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Soil Erosion Assessment of a Hilly Terrain by RUSLE Model - A Case Study of Chittagong Hill Tracts

RUSLE Modeli ile Tepelik Bir Arazinin Toprak Erozyonunun Değerlendirilmesi - Chittagong Hill Tracts Örneği

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Abstract

Among many environmental problems, soil erosion poses a serious threat to the region known as Chittagong Hill Tracts (CHTs) in Bangladesh, comprising three districts, namely Bandarban, Rangamati, and Khagrachari. The annual soil erosion rate for this hilly terrain was calculated using the Revised Universal Soil Loss Equation (RUSLE) model integrated with Remote Sensing and Geographic Information System (GIS). The ranges of the estimated erosivity of rainfall, erodibility of the soil, slope length and slope steepness, crop management factor and conservation practices are 806.2 to 1513.2 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} (or an average of 1121.5 MJ.mm.ha^{-1}.h^{-1}.yr^{-1}), 0 to 0.02 t.h.MJ^{-1} mm^{-1}, 0 to 78.8 (or average 0.41), 0 to 0.63 (or average 0.57) and 0.55 to 1 (or average 0.73), respectively. As per the findings, the study area is expected to lose 182621.5 *tons of soil annually, with the estimated annual soil erosion rate of 15.18 t.ha^{-1}.yr^{-1} also predicted. The weighted overlay index approach was used to produce the probability zone map, which shows that the majority of the research region falls within the slight probability zone and that only a small percentage falls inside the high and very high probability zones. This study proves RS-GIS is useful for predicting erosion and can be used in soil conservation programs.*

Keywords: *Soil erosion, USLE, RUSLE, Remote sensing and GIS*

Özet

Pek çok çevre sorunu arasında toprak erozyonu, Bangladeş'teki Bandarban, Rangamati ve Khagrachari olmak üzere üç ilçeden oluşan ve Chittagong Hill Tracts (CHTs) olarak bilinen bölge için ciddi bir tehdit oluşturmaktadır. Bu engebeli arazi için yıllık toprak erozyon oranı, Uzaktan Algılama ve Coğrafi Bilgi Sistemi (GIS) ile entegre edilmiş olan Yenilenmiş Evrensel Toprak Kayıpları Eşitliği (YETKE) modeli kullanılarak hesaplanmıştır. Yağışın tahmini erozivitesi, toprağın erodibilitesi, eğim uzunluğu ve eğim dikliği, mahsul yönetim faktörü ve koruma uygulamaları aralıkları, sırasıyla, 806,2 ila 1513,2 MJ.mm. ha^{-1}.h^{-1}.yr^{-1} (veya ortalama 1121,5 MJ.mm. ha^{-1}.h^{-1}.yr^{-1}), 0 ila 0.02 t.h.MJ^{-1} mm^{-1}, 0 ila 78.8 (veya ortalama 0.41), 0 ila 0.63 (veya ortalama 0.57) ve 0.55 ila 1 (veya ortalama 0.73) olarak ölçülmüştür. Elde edilen bulgulara göre, çalışma alanında yılda 182621,5 ton toprak kaybı beklenmektedir ve tahmini yıllık toprak erozyon oranı da 15,18 t.ha^{-1}.yr^{-1} olarak öngörülmüştür. Ağırlıklı bindirmeli indeks yaklaşımı kullanılarak oluşturulan olasılık bölgesi haritası araştırma bölgesinin çoğunluğunun hafif olasılık bölgesi içinde kaldığını ve yalnızca küçük bir yüzdesinin yüksek ve çok yüksek olasılık bölgeleri içinde kaldığını göstermektedir. Bu çalışma, Uzaktan Algılama (RS) ve CBS teknolojilerinin erozyonu tahmin etmede yararlı olduğunu ve toprak koruma programlarında kullanılabileceğini kanıtlamaktadır.

Anahtar Kelimeler: *Toprak erozyonu, USLE, RUSLE, Uzaktan algılama ve CBS*

1. Introduction

Soil erosion is a natural occurrence of the earth caused due to the displacement of the top layer of soil by water or wind to another location as well as anthropogenic actions, including agroeconomic practices, deforestation, shifting forest into agricultural land, etc., would also enhance erosion. Some factors – for example, slope steepness, climatic changes including heavy precipitation, inept land use and land cover patterns – drive soil erosion (Ganasri and Ramesh, 2016). It is regarded as the second significant environmental issue confronted by the world following population expansion (Jahun et al. 2015). It decreases the efficiency of soil and ecosystems, such as vegetation and agricultural ecosystems, and has a negative impact on the biodiversity of plants, animals, and soil microorganisms. Every year, around 10 million hectares of agricultural land are abandoned worldwide due to a lack of productivity brought by soil erosion (Saha et al. 2022).

Soil erosion is a major problem in several hilly areas of Bangladesh, including Sylhet, Chattogram, and the Chittagong Hill Tracts (CHTs), while more than half of the CHTs are in danger of experiencing it. With heavy monsoon rains, the topsoil of the area is washed away, while the areas of Bangladesh have gradually declined due to soil erosion over time (Islam et al. 2015). Given the encroachment on reserve forests, the earlier management method is no longer practicable. Farmers are under increasing pressure to reduce fallow time, which hastens soil erosion and depletion of nutrients, putting rural livelihoods at risk (Bai, 2006). Furthermore, Jhum cultivation and burning, accounting for almost 37%, has also exacerbated soil loss in the area, which could negatively influence biodiversity, stream flow, agricultural production, soil condition, and flood severity (Das et al. 2018). The maximum erosion in the fallow season is 7.40 $t.ha^{-1}.yr^{-1}$, whereas it is 70.05 $t.ha^{-1}.yr^{-1}$ during the cropping season (Hasan and Alam, 1970).

