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Assessment of Soil Erosion Impacts at the Panchhari Sub-district of Chittagong Hill Tracts in Bangladesh Using Remote Sensing and GIS Techniques Based on RUSLE Model

Rathindra Nath Biswas[1,*], M. Nazrul Islam[2], Samia Islam[3]

Abstract

Soil erosion has been identified as a significant issue around the world. It is often exacerbated due to land deterioration, conversion of agricultural land, and other anthropogenic activities. It negatively impacts soil productivity, water quality deterioration, river and reservoir bed sedimentation, nutrient loss, and sustainability of natural resources. Understanding the controlling factors of soil erosion can help us to identify erosion-prone areas and improve land use management. The novelty of the present research is to explore spatial patterns of soil loss through sophisticated GIS and RS technology for sustainable management of the forest landscape of Bangladesh. To approximate of the mean annual soil loss at the Panchhari Upazila under Chittagong Hill Tract (CHTs), present study applied RUSLE approaches by using remotely sensed data, climate variable and lithology information. The climate of the Chittagong Hill Tracts, particularly in Panchari Upazila, was influenced by a tropical monsoon climate with abundant rainfall. The RUSLE model's findings show that the yearly average soil loss in the studied region fluctuated from 0 to 108517 t ha^{-1} y^{-1}. The probability map of soil erosion shows that roughly 0.71%, 4.02%, 61.26%, and 34.01% of the region fall into the low, moderate, and high erosion categories, respectively. The goal of the study is to fulfill the personnel duties of many different sectors, including those of environmental managers, agriculturalists, water resource managers, ecologists, geologists, geomorphologists, and socio-hydrologists for the implementation of development initiatives and implementation of sustainable development management strategies for the forest landscape. Geomorphometric analysis and a computation of the region's sediment production will be part of further research for ecological development and long-term watershed management.

Keywords: Soil Erosion, RUSLE Model, Remote Sensing, Geographic Information System (GIS), Forest Landscape, Bangladesh

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INTRODUCTION

Soil is the essential component of the earth's surface and functions in the ecosystem of its landscape. Soil erosion significantly impacts natural ecological systems including ecosystem productivity, ecosystem services, agro-ecological species, forest diversity, soil microorganisms, soil nutrient, water resources, as well as food security (Zhang, et al., 2007; Cowie, et al., 2011; Zhu, 2012; Lemaire, et al., 2014;; El Carsan, et al., 2014;Taye, et al., 2018; Tuo, et al., 2018; Mujtar, et al., 2019; Zhao, et al., 2019) [1–8]. Globally, soil loss rate statistics reveal that ~25 billion tons of topsoil is lost each year, especially in Asia, which amounts is more than 600 $Mhay^{-1}$, a huge amount compared to the rest of the continents (Saha, et al., 2022) [9]. For the last two decades, tropical forest landscapes around the world have been dramatically declined at a rate of ~20 $Mhay^{-1}$ because of the combined influence of human interventions and climate extremes. On tropical forest landscape slopes, complex primitive cropping pattern systems and global climate change further exacerbated massive soil losses. (Kammerbauer and Ardon., 1999; Lewis, et al., 2015) [10, 11].

During the contemporary time, the Tertiary Hilly Region of South Asia, in particular, the CHTs of Bangladesh, has been suffering drastic soil erosion. Topographically, the Tertiary Hills of CHTs comprise of landslip scars, steep slopes, deep rills and gullies, and parallel ranges with a summit reaching ~300-1000 m. The pedology of the CHTs has complex patterns including diverse rock formations (i.e. hard rock, consolidated rock, and unconsolidated rock); soil textures class, primarily, consist of sand to clay, and those are extremely acidic to considerably acidic; continuous extreme weathering processes mostly physical and chemical; primitive agriculture practices on the steep slope and massive soil erosion as well. Therefore, the persistent land degradation profile and forested landscape exploitation have had a tremendous impact on the soil efficiency of mountainous regions in recent decades. The drastic loss of soil in the CHTs is because of unplanned agriculture practices including (*Jhum practice*), agro-farming, agro-forestry, rubber plantation, and so on (Gafur., et al., 2003; Thapa and Rasul., 2006; Valentin, et al., 2008) [12–14]. In addition, rapid structural development and hill cutting, poor management strategies, and lack of policy and planning are crucial causative factors for the rapid soil loss in the region.

The north-western portion of CHTs, in particular, Panchhari Upazila has been seriously facing the environmental challenge and ecological stress by massive soil erosion in recent times. There is, however, a tremendous increase in traditional agriculture practices along with commercial farming over the steep hill slope that intensifies soil erosion during the wet season (June-July). Moreover, climate change has produced massive sediments from the landscape during flash floods in the region and transported by numerous rills and gullies. Additionally, the devastating fire on agriculture burn along with slash accelerated in depletion of soil nutrients and productivity. Meanwhile, shifting cultivation on hill slopes and hill cutting for road construction have significant impacts on soil erosion as well.

There are numerous models to estimate annual soil losses at the regional and local scale and variation was observed due to environmental conditions including climatic scenarios, physical setting, geological formation, geomorphological unit, hydrological regime, landscape and cropping patterns, and soil taxonomy (Seutloali, et al., 2018; Teng, et al., 2018; Sujatha and Sridhar, 2019; Guo, et al., 2019; Elnashar. Et al., 2021; Mhaske, 2021; Salesa, et al., 2021; Lucas-Borja, et al., 2022; Chen, et al., 2022; Senanayake and Pradhan, 2022; Shi, et al., 2022; Wang and Watanabe, 2022) [15–26]. Similarly, the model parameters of the methodological approach to soil erosion analysis may differ due to differences in spatial data collection and complex data structures, and their use in different environments (Chen, et al., 2019) [27]. In 1965, Wischmeier and Smith have developed an empirical Universal Soil Loss (USL) model to assess topsoil and rill erosion. After 32 years, Renard et al. (1997) have explored conservation planning by applying the RUSLE approach in their handbook titled "*Agriculture Handbook*" [28]. The RUSLE approach has been commonly employed on local and regional scales, notably in the gentle slope terrain and agricultural land, despite the contradictions in the existing model and sub-model to assess soil losses (Terranova, et al., 2009; Panagos, et al., 2016; Biddoccu, et al., 2020; Borrelli, et al., 2017; Li, et al., 2020) [29–33].

The inclusive methodologies of sophisticated RS and GIS new technology to predict soil erosion spatial patterns is a low-cost process and less time-consuming for resource conservation planning and management (El Jazouli, et al., 2019; Eniyew, et al., 2021; Getachew, et al., 2021; Acharki, et al., 2022; Habtu and Jayappa, 2022; Getu, et al., 2022) [34–39]. Nevertheless, RUSLE model-based soil erosion assessment is regarded as cost-effective and provides robust results in comparison to traditional soil erosion assessment and conservation planning, but these types of investigations are almost absent in the present research site (Sinha, et al., 2018; Vijith, et al., 2018) [40, 41]. Saha et al. (2022) used RUSLE methodologies to calculate the mean annual soil loss rate in GIS environment at the Brahmaptura-Jamuna floodplain in Bangladesh. Similarly, Hossain, et al. (2022), have quantified soil degradation causal factors and erosion vulnerability in the rapid urbanization coastal Cox's Bazar region along with the Rohingya refugee camp [42]. Niral, (2021), has applied RUSLE techniques to compute losses of soil rate and development management plan in the central portion watershed of CHTs. For forest landscape management, comprehensive as well as strategic research is an urgent need to monitor, evaluate, and analysis of soil loss in the CHTs. However, examination of current research will fill the previous study gaps and promote sustainable management strategies for forest resources and strengthen the ecological balanced and lessen environmental stress. Moreover, our examination may ensure a natural resource conservation plan at the national level and encourage associated stakeholders, government and non-government organizations, environmental resource management managers, soil scientists, agriculture experts, environmentalists as well as researchers for further studies and implementation.

The principal purpose of the research work is to compute soil loss and explore the implications of soil loss on ecosystem services, ecological diversity along with food security and provide proper direction to an environmental conservation plan for the sustainable development of natural resources. To achieve the examination goal, just a few of the key targets under the goal that have been chosen such as the quantification of surface soil losses using the RUSLE approach, documentation of the causal mechanism of soil erosion and its implications to natural systems and food security and suggest strategic policy and plan for sustainable development of natural resources.

GEO-ENVIRONMENTAL SETTING OF THE RESEARCH SITES

The Panchhari Upazila under Khagrachari District is situated at the north-eastern Tertiary Hilly area of the Chittagong Hill Tract in Bangladesh. It has a spatial coverage of ~334 km^2, with geographical references between 23º15′ and 23º28′ North latitude and between 91º50′ and 92º0′ East longitude and bounded by the Tripura State of India in the North (Figure 1). The upazilla consists of five unions (i.e. the fourth-order administrative unit of Bangladesh) Logang, Ulta Chari, Latibian, Panchhari, and Changi. Geologically, the study area comprises Dupi tila formation, Tipam sandstone, Bokabill formation, valley alluvium and colluvium, Dihing and Dupitila formation,s and Bhuban formation. In the Geomorphological unit, the study makes up of deep fills, isolated valleys gully fills, natural depression, rounded top highly dissected hills, sharp crest highly dissected hills, sharp crest slightly dissected hills, steep hill slopes, a flood plain with point bar, and active channel with river valley. Physiography of the region has demonstrated that most of the study area constitutes the Tertiary age, during the time of uplift of the Himalayas Mountain ranges. Topographically, the study area lies between 26 m to 400 m above the mean sea level (MSL) (Figure 2). The Chengi River is the prime river of the area and its tributaries including Logang River, Pujgang River, Latiban Chhara, and Golok Patima Chharathe are the main sources of water for irrigation in cropland, domestic uses, and keeping the ecological balance for the forest landscape. Climatologically, the tropical monsoon season had an impact on the research area, with rainfall averaging between 1375 mm to 3386 mm with a mean of 2530 ± 5255, and temperature varied from 21.4ºC to 30.6ºC.

