsymbol{f_{cl-si} = \left(\frac{msilt}{mc+msilt}\right)^{0.3}} \quad \textbf{(5)}$$

$$\boldsymbol{f_{orgc} = (1 - 0.25 \times orgc + exp^{3.72 - 2.95 \times orgc})} \quad \textbf{(6)}$$

$$\boldsymbol{f_{hisand} = \left(1 - \frac{0.7 \times \frac{1-ms}{100}}{\frac{1-ms}{100}} + exp^{-5.51 + 22.9 \times (1 - ms/100)}\right)} \quad \textbf{(7)}$$

Where K_{usle} is the erodibility factor, *ms* is the % sand, *msilt* is the % silt, *mc* is the % clay, and *orgc* is the % organic matter, calculated as follows:

Table 1. Soil erodibility factor (K) values for various soil types

Soil Types	Area (in km^2)	K factor
Dystric Cambisols (Bd29-3c)	5001.70	0.006165
Eutric Cambisols (Be72-2c)	2101.39	0.013694
Eutric Regosols (Re53-2b)	861.32	0.082591
Dystric Regosols (Rd30-2b)	3780.61	0.630876
Orthic Luvisols (Lo35-2a)	369.79	0.195476
Eutric Cambisols (Be74-2a)	10576.38	0.042703

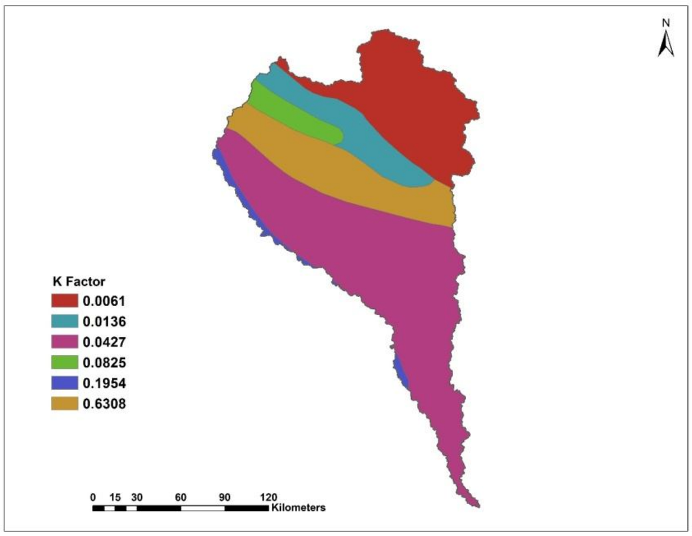


Fig. 3. Soil erodability factor (K) map of the Ramganga river basin

3.1.3 Slope length and steepness factor (LS)

The slope length and steepness factor (LS) of RUSLE show how topography affects soil loss. With increasing slope steepness, soil erosion increases (Prasannakumar et al., 2012), As a result of the length and steepness of the slope, the water flow of surface runoff is accelerated (Beskow et al., 2009). The basin's combined LS factor was calculated in ArcGIS using SRTM DEM data (30 m spatial resolution), which were obtained from the USGS Earth Explorer (Fig. 4). The computation of LS factor has been done using the equation (5) that was given by Moore and Burch, (1986). This equation includes the flow accumulation that has been derived in the ArcGIS platform from the SRTM DEM data. The Flow accumulation operation represents a total count of pixels that drain naturally into outlets. The equation of LS factor is as follows:

$$\boldsymbol{LS = \left(flow\ accumulation \times \frac{cell\ size}{22.13}\right)^{0.4} \times \left(\frac{sin\ slope}{0.0896}\right)^{1.3}} \quad (8)$$

Where LS denotes the slope length and steepness factor, flow accumulation denotes the upstream accretion area of a given cell, cell size denotes the spatial resolution of the DEM data (30 m in this study), and sin slope denotes the slope degree value in sine.