Geospatial innovation has recently progressed, transforming it into an effective technology for managing, analyzing, and monitoring natural resources (Prasannakumar et al. 2011). Models of soil erosion can be categorized into two basic categories such as empirical models and physically-based models. RUSLE (Revised Universal Soil Loss Equation), USLE (Universal Soil Loss Equation), MUSLE (Modified Universal Soil Loss Equation), and CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems), etc., are empirically based models, whereas EUROSEM (European Soil Erosion Model), SHE (Systeme Hydrologique Europeen or European Hydrological System), etc., are physically-based models (Jha and Paudel, 2010). One of the most common techniques is USLE, which was first designed for the assessment of soil erosion in such areas with a gentle slope (Wischmeier and Smith, 1978). Afterwards, RUSLE was improved, expanding its spectrum of uses by incorporating conditions such as forests, farmlands, and barren lands (Renard et al. 1997). Because of its simplicity of computation and application, the RUSLE has been frequently used for soil loss evaluation at the catchment level (Lu et al. 2004). Over the past few decades, geographic information systems (GIS) have played a significant role in the creation and analysis of maps, enhancing the RUSLE and making it a more precise and advanced model (Farhan et al. 2013).

However, in Bangladesh, no baseline research on soil erosion exists in any part of the country (Saha and Sauda, 2019). With this perspective, the current study is conducted in CHTs of Chattogram, Bangladesh, to identify the most vulnerable areas and estimate the geographic distribution of surface soil erosion using RUSLE. Therefore, the overall objective of this research is – to calculate the total surface soil erosion by delineating the probability zone in a tropical hilly area, CHTs using the RUSLE model.

2. Study Area and Data

2.1 Description of the study area

The location of CHTs, as seen in Figure 1, has a physical area of 13,184 square kilometers, or 10% of Bangladesh's total land. Without kaptai lake, however, the area of CHTs would be 12027.5 square kilometers. Rangamati, Khagrachari, and Bandarban are the three districts that make up the area. The Chittagong Hill Tracts (CHTs) are predominantly composed of alluvial plains, rivers, hills, ravines, and cliffs, which are heavily forested, in contrast to the majority of Bangladesh. The annual rainfall ranges from 2540 mm to 3810 mm in the north and east, and is nearly 2540 mm in the south and west. The cold and dry season runs from November to March; the sunny and hot pre-monsoon season runs from April to May; in addition, the cloudy and rainy monsoon season runs from June to October. The soils of the hill (dystric cambisols) consist of yellowish-brown to reddish-brown loams that develop into fractured sandstone or shale and mottled sand at various depths. The grounds are pretty acidic. Despite the challenges of farming on hills, there is still enough natural vegetation to be found. According to Bangladesh's physiography, the CHTs is part of the Eastern and Northern Hill units.

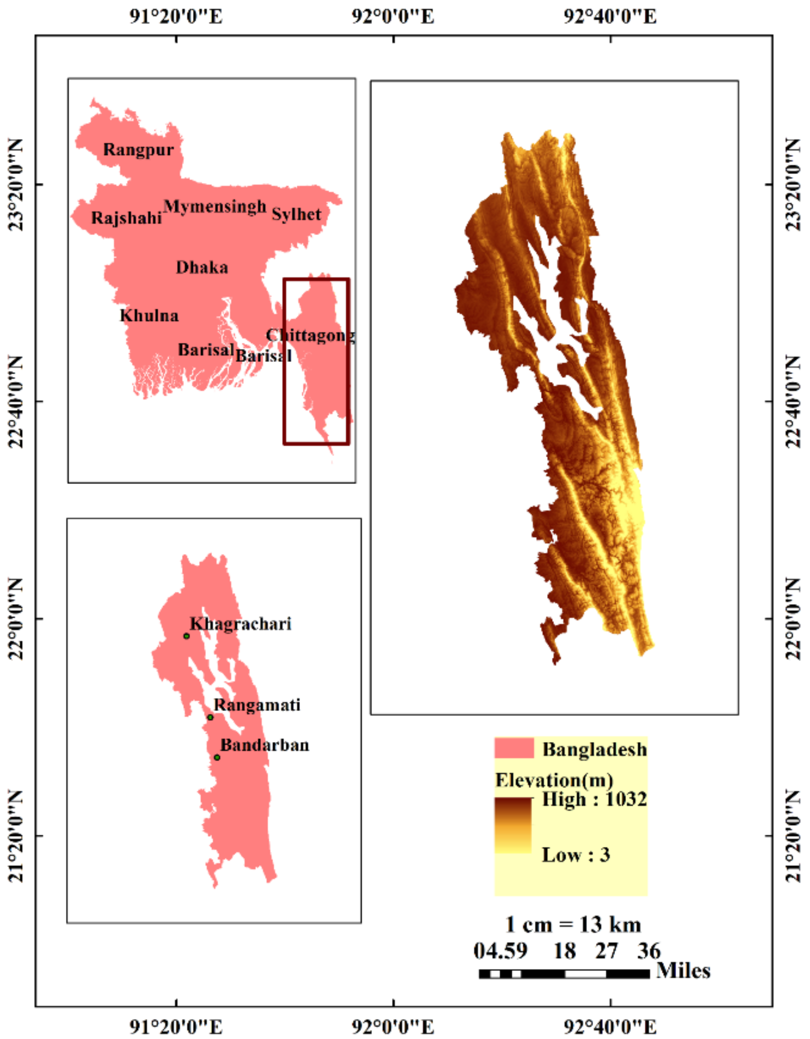

Figure 1. Study area map of the CHTs with Digital Elevation Model (DEM) in Bangladesh