METHODS AND MATERIAL

Remote Sensing and Environmental Data

Five determining parameters and data gathered from diverse sources were used to build the RUSLE equation. Monthly average rainfall (mm) data for 30 years from 1987 to 2017 of 35 stations in Bangladesh were obtained from the Bangladesh Metrological Department (BMD) to compute rainfall-runoff erosivity factors (R). Soil texture vector data from the SRDI of Bangladesh were compiled in 1995 to determine the K factors of the research area. ASTER DEM was obtained from EARTHDATA (https://earthdata.nasa.gov) to create a slope, elevation, flow accumulation, slope length, slope steepness factors (LS), and conservation support practice factors (P) for the study site. The KOMPSAT satellite image (spatial resolution 0.5 meter) collected from the Korea Aerospace Research Institute (KARI) to delineate land use and their respective cover management factors (C) for the study location.

Software Application

The remotely sensed satellite imagery processing including layer stake, sub-set was according to study AOI carried out via ERDAS IMAGINE software version 14. The initial geographic projection system was re-projected into Bangladesh Transverse Mercator (BTM) with Dhaka Jaika Datum using ERDAS IMAGINE *v* 14. All the mathematical equations of the RUSLE model and its sub-model was computed using ArcGIS *v* 10.6 software. The *R* programing language was utilized for exploring the association and coherence among controlling factors of soil erosion using Pearson's correlation matrix.

RUSLE model and its Sub-model

The Revised Universal Soil Loss Equation (RUSLE) in a GIS system was used to determine the annual soil erosion rate within the research area. It is quantitative erosion assessment model that has become a widely accepted way to approximation the typical risk of soil erosion on agricultural land. It was developed from the Universal Soil Loss Equation (USLE) established by the US Department of Agriculture. It is a well-known erosion model (Figure 3) and has been extensively applied worldwide to measure soil loss at the regional or local scale. Additionally, this model was created to predict average soil erosion in run-off specific field areas in specific cropping and management system. Furthermore, a variety of environmental variables as well as controlling factors are taken into account while determining a certain location's soil loss. The following Eq. 1 is used in the RUSLE model to estimate soil erosion or loss

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

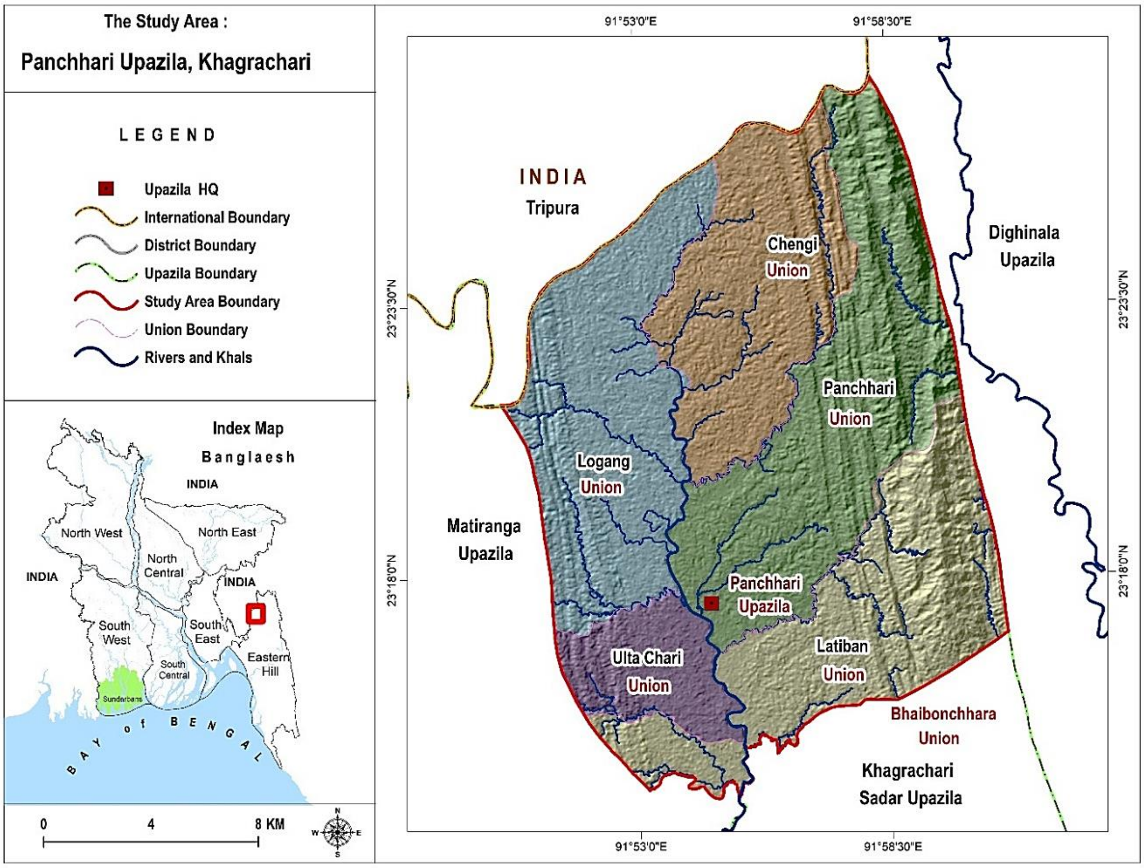

Figure 1. Locational map of the study area.

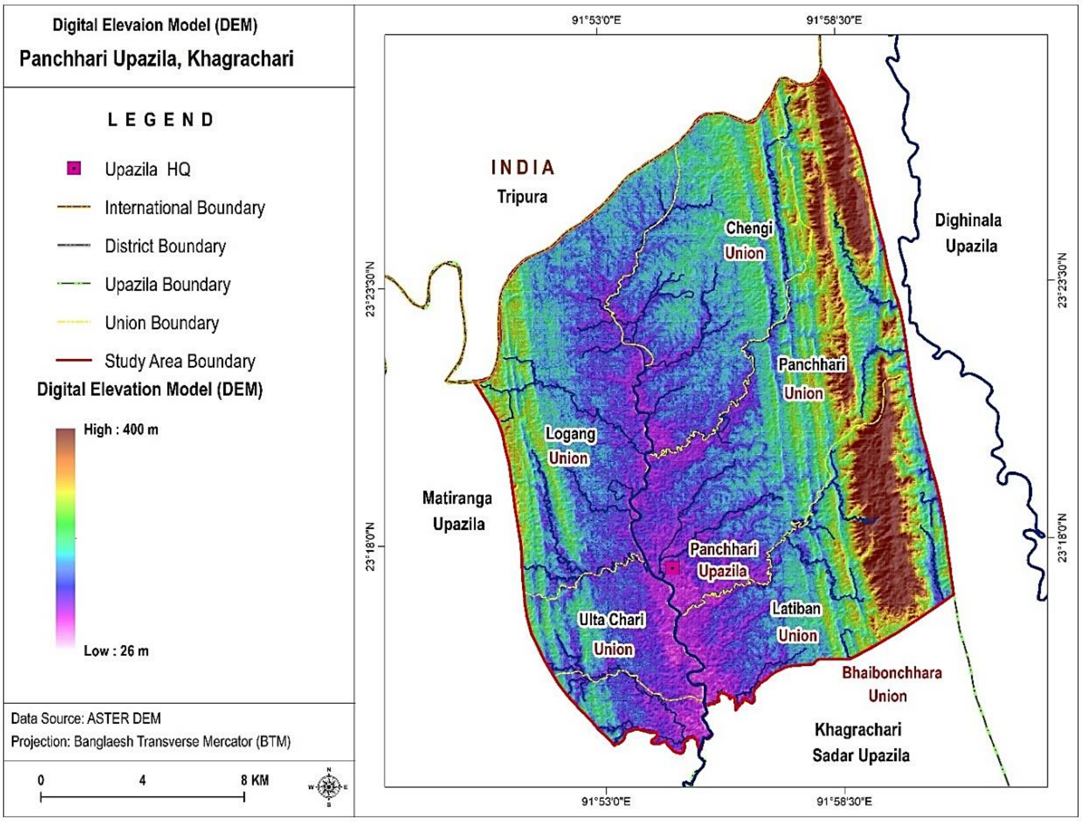

Figure 2. Topographic elevation of the study area.

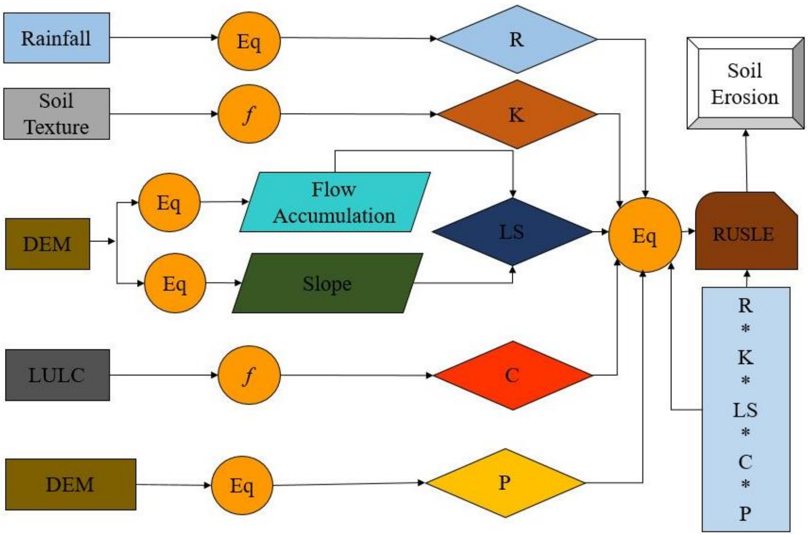

Figure 3. Methodological flowchart of the RUSLE model and its sub-model.