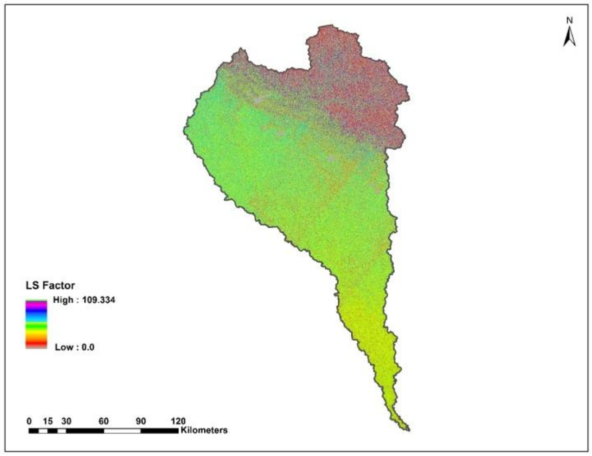


Fig. 4. Slope length and steepness factor (LS) map of the Ramganga river basin

3.1.4 Cover management factor (C)

The cover management factor depicts the surface soil influencing activities in the region through various land use practises, cropping patterns, and plant cover. It describes the proportion of soil erosion from diversified cropland in a given condition versus erosion from continuous tilled land with the same edaphic characteristics and gradient (Wischmeier & Smith, 1978; Pandey et al., 2007). To calculate the C factor, the basin was divided into seven major land use/land cover categories. The C factor was mapped by assigning C values to various land use categories (Fig. 6). The C factor values range from 0 to 1. The highest value has been assigned to land use categories that favour high soil erosion, and vice versa. The C factor values have been listed in table 2, and these are assigned considering the several carried out studies throughout India (Pandey et al., 2007, 2009; Prasannakumar et al., 2012; Biswas & Pani, 2015; Magesh and Chandrasekhar, 2016).

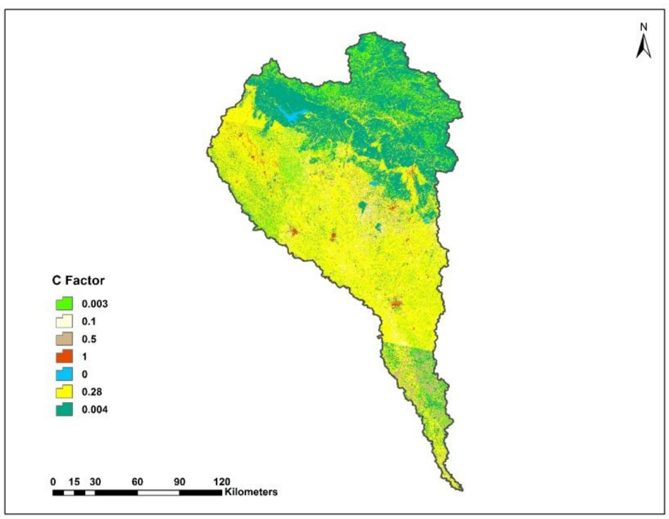


Fig. 5. Cropping management factor (C) map of the Ramganga river basin

3.1.5 Support practice factor (P)

The Support practise factor (P) is the ratio of soil erosion caused by certain conservation practises to soil loss caused by unscientific farming (Brady and Weil, 2012). It refers to farming or other field practises that reduce surface runoff and thus soil loss. The P factor values range from 0 to 1, with 1 indicating no conservation practises. These are assigned based on the basin's conservation practises.

Agricultural practises, particularly paddy cultivation, predominate in the current study (Fig. 6). The supervised classification of a Landsat 8 (2018) satellite image yielded the paddy crop cultivation lands. So the value of paddy cultivated lands has been assigned as 0.28, and non-paddy cultivated lands are assigned as 1 (Table 2). These values are assigned based on several previous studies from the different parts of India. The annual potential soil erosion has been estimated by overlying the prerequisite predisposing factor of the RUSLE model through ArcGIS software.