2.2 Data source

In this study, the data was used to calculate all factors derived from secondary databases, remote sensing methods and open-source sources, as seen in Table 1. The ASTER DEM was obtained from NASA EARTHDATA and the LANDSAT 8 images from Earth Explorer. The NDVI is calculated on the Google Earth Engine platform using JavaScript code. The Digital Soil Map (vector data) of the world can be freely downloaded from mentioned website (Table 1). The soil loss map was created using ArcGIS 10.8 after all the data had been collected.

Table 1. Comprehensive overview of the data used

Category	Source	Spatial Resolution	Temporal Period	Variables	Reference
Rainfall Data	Giovanni	-	2009-2019	10 years average annual rainfall	Earthdata (2022a)
Soil Data	FAO-UNESCO	5 arc min	1974	Texture: Sand, silt and clay, and organic matter (%)	FAO (2022)
DEM	ASTER	30 m	-	Slope	Earthdata (2022b)
Satellite Image	LANDSAT 8	30 m	2009-2019	Normalized Difference vegetation index (NDVI)	USGS (2022)

3. Methodology and Parameter Estimation

RUSLE is a combination of mathematical formulas that may calculate average soil loss annually from erosive processes. This method- has been used to assess soil erosion loss, and help to develop conservation strategies for soil erosion management in various scenarios, including rangelands, croplands, and disturbed forestlands. A schematic representation of the general methodology followed in the study is presented in Figure 2.

3.1 Estimation of RUSLE parameter

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) remain the most commonly used formula for evaluating soil erosion, despite the flaws and limitations (Zhang et al. 2013). RUSLE is easy to use since it uses a modern computer interface with physically relevant input variables often accessible in current databases. Besides, it can also be retrieved quickly from DEM and remotely sensed images. RUSLE is the most effective method for erosion analysis currently available, and it may be used locally or regionally. Climate, topography, soil properties, and land cover management are part of the RUSLE model, which is an equation that depicts the essential components that cause soil erosion. The RUSLE equation is expressed as:

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

Where,

A = The predicted spatial average annual soil loss per unit of area (t $ha^{-1}.yr^{-1}$);

R = Rainfall-Runoff Erosivity Factor (MJ mm. $ha^{-1}.h^{-1}.yr^{-1}$);

K = Soil Erodibility Factor ($t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$);

LS = Slope length and slope steepness Factor (dimensionless);

C = Cover-Management Factor is the ratio of soil erosion from a defined site (dimensionless);

P = Conservation/Support Practices Factor is soil erosion ratio with contour tillage and support practice, terracing, and strip cropping (dimensionless).

3.2 Rainfall Erosivity Factor (R)

The influence of rainfall intensity on surface soil erosion is calculated using the rainfall erosivity factor (R), and it requires a large amount of consistent precipitation data (Ganasri and Ramesh, 2016). Regional differences in precipitation patterns are reflected in R factor variations. Low erosivity R-values are seen in regions with downward slope degrees, meaning that low areas would improve water infiltration on the surface, preventing raindrops from eroding soil particles. When the R factor exceeds a specific level, it indicates more severe weather. Rainfall values may be obtained from computed using existing data or iso-erodent maps and tables (Farhan et al. 2013).

The Monthly precipitation data from 2009 to 2019 was used in this study to estimate the R factor using the following equation established by Singh et al. (1981).

$$R = 79 + 0.363R_{\mathrm{N}} \tag{2}$$

Where R_N is the average annual rainfall (mm).

The Chittagong Hill Tracts' study area accounted for 11 years of rainfall data from 36 locations over 25 Upazillas. The inverse distance weighted (IDW) technique of interpolation was utilized to estimate the spatial distribution of average annual rainfall (R_N) in the study area.