Where *A* represents the annual mean soil erosion rate in t. ha^{-1}. y^{-1}; *R* is the rainfall-runoff factor in MJ.mm. ha^{-1}. h^{-1}. y^{-1}; K designated as a soil erodibility factor in t.ha. MJ^{-1}mm^{-1}; *LS* signify as the unit less topographic factors; and *C* and *P* indicate unit less cover management and support practice factor, respectively.

Rainfall-runoff Erosivity Factors (R)

The long-term annual mean rainfall energy is used to establish the rainfall-runoff erosivity factors (R), and in the case of storm events, the intensity of rainfall would be maximum of 30 min (Thomas, et al., 2018) [43]. Additionally, the arithmetical value of R represents the mechanical energy of droplets of water, which may have a considerable impact on the stability of soil aggregates and promote soil loss (Abdo and Salloum, 2017; Mohammed, et al., 2020; Duulatov, et al., 2019; Hateffard, et al., 2021) [44–47]. For approximately, 30 years from 1987 to 2017, monthly average rainfall data of 35 stations over Bangladesh has been achieved from the Bangladesh Metrological Department (BMD) (Table 1) and utilizing IDW (Inverse Distance Weighting) interpolation methods in a GIS framework to compute rainfall spatial patterns. The *R* factor from the following Eq. 2 was calculated using the outcomes of IDW interpolation of rainfall intensity (Tirkey, et al., 2013) [48].

$$R = 81.5 + 0.38 \times P \ \textbf{(2)} \text{ for } 340 \leq P \leq 3500(\text{mm}) \qquad (2)$$

Where P is the mean annual rainfall (mm) and R is the erosivity ($MJmmha^{-1}yr^{-1}$) factor for rainfall-runoff.

Soil Erodibility Factor (K)

The level of soil fertility, nutrient content, and other inherent qualities of the soil all substantially influence how fast the soil erodes through time and space. There are many methods to calculate the soil erodibility factor (K) depending on the soil's mechanical, microbiological, and chemical stability. Data on soil texture was gathered to calculate K factors from Bangladesh's Soil Resource Development Institute (SRDI), which was updated in 1995. Using the mean amount of organic matter and soil textural class, the K factor was calculated (Table 2).

Slope length (L) and Slope Steepness Factors (S)

The determining element for potential soil losses involves topography. The slope length (L) and slope steepness (S), in particular, have an impact on soil qualities and the possibility of erosion. In general, more slope steepness produces rapid erosion in comparison to the slope length. Topographic factors LS assume that soil erosion will increase with the slope length, and there without considering any three-dimensional complexity of the landscape. The following Eq. 3 was used to calculate the LS factors of the research region (Moore and Burch, 1986) [49].

$$\text{LS} = \left(\left(\text{Flow Accumulation} \times \frac{\text{Cell Size}}{22.13}\right)^{0.4} \times \left(\frac{\sin(\text{slope})}{0.0896}\right)\right)^{1.3} \qquad (3)$$

Flow Accumulation derived from DEM with cell size 30 m. The weights of all the cells that flow into each downslope cell are added up to create a raster known as Flow Accumulation, which represents the accumulated flow to each cell of DEM. The slope is measure form by DEM by the rate of maximum change in z-value from each cell.

Table 1. Details of the data used in the present study.

S.N.	Data Type	Description	Factor	Data Source
01	Rainfall Data	Monthly average rainfall data of 30 years from 1987 to 2017.	Rainfall-runoff Erosivity factors (R)	Bangladesh Metrological Department (BMD)
02	Soil Texture Data	Soil texture vector data for the year 1995. Soil classify on the basis of soil texture classes.	Soil Erodibility Factor (K)	Soil Resource Development Institute (SRDI) of Bangladesh
03	Digital Elevation Model (DEM)	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 3 (GDEM 003). (spatial resolution 30 meter)	Slope Length and Slope Steepness Factors (LS) and Conservation support Practice Factors (P)	https://earthdata.nasa.gov
04	Satellite Image	KOMPSAT satellite Image (KOMPSAT is an optical high-resolution satellite Image of the Korean observation mission of KARI (Korea Aerospace Research Institute) (spatial resolution 0.45 meter).	Cover Management Factor (C)	CEGIS Archive

Table 2. Soil textural classes and their respective K factors.

S.N.	Textural Class	K factors		
		Average OMC	*Less than 2% OMC*	*More than 2% OMC*
01	Clay	0.49	0.54	0.47
02	Clay loam	0.67	0.74	0.63
03	Coarse sandy loam	0.16		0.13
04	Fine sand	0.18	0.2	0
05	Fine sandy loam	0.4	0.49	38
06	Heavy clay	0.38	0.43	0.34
07	Loam	0.67	0.76	0.58
08	Loamy fine sand	0.25	0.34	0.2
09	Loamy sand	0.09	0.11	0.09
10	Lomy very fine sand	0.87	0.99	0.56
11	Sand	0.04	0.07	0.02
12	Sandy clay loam	0.45		0.45
13	Sandy loam	0.29	0.31	0.27
14	Silt loam	0.85	0.92	0.83
15	Silty clay	0.58	0.61	0.58
16	Silty clay loam	0.72	0.79	0.67
17	Very fine sand	0.96	1.03	0.83
18	Very fine sandy loam	0.79	0.92	0.74

Source: Stone, RP & Hilborn, D. 2015, 'Universal Soil Loss Equation (USLE)', Ontario Ministry of Agriculture, Food and Rural Affairs, http://w.w.w.omafra.gov.on.ca/english/engineer/facts/12-05.htm#2.

Cover Management Factor (C)

The effects of cropping patterns and management techniques on soil erosion rates are taken into consideration by the C factor of RULSE. High-resolution KOMPSAT satellite imagery has been used to analyse the land use of the study region. Most of the images were acquired in the dry season of 2020. The spatial resolution of the high-resolution images varied from 0.5 to 1 meter. The research region includes various LULCs such as forest cover, shrub dominated area, rubber plantation, shifting cultivation, crop land, urban area, rural settlement, brickfield, lake, ponds, and rivers and khals. The above-mentioned LULCs were identified from the images using the visual interpretation technique. Those identified features were digitized on-screen digitization techniques in the ArcGIS software version. After digitization, the land use database was finalized through editing and checking topological errors.

A proper soil loss investigation depends greatly on the accuracy of the research region's landscape class. Similar to this, a high-accuracy landscape feature aids in better decision-making for the corporation and associated stakeholders to take initiative. By using a stratified sample technique in an ArcGIS platform, 500 reference points were used in the current study. The high-quality remotely sensed satellite data (i.e WorldView 3 imagery available in the Google Earth Platform with spatial resolution 0.3 m) was then used to confirm the reference point. Finally, confusion error matrix was applied to compute user accuracy, producer accuracy, and kappa statistics to evaluate landscape feature accuracy (Eqs. (4), (5), and (6). However, based on LULCs, the cover management factor (C) was assigned by following the guidelines of numerous researchers for the research location (Prasannakumar, et al., 2012; Senanayake, et al., 2013) [50, 51].

$$\text{Users Accuracy} = \frac{x_{ii}}{x_{i+}} \quad (4)$$

$$\text{Producer Accuracy} = \frac{x_{ii}}{x_{i+}} \quad (5)$$

$$\widehat{K} = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+} + x_{+i})}{N^2 - \sum_{i=1}^{k}(x_{i+} + x_{+i})} \quad (6)$$

Conservation Support Practice Factors (P)

The ratio of soil loss or erosion following the application of management practice to soil loss for upslopes and downslopes in straight-row farming practice spatial coverage is known as the conservation support practice fact. In this investigation, the conservation support practice factor was calculated using the formula Eq. 7 below.

$$P = 0.2 + 0.03 \times S \quad (7)$$

Where S is represented as the percentage slope gradient, and P is the element of the conservation support practice.

RESULTS AND DISCUSSION

Rainfall Erosivity Factor (R)

The spatial annual average rainfall distribution map of the study site shows the decreasing patterns from south-western toward north-eastern (Figure 4). In addition, the range of the mean yearly precipitation in the research site has been exhibited from ~230 mm $year^1$ to ~236 mm $year^{-1}$. Moreover, Ulta Chari and Latiban union of the Panchhari Upazila experience the highest annual average rainfall, whereas the north-eastern portion of Chengi and Panchhari union of the same Upazila experience the lowest annual mean rainfall.

The rainfall erosivity factors (R) of the research region varied from ~169 MJ ha^{-1} $year^{-1}$ to ~ 171 MJ ha^{-1} $year^{-1}$ (Figure 5). The study's analysis results also displayed a optimistic correlation between the rainfall erosivity factor and annual average rainfall (R). Additionally, the spatial patterns of the rainfall erosivity factors in the research area exhibits a declining trend from south-western toward north-eastern patterns that are similar to the annual average rainfall patterns. Furthermore, maximum and minimum rainfall erosivity (R) flowed by ~169 MJ ha^{-1} $year^{-1}$ and ~ 171 MJ ha-[1] $year^{-1}$ in the Chengi and Panchhari union, and Ulta Chari and Latiban union, respectively.