Table 2. Crop management factor and supporting conservation practice factor for varied land use/land cover classes.

LULC Categories	Area (in km^2)	C factor	P factor
Built-up Areas	386.46	1	0
Crop lands	11706.54	0.28	0.28
Fallow land	645.29	0.3	0.2
Forest	6906.78	0.004	0.1
Sand bar	682.14	0.1	0.8
Shrubs	2248.74	0.16	0.4
Water	115.27	0.0	0.5

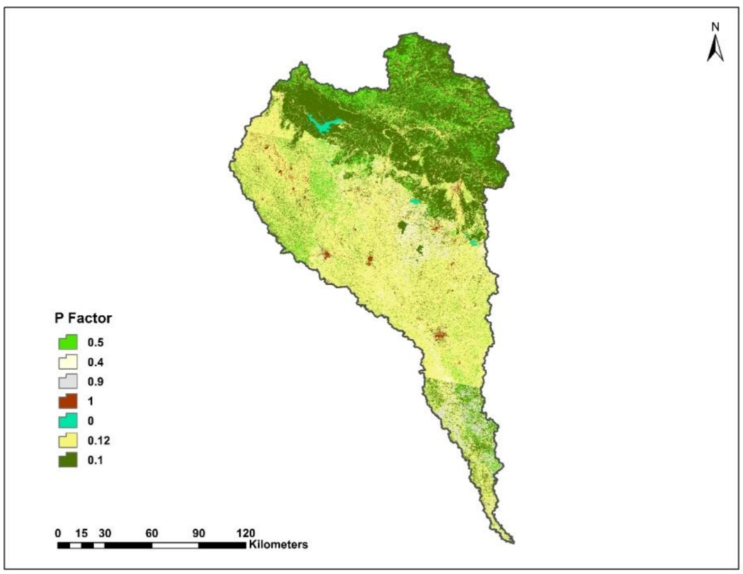


Fig. 7. Supporting conservation practice factor (P) map of the Ramganga river basin

4. RESULTS AND DISCUSSION

4.1 Spatial distribution of soil erosion factors

The RUSLE's prerequisite maps represent the various factors' distinct characteristics. The R factor map is associated with the high values in the northern portion of the watershed. This region is under sub-tropical monsoon climate (Cwa according to Köppen-Geiger's climatic classification), and it is characterised by seasonal and heavy rainfall (Kottek et al., 2006; Beck et al., 2018). Thus, the rainfall erosivity is significantly high for its climatic character. However, in the southern portion of the watershed, erosivity is relatively low for its tropical wet and dry climate. The K factor map signifies the properties of the soil. The soil erodibility value is ranging from 0.0061 to 0.6308. The high value of LS factor indicates tremendous potential for erosion. Since the study area is part of upper ganga region, the value of LS factor is mostly high.

The study area has seven major land-use types (Shrubs, Forest, Fallow land, Built-up Areas, Croplands, Sandbar, Water bodies). Built-up areas have the highest values of C factor as it has the enormous potential for erosion. The Built-up areas accelerate the erosion by disturbing the soil texture, organic matter and other physical and chemical properties (Biswas & Pani, 2015). Conversely, the water bodies have the lowest value of C factor for their protection of soil erosion. Most of the watershed areas have coverage of forests that reduce soil erosion, especially in mountainous regions.

The values of support practice factor of the watershed have significantly low as most of the area is belongs to the forested area. The value of P factor of the forest area ranges from 0.01 to 0.1.