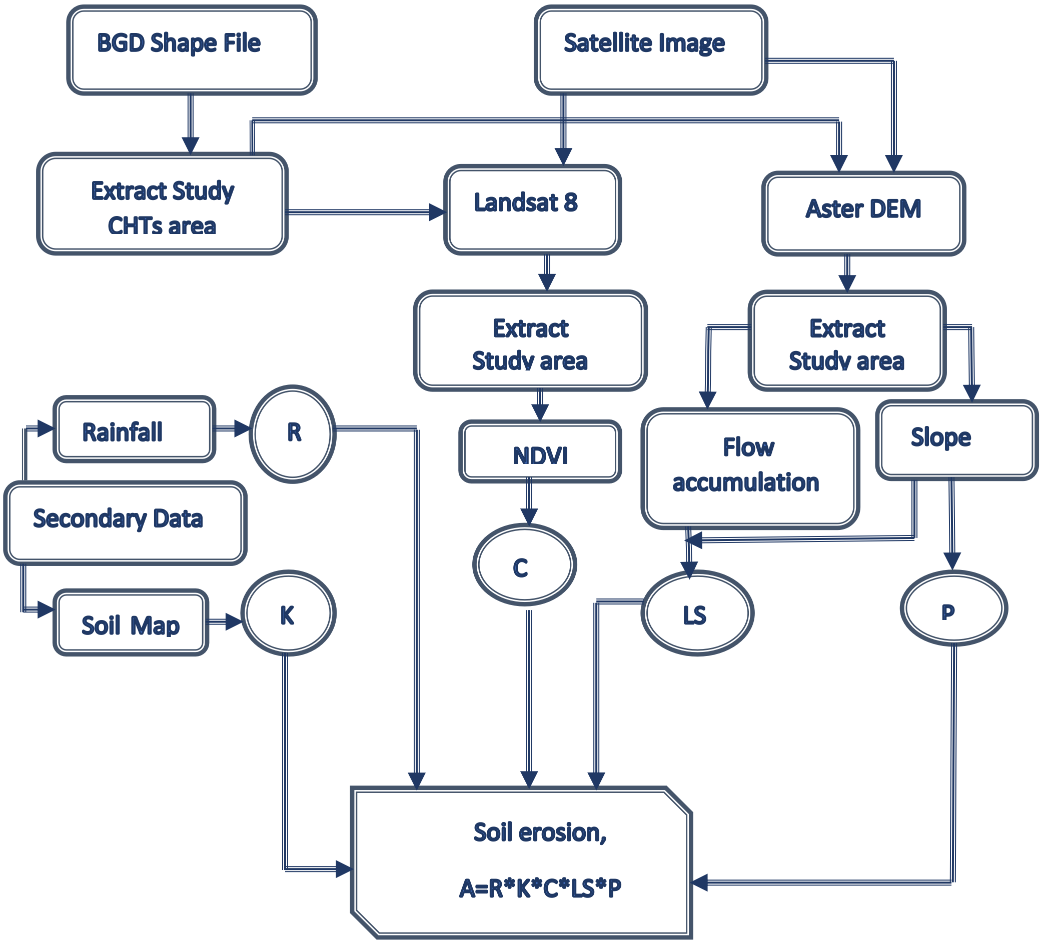

Figure 2. Flow chart of RUSLE methodology

3.3 Soil Erodibility Factor (K)

Soil erodibility is influenced by structure (e.g. macro porosity, aggregate characteristics), texture, organic matter content, hydraulic properties, and wettability. Several meteorological, physical, hydrological, chemical, mineralogical, and biological variables impact soil erodibility, are also known as soil susceptibility to erosion (Ostovari et al. 2017). The combined effect of soil properties as seen in Table 2, and profile features on soil erosion rates are important for the soil erodibility factor (K) (Kim et al. 2005). The following is the equation developed by Wiliams and Singh (1995) for calculating the K-factor:

$$k_{usle} = k_w = f_{c/sand} \times f_{cl/si} \times f_{orgc} \times f_{hisand} \times 0.1317 \tag{3}$$

Where,
$f_{c/sand}$ is a factor that affects how much or how little coarse sand is in a soil's composition, reducing the k indicator.
$f_{cl/si}$ provides high soil erodibility factors on soils with low clay-to-silt ratios
f_{orgc} indicates that soils with a high carbon content have lower k values, and
f_{hisand} rises in K values for shallow soils with sand content.

$$f_{c/sand} = 0.2 + 0.3 \times \exp[-0.256 \times m_s \times (1 - \frac{m_{silt}}{100})] \tag{4}$$

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

$$f_{orgc} = \left(1 - \frac{0.25 \times C_{org}}{C_{org} + \exp[3.72 - 2.95 \times C_{org}]}\right) \tag{6}$$

$$f_{hisand} = \left(1 - \frac{0.7\times\left(1-\frac{m_S}{100}\right)}{\left(1-\frac{m_S}{100}\right)\times exp\left[-5.51+22.9\times\left(1-\frac{m_S}{100}\right)\right]}\right) \tag{7}$$

Here,
m_s = the proportion of sand with a diameter of 0.05 to 2.00 mm [%];
m_{silt} = the proportion of silt with a diameter of 0.002–0.05 mm [%];
m_c = the percentage of clay with a diameter of <0.002 mm [%] and
C_{org} =the proportion of carbon content in organic matter (SOC) [%].

Table 2. Soil characteristics of the CHTs region (FAO-UNESCO, 1987)

Soil unit symbol	Types of soil	Sand % topsoil	Silt % topsoil	Clay % topsoil	OC % topsoil
Bd	Dystric Cambisols	32.7	30.3	37.1	3.28
Af	Ferric Acrisols	61.7	14.4	23.9	0.91
Bd	Dystric Cambisols	32.7	30.3	37.1	3.28
Af	Ferric Acrisols	61.7	14.4	23.9	0.91
Ge	Eutric Gleysols	42.8	20.4	36.8	1.3
Bd	Dystric Cambisols	32.7	30.3	37.1	3.28

Here,
Af = Ferric Acrisols;
Bd = Dystric Cambisols
Ge = Eutric Gleysols.

The K ($t.h.MJ^{-1}\ mm^{-1}$) value was calculated using Eq. 3, and the K factor map was created as a result in ArcGIS. The soil map was obtained from the FAO website, and the organic matter and texture of the soil, (silt (%), sand (%), clay (%)) were found from the FAO information excel sheet and calculated using Eq. 4, Eq. 5, Eq. 6, Eq. 7, and the estimated findings can be as seen in Table 3.