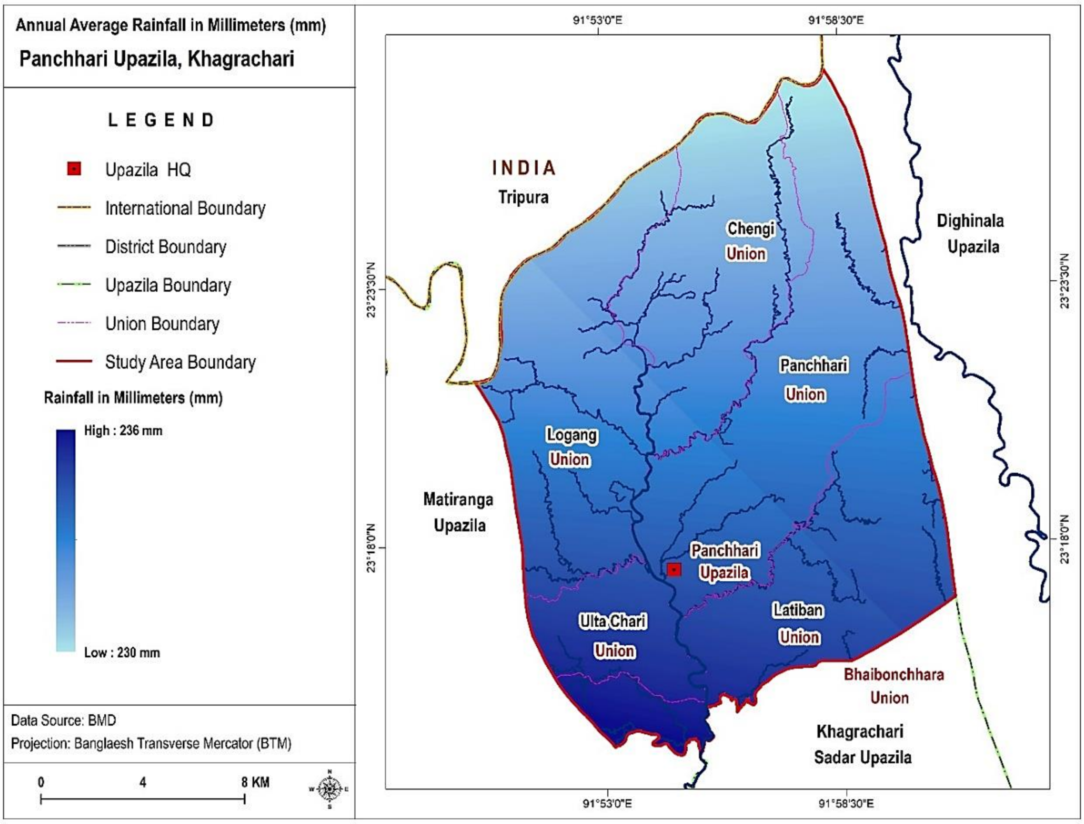

Figure 4. Annual average rainfall (mm) patterns of Panchhari Upazila.

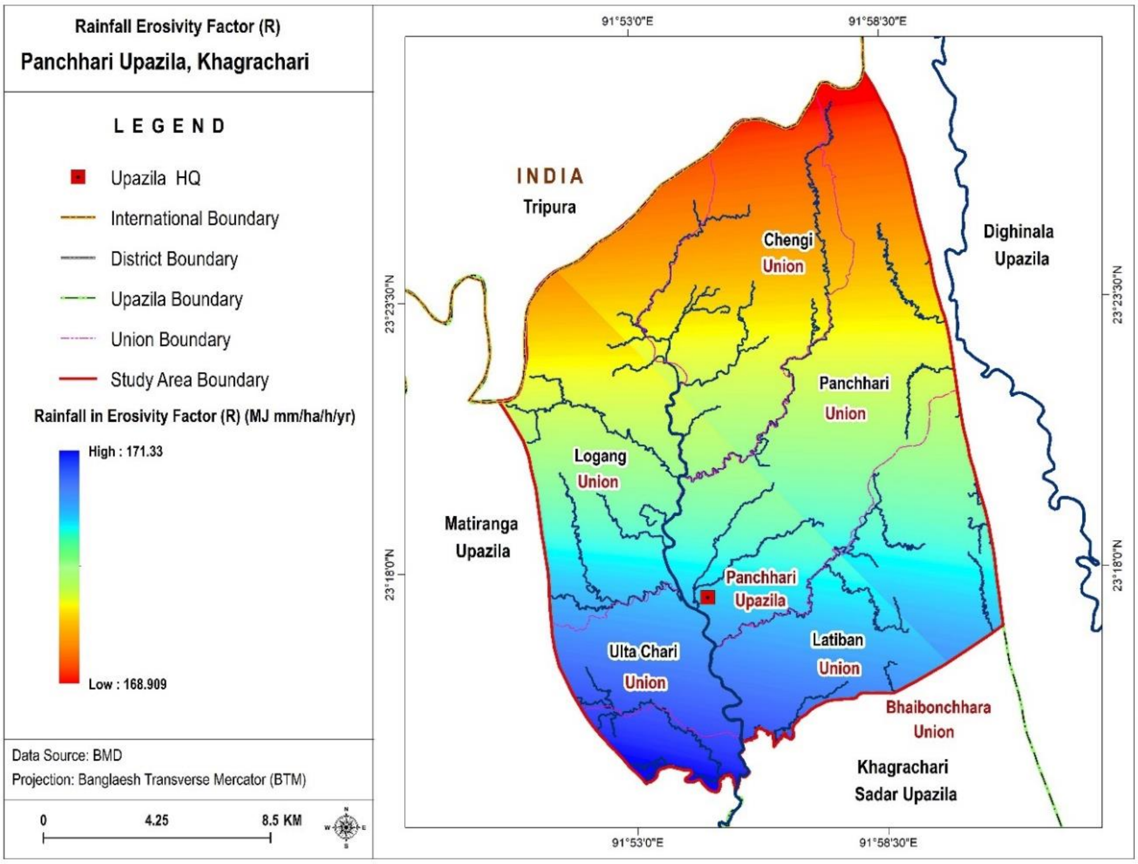

Figure 5. Rainfall erosivity factor (R) of the study area.

Soil Erodibility Factor (K)

The majority of the research area's soil was clay loam to sandy loam, and their respective spatial coverages were 48% (16105.50 ha) and 52% (17265.28 ha), respectively. (Figure 6). In comparison to clay soil texture, sandy soil texture has higher soil erodibility. The K factors for the study region ranged from 0.29 to 0.67 MJ.mm. ha^{-1}. h^{-1}. y^{-1}.

Slope Length and Slope Steepness Factors (LS)

The rise in flow accumulation in numerous streams considerably influenced the regulation of LS variables. In the research area, flow accumulation values ranged from 1 to 285366. (Figure 7). Another influencing element for soil erosion in the research region is the slope.

The research area's slope ranges from 0.33° to 54.88°, indicating that it is either gentle or steep in nature (Figure 8). From the figure, it is also displayed that gentle slope areas are predominant in comparison to steep slopes in the study area. In general, a steep slope where agriculture practices have been done over the years is more vulnerable to severe soil degradation.

The LS factors spatial distribution in the study increased from o to ~171 (Figure 9). In addition, an increase in the slope angle is also responsible for higher results of LS factors. In contrast, the lowest value of LS factors was found in the gentle slope which significantly enrolled to compute LS factors.

Cover Management Factor (C)

From remotely sensed satellite imagery, the landscape class of the research region was identified, prepared for mapping, and given a C factor for its features. There are 11 different landscape classifications for the research region including forest cover, shrub dominated area, rubber plantation, shifting cultivation, crop land, urban area, brickfields, lake, ponds, and rivers and khals, and their spatial coverage followed by 34.59% (11542.80 ha), 36.66% (12235.06 ha), 0.09% (29.65 ha), 5.81% (1939.43 ha), 12.82% (4278.62 ha), 0.56% (187.53 ha), 8.16% (2723.20 ha), 0.02% (7 ha), 0.004% (1.40 ha), 0.24% (79.95 ha) and 1.04% (346.15 ha), respectively (Figure 10 and Table 3). Moreover, spatial statistics of the stud area also demonstrated that shrub dominated area has had the largest spatial coverage in comparison to the forest and other landscape features. Accuracy assessment results demonstrated that all the landscape features have a user accuracy of 97%, whereas producer accuracy is more than 87% except for the rubber plantation landscape (Table 4). The kappa coefficient value ($K > 0.80$) illustrates a strong level of landscape accuracy.

For the landscape features of the research site, the controlling cover management factors (C) of soil erosion value range from 0.2 to 0.73 (see, Figure 10). Generally, the scale of the C factors value is $0 \leq C \leq 1$, whereas the landscape features of study assign values showing very low to high cover management factors in nature. Moreover, the high C factor represents shifting cultivation, crop land, urban area, brickfield, and their assigned value of 0.73. The lowest cover management component, however, was wetlands, which included lakes, ponds, rivers, and khals, and it was assigned a value of 0.2.

Conservation Support Practice Factors (P)

The soil loss equation uses the conservation support practice factor (P), which is the ratio for contouring, strip cropping, or up-and-down slope farming. By implementing these supportive conservation activities, the value of P factors drops significantly. Moreover, if the value of P factors is low, it means that the conservation practice is better for controlling soil loss. The P values in the research area range from 0.2 to 38.1857, respectively (Figure 11). The P value spatial pattern displayed that the southwestern site shows the lowest value whereas the north eastern location shows the highest value in the study area.