4.2 Estimation and spatial distribution of potential soil loss of the Ramganga river basin Estimation and Spatial Distribution of Potential Soil Loss

All the predisposing factors were combined using the empirical RUSLE equation (Equation 1), and a soil erosion result was obtained. The soil erosion values estimated for the Ramganga river basin ranged from 0 to 152.41 t/ha/yr with an average of 26.18 t/ha/yr. This soil erosion is considered moderate to high soil erosion compared to the previous study in this region and other country regions (Table 3). In the study area, 13.08 percent of the total area is moderate soil erosion (2968.22 km^2), while about 10.97 percent of the total area (2488.57 km^2) is high soil erosion. Significant parts (41.76 %) of the watershed experiences low soil loss, which is less than 0.59 t ha^{-1}yr^{-1}. Contrariwise, very high soil loss (more than 20.32 to 152.41 t ha^{-1}yr^{-1}) is significant only in 5.63 percent of the basin. Hence, the area of soil loss is inversely proportional to the amount of soil loss, revealing that there is significant soil loss in some parts of the catchment (Figure 7).

Table 3. The area and the intensity of soil loss of different erosion categories in the Ramganga river basin

Erosion Category	Soil Loss Range (t/ha/yr)	Area (in km^2)	Area (%)
Very Low	0.0 - 0.59	9476.42	41.76
Low	0.59 - 1.79	6479.63	28.56
Moderate	1.79 - 5.97	2968.22	13.08
High	5.97 - 20.32	2488.57	10.97
Very High	20.32 - 152.41	1278.38	5.63

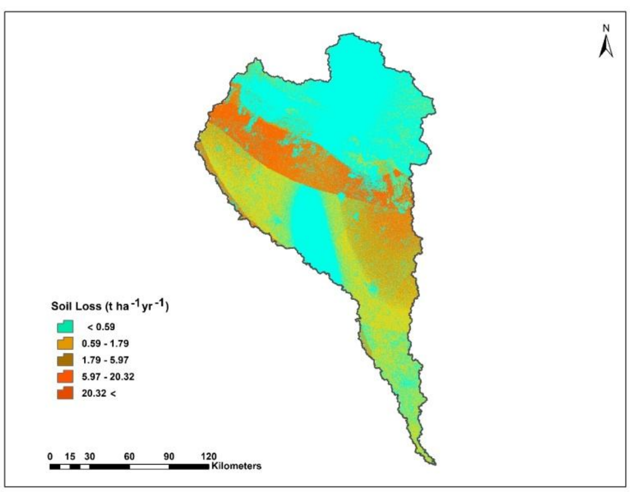


Fig. 7. Spatial distribution map of the average annual soil erosion in the Ramganga river basin

This region's high soil erosion is linked to the upper basin or foothills region of the Western Himalayas. Deforestation, overgrazing by cattle, use of agrochemicals in tillage activities, road and building construction, as well as widened river due to lateral erosion and extreme streamflow/inundation in down streams during monsoon, cause maximum soil erosion in the lower portion of the basin, are all associated with the region. Support practises are minimal in this region, and the northern portion is attributed to a steep slope. In addition to the large amount and intensity of rainfall, the potential for soil erosion is high. Furthermore, relatively low rainfall in rain shadow areas can help to reduce watershed soil erosion.

5. CONCLUSION

Soil erosion is a major issue that threatens agricultural sustainability and productivity. Soil is one of the mysterious components required to sustain an ecosystem and biodiversity. This study illuminates the spatial potential of soil erosion over the Ramganga river basin using the RUSLE model integrated with GIS and remote sensing. The basin's spatial distribution of soil loss ranges from 0 to 152.41 tonnes per acre per year. Approximately 41.76 percent of the study area has a very low erosion risk, with values ranging from 0 to 0.59 -ton ha-1 year-1. The hotspot of soil erosion has revealed that the central and lower portions of the basin are more vulnerable to erosion, with soil erosion rates ranging from 20.32 to 152.41 t/ha/year. Soil erosion from these steep landscapes, specially cultivated areas, and deep alluvial loamy soil accounts for a large portion of total soil erosion in the Ramganga river basin. However, the rate of imperious erosion and deposition is very high in other regions with similar edaphic management interventions. This paper provides insight into identifying erosion-prone areas and implementing effective conservation measures. The government, as well as local governments, should take the initiative to implement conservation measures and proper planning.

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