Table 2. Estimated soil properties according to the formula

Soil unit symbol	$f_{c/sand}$	$f_{cl/si}$	f_{orgc}	f_{hisand}
Bd	0.2009	0.7867	0.9744	0.99998
Af	0.2000	0.7457	0.9937	0.98986
Bd	0.2009	0.7867	0.9744	0.99998
Af	0.2000	0.7457	0.9937	0.98986
Ge	0.2001	0.7340	0.9848	0.99980
Bd	0.2010	0.7867	0.9744	0.99998

3.4 Slope length and slope steepness (LS)

The dimensionless LS, or topographic factor, demonstrates how topography affects soil erosion by combining the slope length factor (L) and slope steepness factor (S). Slope steepness is relatively more responsible for soil loss compared to slope length (Thomas et al. 2018; Shi et al. 2004). The slope length and slope steepness (LS) factor in this study were computed using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model with a 30 m spatial resolution, as seen in Figure 1. The following equation developed by Moore and Burch (1986) was used to calculate the slope length and slope steepness factor (LS):

$$LS = \left(\frac{\lambda}{22.13}\right)^m \times \left(\frac{sin\beta}{0.0896}\right)^n \times Z \tag{8}$$

where,
β is the angle of slope in radian and $= 3.14 \times \frac{\theta}{180}$
Z is the riling factor of value = 1.62 and *n* is a coefficient of value = 1.3 (Moore and Burch, 1986).
λ = flow accumulation x cell size
m = 0.14, which is a universal constant.

LS factor has no dimension. Using the ArcHydro tools of ArcGIS 10.8, the slope angle, flow accumulation, and flow direction from the DEM were obtained. The LS factor was then calculated using the above equations.

3.5 Crop Management Factor (C)

The C factor is most likely the critical USLE component since it highlights conditions that are easier to control in terms of erosion reduction. Depending on the season and agricultural production method, plant canopy and ground cover influence soil erosion in the forest environment. The seasonal change in the C-factor is influenced by several factors, including rainfall, agricultural practices, crop variety, and so on (Ganasri and Ramesh, 2016).

Data sets based on remotely sensed sources were utilized to estimate the C factor because the variability in land cover, fluctuations in spatial and temporal aspects. A clear indication for calculating plant health, vegetation energy, and green biomass is the Normalized Vegetation Difference Index (NDVI) (Mukanov et al. 2019). NDVI is generated from the equation for Landsat-8 OLI, represents the energy reflected by the earth under various circumstances of surface cover type. The NDVI scale has two bands, ranging from -1.0 to +1.0. NDVI readings at the extremities of the data range are caused by a substantial discrepancy between the two bands. Landsat 8 (band 4 and 5) satellite images were used from January 2009 to December 2019 to calculate NDVI. The formula is:

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

Under tropical climate conditions the cover management factor (C) of the study area was calculated by using the equation proposed by Durigon et al. (2014).

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

3.6 Conservation support-practice factor (P)

By modifying the flow pattern, slope, or direction of surface runoff and reducing runoff rates, the P factor shows the need for supporting measures that prevent soil loss. P factor compares soil loss caused by one support system to losses caused by gradual incline and downhill slope tillage. Lower P values, in general, imply that conservation practices are effective in reducing soil erosion (Thomas et al. 2018).

Khosrokhani and Pradhan (2014) used the following equation for calculating the P factor.

$$p = 0.03 \times S + 0.2 \tag{11}$$

Where, S = slope in percentage.

Based on this computation, the P factor value was applied as a slope function for regions lacking support practices or locations where support practices weren't accessible. The only thing needed for the equation is the slope, which may be easily derived from a DEM.

The activities that conserve soil in order to prevent soil erosion are referred to as Support Practice Factor, P. Some of the most well-known and documented management strategies are contour farming, terracing, and strip cropping (Byizigiro et al. 2020). Table 4 displays the P values are between 0 and 1, with 1 indicating no conservation and 0 showing excellent resistance. Contouring conservation indicators were used because the research region features steep slopes, and farming methods have evolved in response to topographical changes.

Table 3. According to the soil conservation practice, support practice factor values (Shin, 1999)

Slope %	*Contouring*	*Strip Cropping*	*Terracing*
0.0-7.0	0.55	0.27	0.10
7.0 -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	0.50	0.20

3.7 Identifying Risky Areas: Depiction of Soil Erosion Probability Zones

To identify and prepare map vulnerable areas to soil erosion involves the integration of various thematic maps in a Geographic Information System (GIS). To achieve this, major factors that influence soil erosion are taken into consideration, including land use-land cover as shown in Figure 3, soil properties, rainfall intensity, and slope. Weighted Index Overlay (WIO) is a raster overlay analysis technique that involves assigning a weightage to each factor based on their contribution to soil erosion. In WIO, the maximum value is assigned to the feature that is most susceptible to soil erosion, and the minimum value is given to the least susceptible feature. This method integrates all the thematic maps and creates a single map that represents the overall soil erosion vulnerability of the study area. This map can then be used to prioritize areas for conservation and management interventions (Ganasri and Ramesh, 2016).

3.8 Sediment delivery ratio (SDR)

The sediment delivery ratio (SDR) of a watershed represents its overall potential to stock and transport eroded soil, and is influenced by a range of physical characteristics such as drainage area, slope, land use land cover change, relief-length ratio, sediment particle size and runoff-rainfall factors (Gelagay, 2016). In this study, Boyce Model (1975) empirical methods were used to calculate the sediment delivery ratio.

$$SDR = 0.3740 \times (\mathrm{B})^{0.2382} \quad (12)$$

B = Watershed Area in km^2. The SDR was calculated 0.12. The sediment yield or soil loss was calculated by simply multiplying the soil erosion (A) obtained from the RUSLE with the SDR value (Tufekcioglu et al. 2018).