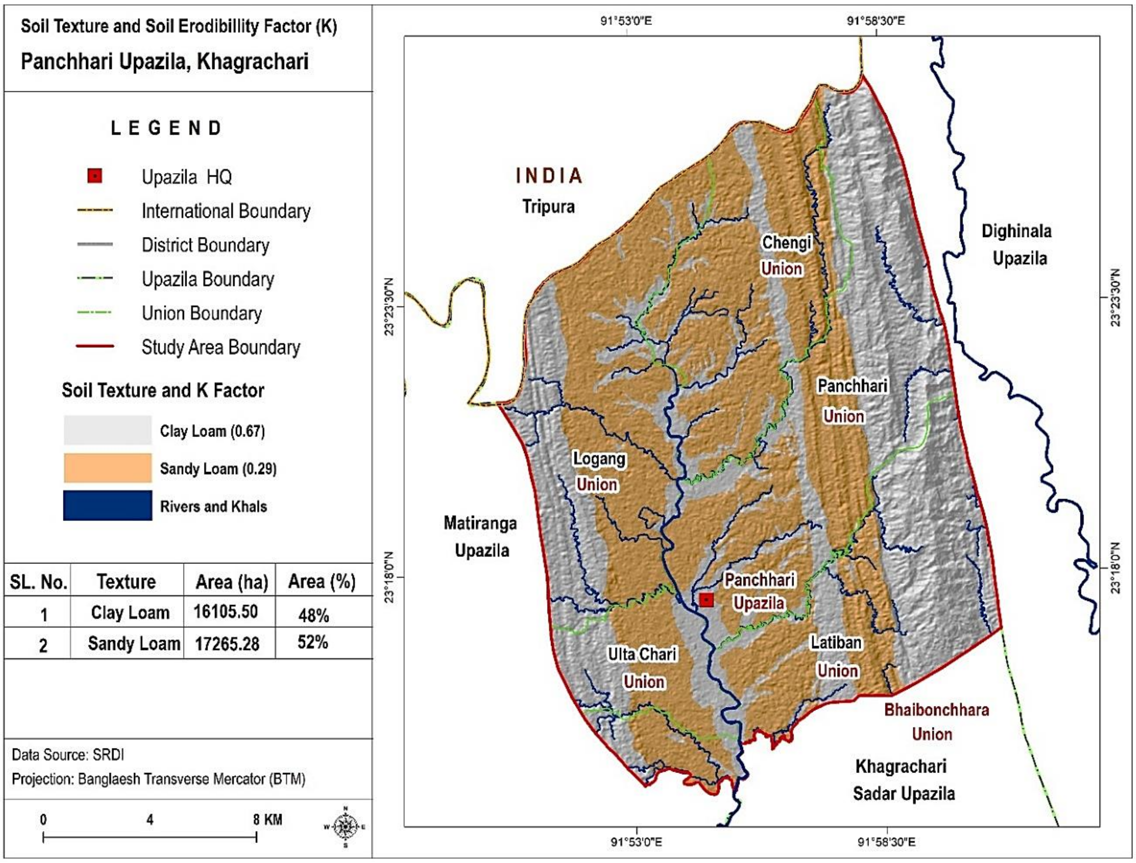

Figure 6. Soil texture and soil erodibillity factor (K) of the study area.

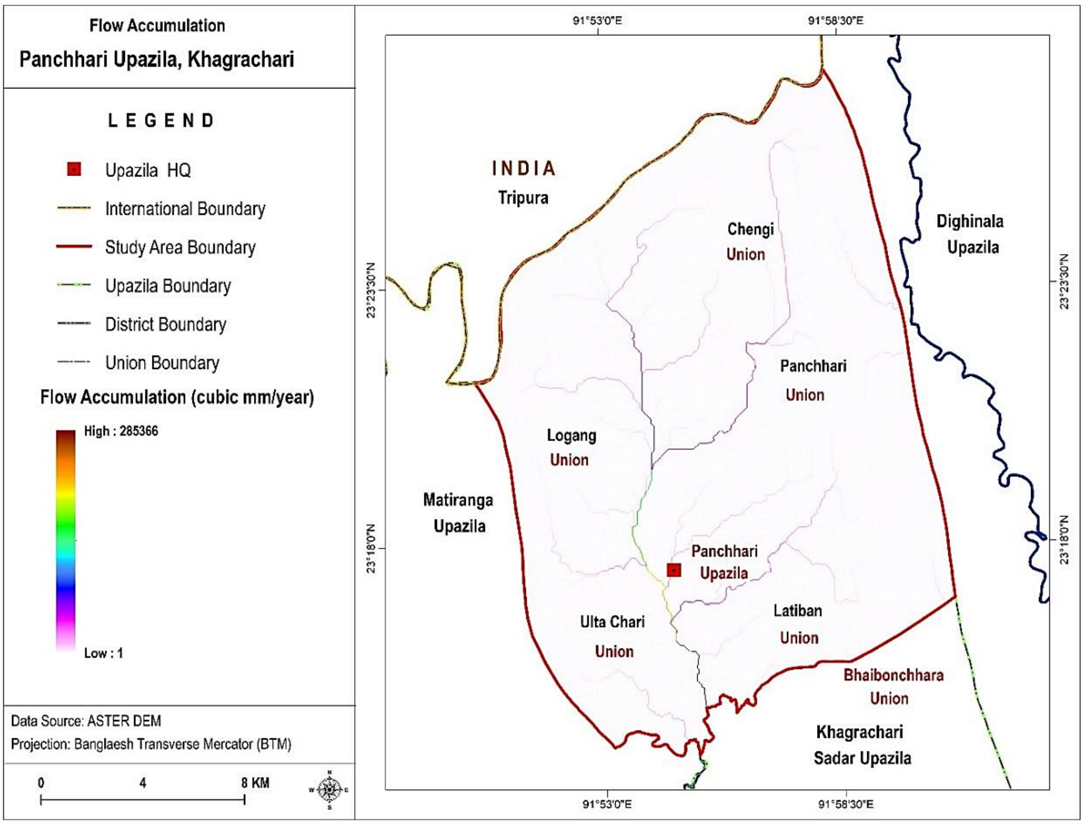

Figure 7. Flow accumulation of the study area.

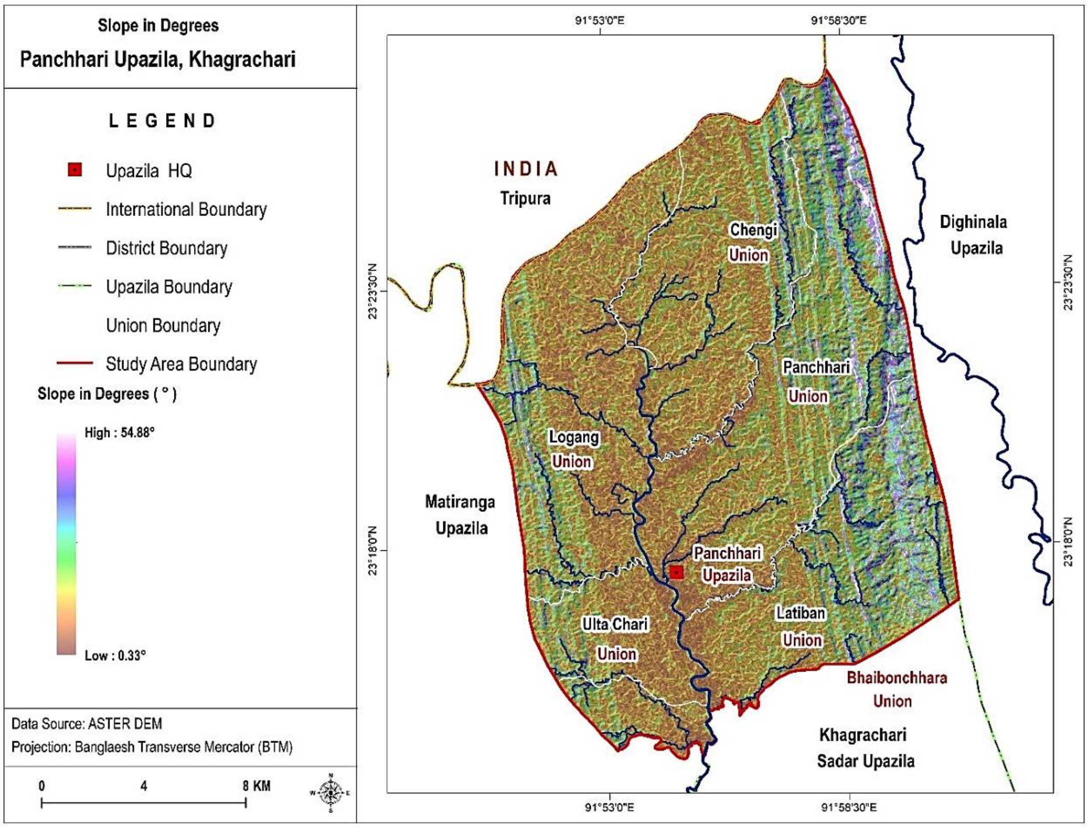

Figure 8. Slope in degrees of the study area.