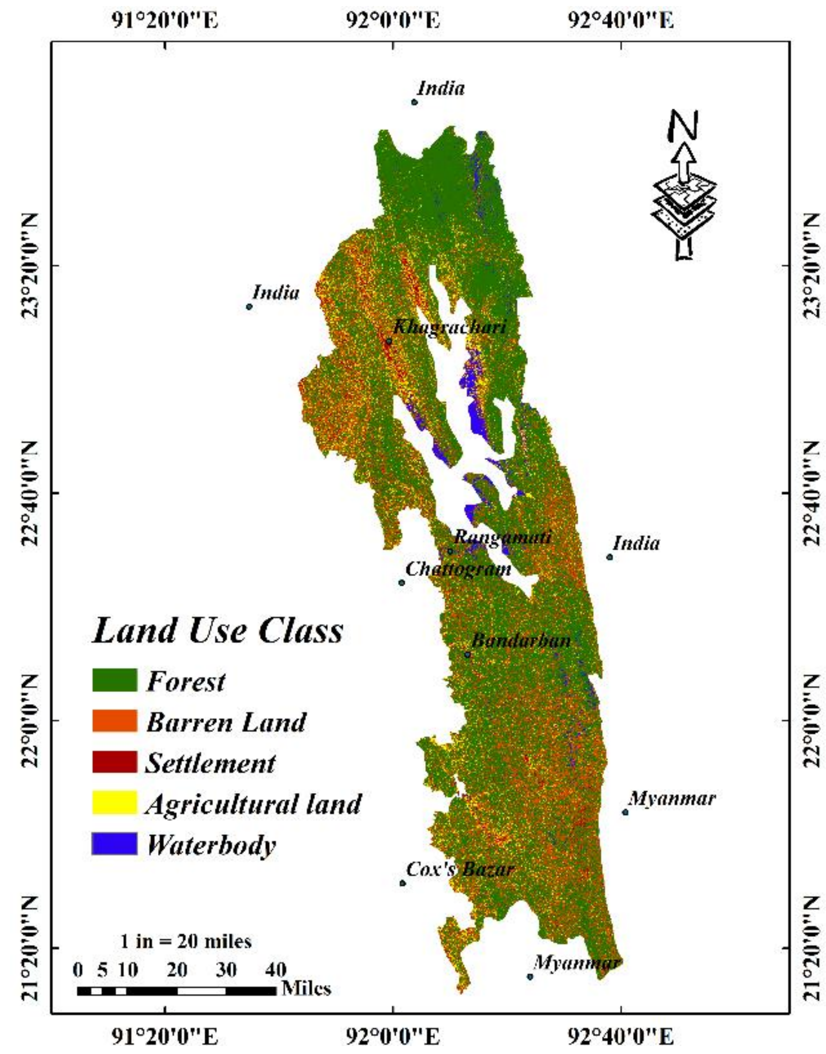

Figure 3. Land use and land cover map

4. Results and Discussion

In the south and south-western portion of CHTs the annual average rainfall distribution is evident from higher compared to north and north-eastern portion. The mean rainfall per year can be as low as 2720.4 mm.yr^{-1} in the south-eastern, which increases to as high as 2934.4 mm.yr^{-1} in the northeast. As a result, Bandarban districts have the highest mean annual rainfall, whereas Khagrachari districts have the lowest mean annual rainfall. The Rangamati area, which lies in the middle of the study, has moderate annual rainfall. With a mean of 1121.5 MJ.mm.ha^{-1}.h^{-1}.yr^{-1}, the R-factor values varied from 806.2 to 1513.2 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} as found in Figure 4. Because the R factor is roughly related to rainfall, therefore the regions with higher annual average precipitation also had greater R factor values. The R factor map, Figure 4(b), shows a similar trend from south to north as like the average annual rainfall.