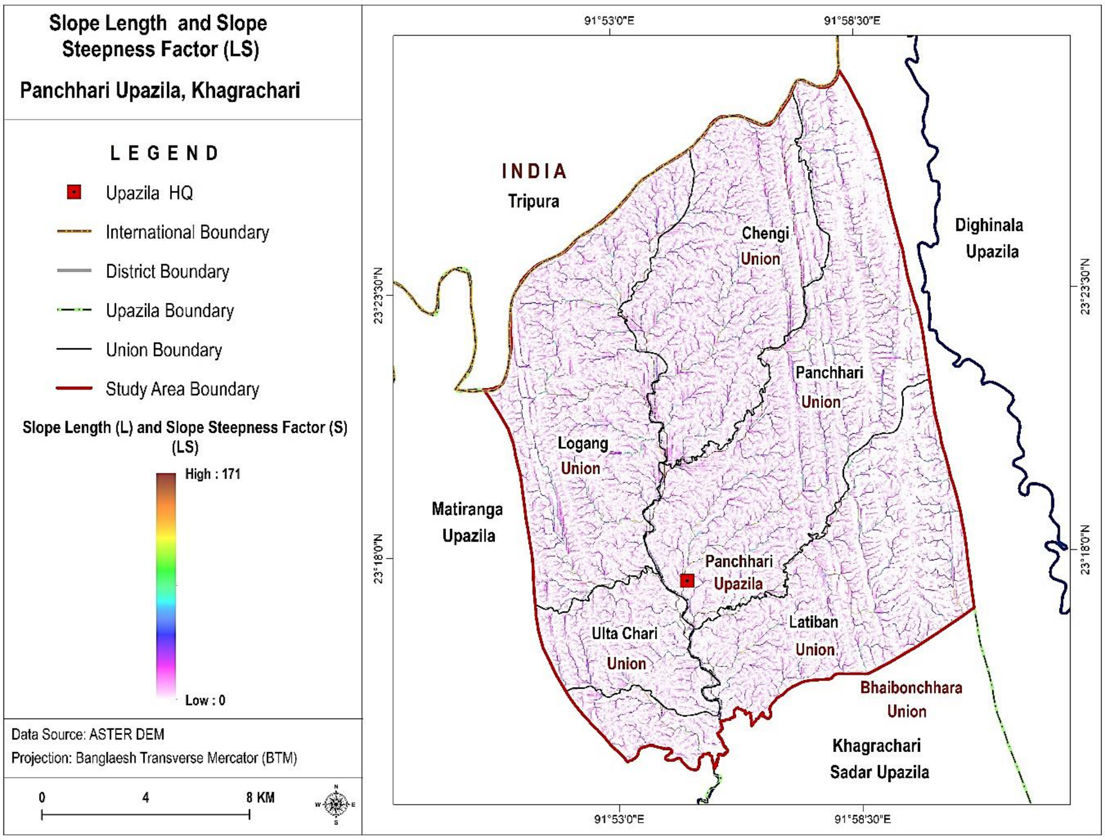

Figure 9. Slope length and slope steepness factor (LS) of the study area.

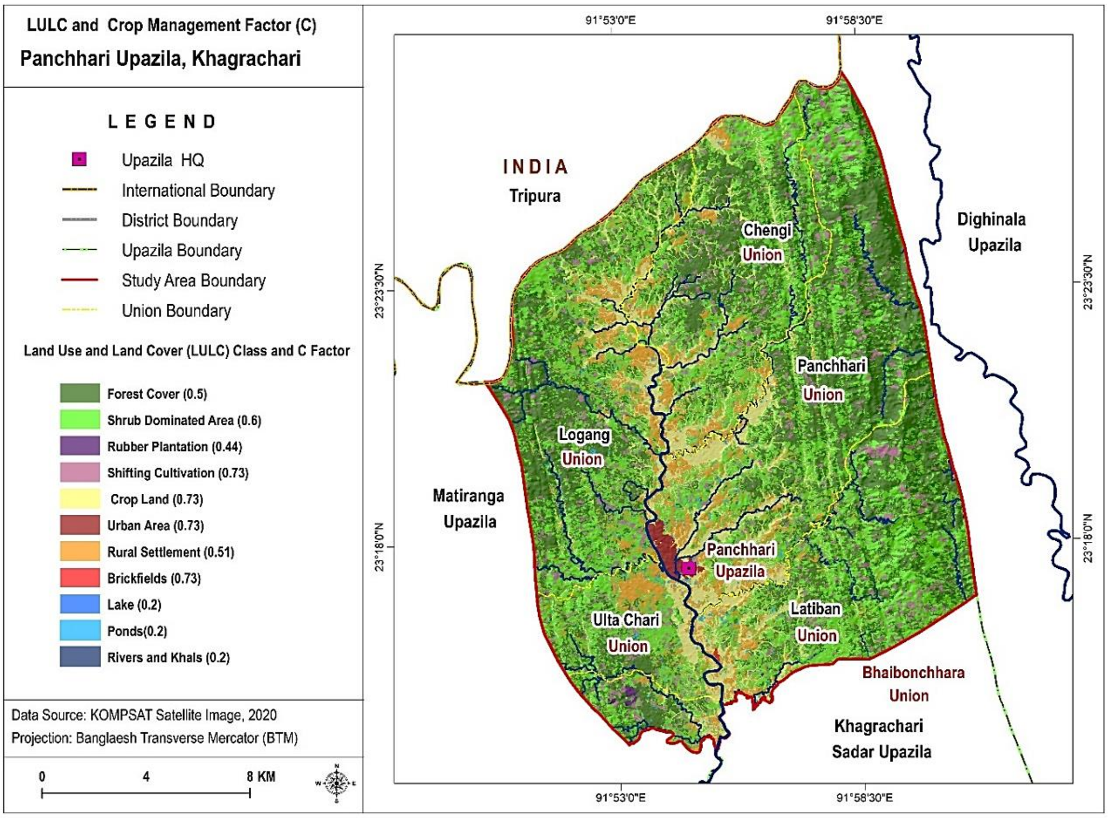

Figure 10. Land use and land cover (LULC) class and C factor of the study area.

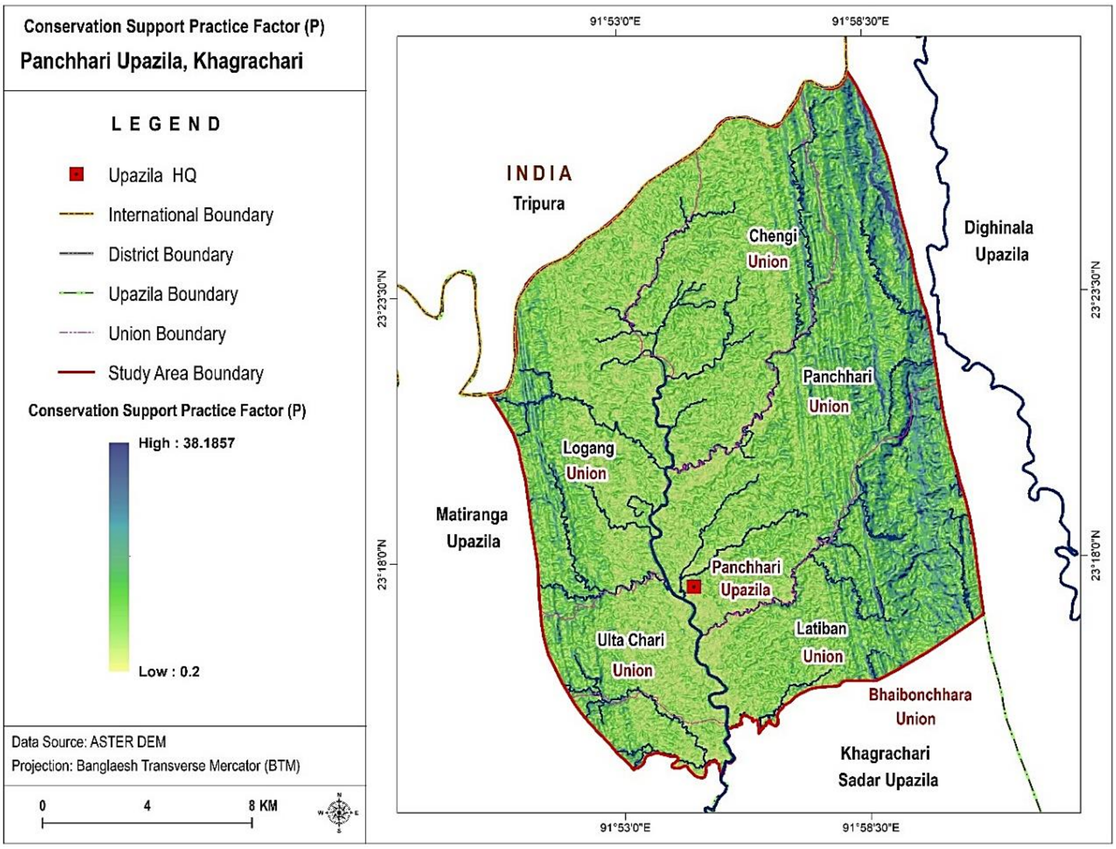

Figure 11. Conservation support practice factor (P) of the study area.

Table 3. LULC and their respective cover management factor (C).

S.N.	**LULC Class**	**Description**	**Area (ha)**	**Area (%)**	**C-factor**
01	Forest Cover	Forest cover consists of Evergreen Hill Forest and Mixed Hill Forest. Generally, the evergreen hill forest is the natural forest area within the reserve forest boundary and protected forest boundary of Chittagong Hill Tracts (CHT). It is made up of semi-evergreen and evergreen trees in moist tropical climates, and its age distribution is typically irregular. On the other hand, a mixed hill forest is the natural forest area, which exists outside of the reserve and protected forest boundary of Chittagong Hill Tracts (CHT. The forest consists of a mixture of moist tropical evergreen and deciduous trees.	11542.80	34.59%	0.5
02	Shrub Dominated Area	The geographic area with natural woody vegetation with a height less than 5 meters. The uppermost canopy layer is dominated by trees. The total percent of shrub cover exceeds 75%. Common in Chittagong Hill Tract.	12235.06	36.66%	0.6
03	Rubber Plantation	The large geographic area where the rubber (Hevea brasiliensis) is planted for latex production. Trees are planted in well-drained soil with 3%-32% slope. It is broadleaved, deciduous in the drier month for a very short period.	29.65	0.09%	0.44
04	Shifting Cultivation	Lands that are temporarily planted with herbaceous crops, abandoned, and let to naturally regenerate as the farmer moves on to another location fall under this category.	1939.43	5.81%	0.73
05	Crop Land	This category covers permanent agricultural areas where a single herbaceous crop is grown each year on the same plot of ground for a number of years.	4278.62	12.82%	0.73
06	Urban Area	The built-up areas that have impermeable surfaces on the land due to non-linear manmade constructions fall under this	187.53	0.56%	0.73

S.N.	LULC Class	Description	Area (ha)	Area (%)	C-factor
		category. The "Hard Materials" or "Light Materials" that are used to manufacture the materials can be either type. The user may choose a cover percentage.			
07	Rural Settlement	Geographical areas of linear or clustered rural homes (often with wooden and tin roofs) may be connected by small-scale vegetable gardens, open spaces, and ponds around the homes. These homes are typically surrounded by plantations of fruit trees.	2723.20	8.16%	0.51
08	Brickfields	Geographic areas used for bricks production	7.00	0.02%	0.73
09	Lake	A lake is a man-made body of water with an irregular shape and a surface area that is typically greater than 50 ha.	1.40	0.004%	0.2
10	Ponds	A pond is an artificial surface of standing water that is usually smaller than a lake and has a regular shape. The ponds more than 0.3 hectare will be include in the class "Ponds" but the ponds functionally related with rural settlement will be included in the class "Rural Settlement (RS)"	79.95	0.24%	0.2
11	Rivers and Khals	Naturally flowing freshwater which serves as water drainage channels.	346.15	1.04%	0.2
Grand Total			*33370.78*	*100.00%*	

Table 4. Accuracy statistics of landscape features of the Panchhari Upazila.

S.N.	Land Use Class and Code	F	S	FPr	SC	CH	BNl	RS	Br	L	P	R	Ground Truth Total	User Accuracy	Kappa
01	Forest cover (F)	159	2	2	0	0	0	0	0	0	0	0	163	0.98	
02	Shrub Dominated Area (S)	2	155	0	0	0	0	1	0	0	0	0	158	0.98	
03	Rubber Plantation (FPr)	0	0	5	0	0	0	0	0	0	0	0	5	1	
04	Shifting Cultivation	0	1	0	28	0	0	0	0	0	0	0	29	0.97	
05	Crop Land (CH)	0	0	0	0	64	0	0	0	0	0	0	64	1	
06	Urban Area (BNl)	0	0	0	0	0	3	0	0	0	0	0	3	1	
07	Rural Settlement (RS)	0	0	0	0	0	0	50	0	0	1	0	51	0.98	
08	Brickfields (Br)	0	0	0	0	0	0	0	5	0	0	0	5	1	
09	Lake (L)	0	0	0	0	0	0	0	0	10	0	0	10	1	
10	Ponds (P)	0	0	0	0	0	0	0	0	0	7	0	7	1	
11	Rivers and Khals (R)	0	0	0	0	0	0	0	0	0	0	5	5	1	
12	Total Reference Point	161	158	7	28	64	3	51	5	10	8	5	500		
13	Producer Accuracy	0.99	0.98	0.71	1	1	1	0.98	1	1	0.875	1			
14	Kappa														0.98

Cross Matrix Association with Several Factors and Causal Mechanisms of Soil Erosion

Table 5 illustrates the association and coherence among the parameters of soil erosion using Pearson's correlation along with the list-wise deletion method. A strong correlation ($p < 0.01$) and significant correlation ($p < 0.05$) was recorded in the correlation matrix which is a clear indication of substantial inter-parameter relationships. *R* had positive correlation with the rest of the parameters while the weakest relationship was found with soil erodibility (r = 0.042). Moreover, *K* showed a negative association with *LS* (r = -0.221) and *C* (r = -0.107) whereas a positive relation was observed with *P*, (r = 0.300) respectively incorporating 95% confidence level. *LS* and P had the highest association between them compared to other inter-parameter relationships, however, negatively correlated r = -0.575).

Table 5. Cross matrix and covariance/association with several factors for soil erosion in the study areas.

Factor	R factor	K factor	LS factor	C factor	P factor
R factor	1				
K factor	0.042***	1			
LS factor	0.083***	-0.221***	1		
C factor	0.096***	-0.107**	0.120***	1	
P factor	0.113***	0.300***	-0.575***	0.182***	1

The alteration of the water cycle caused by the changing climatic conditions has an impact on the process of soil erosion (Figure 12). The climate change affected rainfall in various ways, including intensification, and extreme rainfall events. Additionally, more frequent high temperatures accelerate evaporation and aid in cloud formation, which in turn causes precipitation. Particularly in steep regions like CHTs, increased rainfall that is intense and frequent can erode soil surfaces. However, the erosion of soils in the study area is influenced by several factors, including increased runoff, vegetation loss, slope steepness, soil properties, *Jhum* cultivation, and rubber plantation. For instance, barren slopes that face the sun dry out and become loose because they lack plant roots to sustain them. Moreover, rubber plantation areas utilize more surface water and prevent the proliferation of smaller plants or weeds that can trap runoff. Likewise, extensive slash and burn cropping leaves the soil exposed and full of dry organic components that lack the appropriate strength to hold onto rainwater and slow the rate of surface runoff. As a result, smaller soil particles are washed away by increased runoff rates. These eroded soil fragments moved to the nearby bodies of water, such as lakes and rivers, degrading the water quality and causing sedimentation in the water bodies' margins.

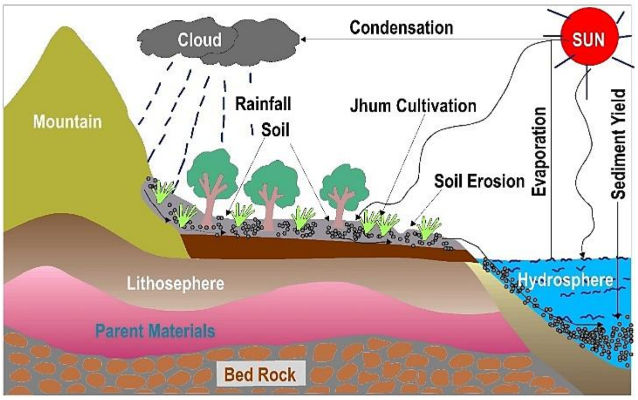

Figure 12. Schematic diagram showing the causal mechanism of soil erosion in the Hilly area of Bangladesh.

Estimation of Average Annual Soil Erosion (A)

The RUSLE model, together with the most advanced RS and GIS approaches, was used to calculate the rate of soil loss in the research region. The research area's average yearly soil loss ranged from 0 to 108517.42 t ha^{-1} y^{-1}. Surprisingly, the highest rate of soil loss derived from the cropland is ~108517.42 t ha^{-1} y^{-1} with a mean value of 546.69 ± 2274.75 (Table 6). Similarly, another cropping practice shifting cultivation generated the second most soil loss, and the maximum rate accounted for 50440.84 t ha^{-1} y^{-1} with a mean rate of 261.95 ± 970.9. However, the lowest soil loss rate is produced from water bodies, particularly lakes where the rate compute at 703.07 t ha^{-1} y^{-1} with a mean value of 153.3 ± 210.66.

Moreover, based on the results of the RUSLE model, the severity of soil erosion risk is categorized into five classes (t ha^{-1} y^{-1}) including Low Erosion (0-100), Moderate Erosion (101-1000), High Erosion (1001-5000), and Very High Erosion (5001-108517) (Figure 13 and Table 7). Furthermore, to identify the spatial risk of unions under the Panchhari Upazilla, the present study compute spatial coverage and soil erosion risk. Table 5 shows erosion ranges pertaining five unions the study area including Chengi, Latiban, Loang, Panchhiri and Ulta Chhari (Table 8). The areas under moderate and high erosion range were soared covering 60.59% and 35.25% area of Chengi union, respectively, whereas intense erosion (5001-108517 ta/ha/year) affected 41.31 ha area. Moreover, the Latiban union had experienced a similar kind of trend regarding moderate and high erosion patterns, however, the very high erosion category hit a peak at 0.79% compared to another unions. Likewise, the very high erosion range covered 0.77% of the area significantly, with drastic rise of moderate erosion class at 5650.02 ha and high erosion class at 3076.16 ha. Besides that, moderate erosion was prevalent in the Loang union with respective amount of 13.87% of the total study area. In addition, 32.12% area of the Ulta Chhari was recorded for high erosion category. Bottom line, maximum 1.35% of low erosion and 0.18% of high erosion area were both observed under the Latiban area; therefore, it is the tended most fluctuated characteristic compared to other unions considering erosion categories.

Table 6. Soil loess statistics from land use class.

S.N.	LULC		Soil losses (t/ha/year)			
	LULC Class	***Area (ha)***	***Area (%)***	***Max***	***Mean***	***Standard Deviation***
01	Forest Cover	11542.80	34.59%	27973.02	286.92	844.11
02	Shrub Dominated Area	12235.06	36.66%	42676.95	279.41	913.3
03	Rubber Plantation	29.65	0.09%	1562.18	62.84	134.05
04	Shifting Cultivation	1939.43	5.81%	50440.84	261.95	970.9
05	Crop Land	4278.62	12.82%	108517.42	546.69	2274.75
06	Urban Area	187.53	0.56%	35900.79	226.1	1376.21
07	Rural Settlement	2723.20	8.16%	49079.55	222.02	1208.96
08	Brickfields	7.00	0.02%	4210.56	360.27	817.96
09	Lake	1.40	0.004%	703.07	153.3	210.66
10	Ponds	79.95	0.24%	4049.77	134.21	341.31
11	Rivers and Khals	346.15	1.04%	47649.79	134.21	341.31
Grand Total		*33370.78*	*100.00%*			

Table 7. Categories of soil erosion, spatial coverages in hector and percentage.

S.N.	Erosion Categories	Soil Erosion Numeric Range (t/ha/year)	Area (ha)	Area (%)
1	Low Erosion	0-100	20443.74	0.61
2	Moderate Erosion	101-1000	11000.56	0.33
3	High Erosion	1001-5000	1687.96	0.05
4	Very High Erosion	5001-108517	238.52	0.01
Grand Total			*33370.78*	*1*

Table 8. Soil erosion rate of Panchhari Upazila.