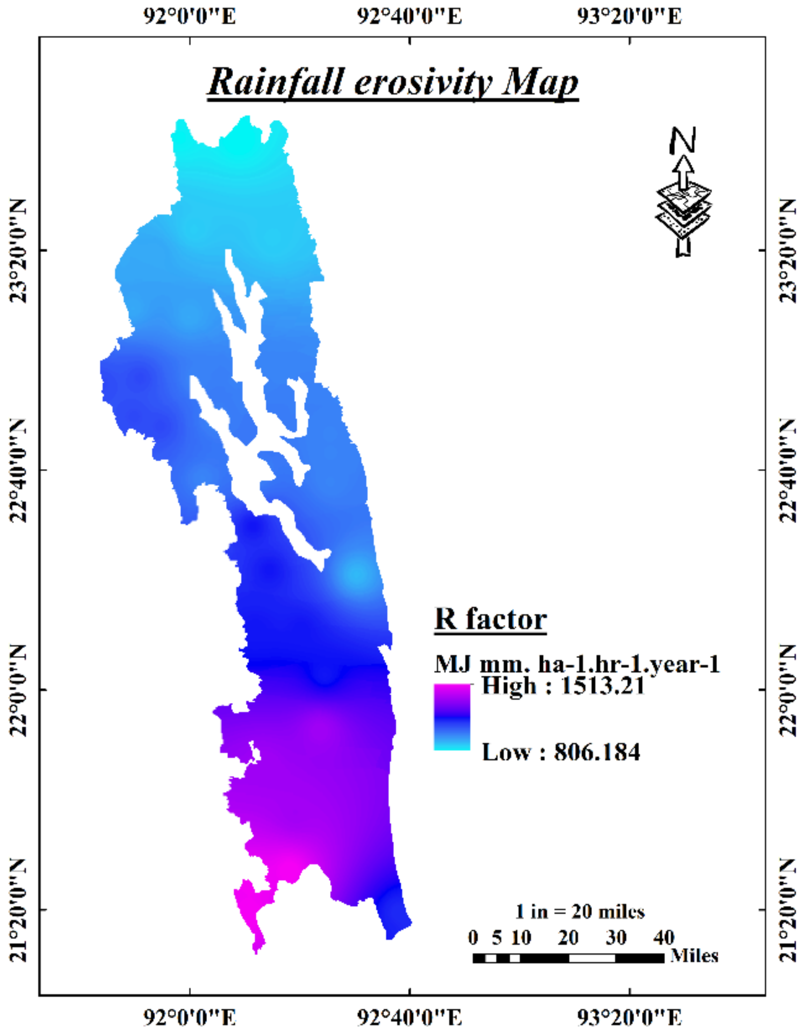

Figure 4. Rainfall erosivity factor map

Figure 5 shows the spatial distribution of the K factor. Since the majority of the research area is made up of the acidic Dystric Cambisols soils, which have heavy precipitation and low organic matter, it may be concluded that the soil has a moderate level of resistance to soil erosion and high K values, 0.02 t.h.MJ^{-1} mm^{-1}. Some of the areas in the north-western portion of Khagrachari are ferric acrisol, thick soils including clay loam or clay with high organic matter cause the K factor to be low, almost zero, as shown in Figure 5.

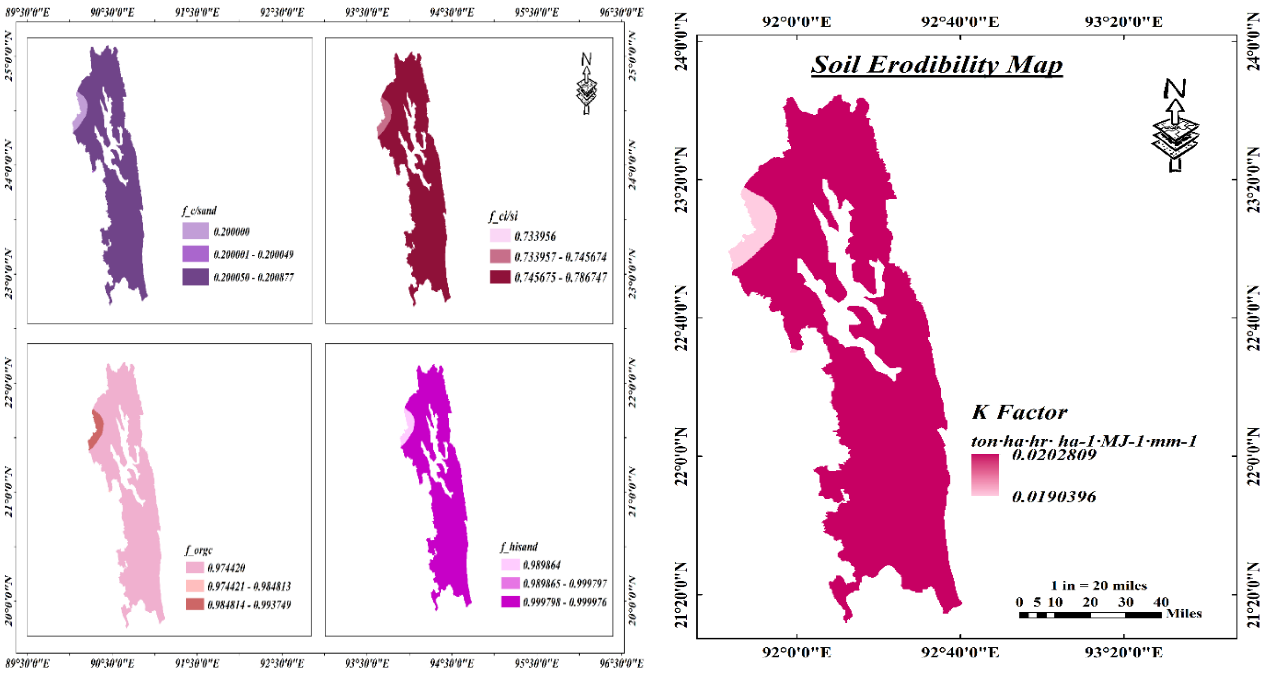

Figure 5. Spatial distribution of soil erodibility map

The study found a variation in the LS-factor values across the study area, with a range of 0 to 78.8 and a mean of 0.41 as seen in Figure 6(b) . However, most of the area falls in the 0-2 $t.ha^{-1}.yr^{-1}$ range, with the hilly sections exhibiting the lowest LS values. The slope of the terrain in Figure 6(a) also shows differences, with Rangamati in the south-east having a high slope and Khagrachari in the north-east having a low slope. Despite these differences, the mean slope length across the research area is relatively similar, with a low mean LS factor of 0.29 and a high mean LS factor of 0.63.