Union and Area	Erosion Categories	Soil Erosion Numeric Range (t/ha/year)	Area (ha)	Area (%)	Union Area (%)
Chengi (6455.59 ha)	Low Erosion	0-100	227.018	0.68	3.52
	Moderate Erosion	101-1000	3911.53	11.72	60.59
	High Erosion	1001-5000	2275.74	6.82	35.25
	Very High Erosion	5001-108517	41.31	0.12	0.64
Latiban (7613.77 ha)	Low Erosion	0-100	451.33	1.35	5.93
	Moderate Erosion	101-1000	4762.07	14.27	62.55
	High Erosion	1001-5000	2340.40	7.01	30.74
	Very High Erosion	5001-108517	59.97	0.18	0.79
Loang	Low Erosion	0-100	347.52	1.04	4.59
	Moderate Erosion	101-1000	4628.63	13.87	61.18

Union and Area	Erosion Categories	Soil Erosion Numeric Range (t/ha/year)	Area (ha)	Area (%)	Union Area (%)
(7565.71 ha)	High Erosion	1001-5000	2541.25	7.62	33.59
	Very High Erosion	5001-108517	48.30	0.14	0.64
Panchhiri (9347.62 ha)	Low Erosion	0-100	549.65	1.65	5.88
	Moderate Erosion	101-1000	5650.02	16.93	60.44
	High Erosion	1001-5000	3076.16	9.22	32.91
	Very High Erosion	5001-108517	71.79	0.22	0.77
Ulta Chhari (2388.09 ha)	Low Erosion	0-100	112.44	0.34	4.71
	Moderate Erosion	101-1000	1491.50	4.47	62.46
	High Erosion	1001-5000	767.00	2.30	32.12
	Very High Erosion	5001-108517	17.15	0.05	0.72
Grand Total			*33370.78*	*100.00%*	

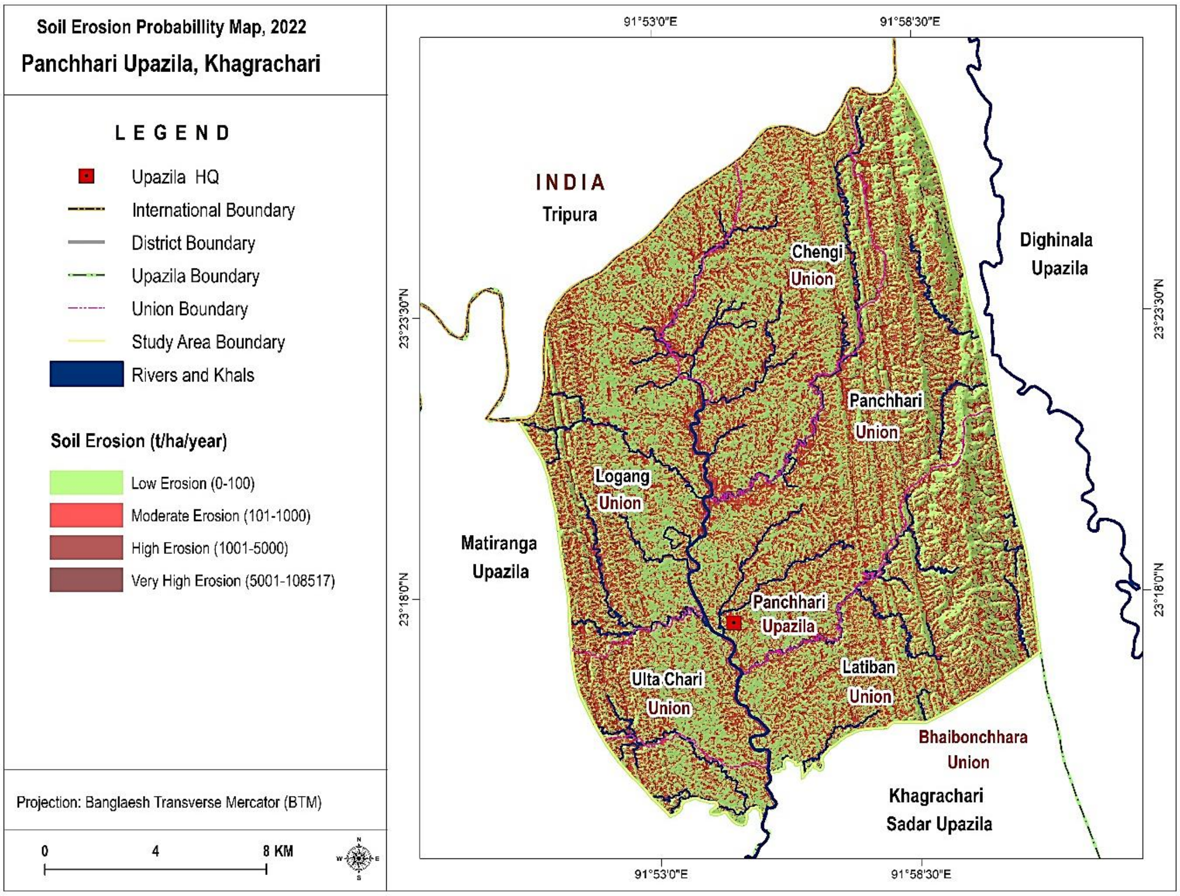

Figure 13. Soil erosion probability map of the study area.

Implication of Agriculture Practices on Soil Erosion in the Forest Landscape

The mass of individuals who live in CHTs depends mostly on crop production for their income. There are variations in cropping patterns in different regions. The hilly areas are difficult to irrigate and are especially vulnerable to erosion. The topography, physiography, climate, rainfall, use of modern technology, irrigation, and transport facilities all have an impact on cropping patterns and changes (Rashid et al., 2005; Quais, et al., 2017) [52, 53]. Due to the significant amount of monsoon rainfall, the CHTs valleys and floodplains are suited for plough agriculture, which is mostly utilized for rice, maize, tobacco, potato, cotton, papaya, sugarcane, pineapple, turmeric, and other crops. In the hilly region, shifting cultivation, also known as *Jhum*, is one of the most ancient agricultural techniques. In shifting cultivation land is cleared by controlled fire, utilized only for subsistence farming, and then left fallow naturally for an extended period of time to allow woody vegetation to take control. Even though Jhum cultivation has dropped significantly in recent years, it remains a dominating land use system in the steep terrain and has been practiced for generations by local indigenous communities of CHTs. However, soil erosion in the CHTs forest landscape is mostly anthropogenic intervention including intensive cropping practices along with deforestation, overgrazing, and tillage and these activities lead to changes in the ecological system. Moreover, the results of human activities have had significant impacts on the carbon and nutrient cycles, land productivity, and ultimately, global socioeconomic conditions.

Soil Erosion Impacts and Risk Management Strategies

Soil provides dynamic ecosystem services and maintains the earth's natural processes and geochemical renovations that are essential for terrestrial ecosystems. But soil erosion is inversely correlated with ecosystem services, creates environmental challenges, and imposes a threat to environmental systems. Over the past few decades, due to the growing demand for arable land for rapid population growth and anthropogenic interventions in the CHTs of Bangladesh, the landscape of the forest has continuously collapsed its ecological balance.

Although, the government and associated various stakeholders has been taken numerous development initiatives to develop the existing forest landscape. But, at the same time, structural development like a communication network over the forest landscape increases the vulnerability of rapid landslides and soil erosion. The forest cover degradation through forest fair, hill cutting, and the mother tree cutting seriously threat to rapid soil erosion which negatively imposes ecosystem services. Commercial rubber plantations increase the vulnerability of soil loss because under its canopy other vegetation cannot grow up. For precious as well as robust results of soil loss rate using the RUSLE model high-resolution DEM is a prerequisite. But our study has a few limitations, we used course resolution DEM for topographic factors assessment of soil loss. Moreover, the present study has no funding support, that’s why we have taken a small portion of CHTs to conduct the research work. Furthermore, there is no relevant study in the CHTs region, from where we can correlate and justify the study results.

In the CHTs region of Bangladesh, particularly on the hill slope of the forest landscape under construction land-use initiatives and unplanned commercial agriculture practices should be controlled by government authorities. Organizations from both the government and non-government sections, step forward to protect the forest environment along with its ecological system by implementing proper land use policies, rules, and regulations. The demolished hill forest should be under the ecological restoration process through associated organizations by involving the indigenous power of the tribal community.

CONCLUSION

The current study demonstrated how to measure soil erosion at the Panchhari Upazila within the Khagrachari district of CHTs using the RUSLE model and its sub-model. Utilizing RS and GIS advanced technologies, the RUSLE model was used in this investigation aimed at quantifying the yearly mean soil loss and its impact on forest landscapes. The outcome of the RUSLE model discloses that, in the research region, yearly mean soil loss ranged from 0 to 108517 t ha^{-1} y^{-1}. The probability map of soil erosion showed that roughly 0.71%, 4.02%, 61.26%, and 34.01% of the region fall into the low, moderate, and high erosion groups, respectively. Soil erosion spatial patterns in the region varied on the basis of topography and landscape features. The spatial risk of soil erosion is relatively high in Latiban Union of the research area with 0.18% (59.97 ha) of the total area falling within very high erosion zones. The maximum high soil erosion spatial coverage displayed in the Loang union of the study area represents 7.62% (2541.25 ha) of the total area. The lowest soil erosion unveils in the Chengi Union of the study area and represents 0.68% (227.01 ha). The C factor values demonstrate that these are unsuitable for the research area's north-eastern region. In such cases, an appropriate soil conservation procedure must be implemented. The probability map of soil loss classified the research region based on their soil loss assessment which will ultimately aid in the development of appropriate protection measures.

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