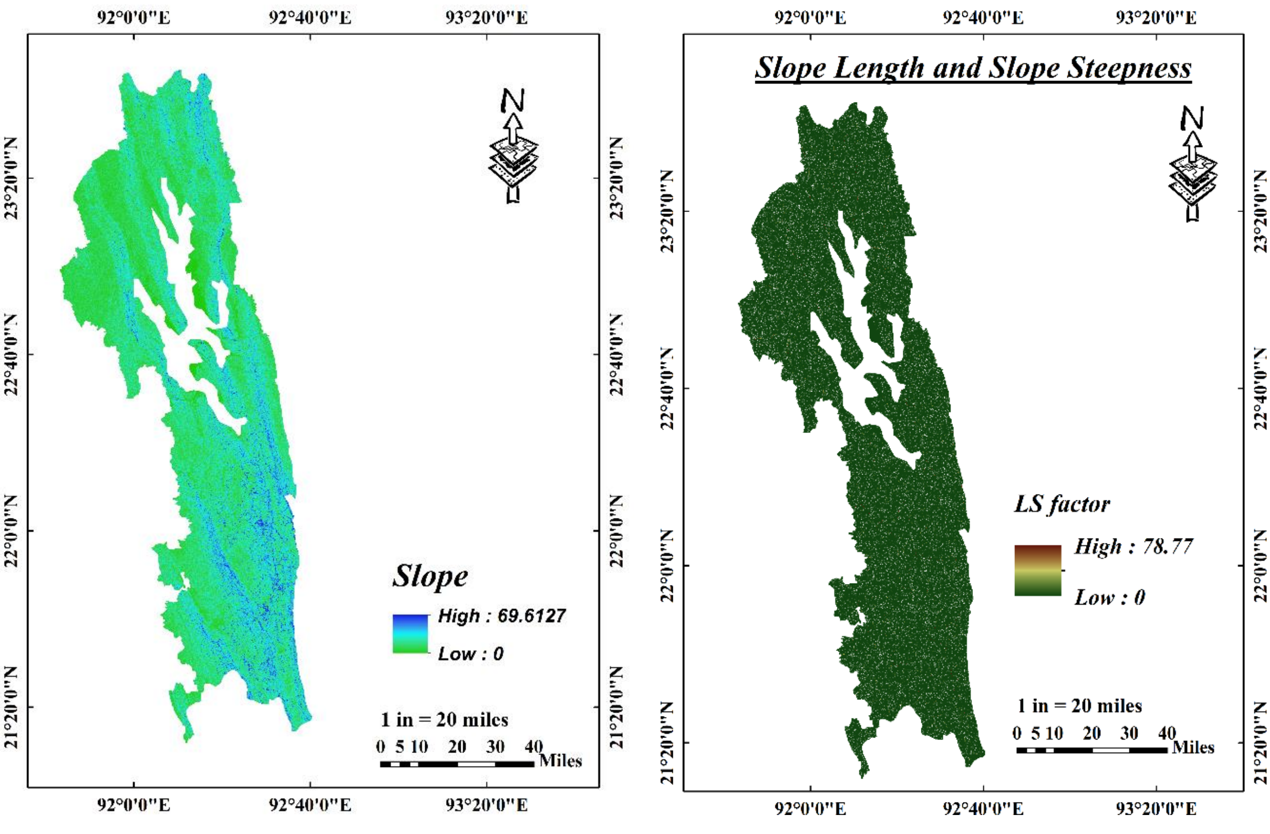

Figure 6. a) Slope and b) slope length and slope steepness map

The NDVI map, as presented in Figure 7(a), shows the distribution of vegetation in the CHTs. Higher NDVI values, indicating dense vegetation, are found in the north-western portion. These areas have poor cover management practices and lower soil erosion rates. On the contrary, region with lower NDVI, representing bare land, have higher cover management factors and higher soil erosion rates in the north-eastern and south-eastern regions. The C factor value, as mentioned in Figure 7(b), ranges from 0.35 to 0.67, with higher values in the Bandarban region and lower values in the north-western part of Khagrachari, where precipitation is high and vegetation is thick, but the north-eastern portion of Khagrachari has higher C factor values.

In the map of the Conservation Practice Factor (P) (Figure 8), the values range from 0.55 to 1, with the value of 1 assigned to jhum cultivation being most common in the study area. The Bandarban and Rangamati districts area have the highest P factor values, indicating a lack of proper conservation measures and a higher likelihood of soil loss. Conversely, lower P factor values are found in the north-western portion of the Khagrachari district, less likely to experience soil loss compared to other districts, as indicated by the P factors values of these districts.

4.1 Estimation of net soil erosion

GIS and erosion model RUSLE has been incorporated to assess the geographical distribution of soil erosion potential and the annual soil loss in the study area on a pixel-by-pixel basis. Five factors, such as Rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), crop management factor (C), and Conservation Practice factor (P), are displayed in Figures 4,5,6,7,8. Then these values were integrated using the empirical formula mentioned in Eq. (1) to obtain annual average soil loss. The final map demonstrates the average soil loss per hectare per year at the pixel level. With an average of 15.18 $t.ha^{-1}.yr^{-1}$, the predicted soil loss values for CHTs vary from 0 to 65.21 $t.ha^{-1}.yr^{-1}$. The total soil loss of the study area is 182621.5 $t.yr^{-1}$ covering an area of 12,027.5 square kilometers. In Figure 9(a), it has been found that higher soil loss was observed in the Bandarban districts. In comparison, Khagrachari showed lower amounts of soil loss.

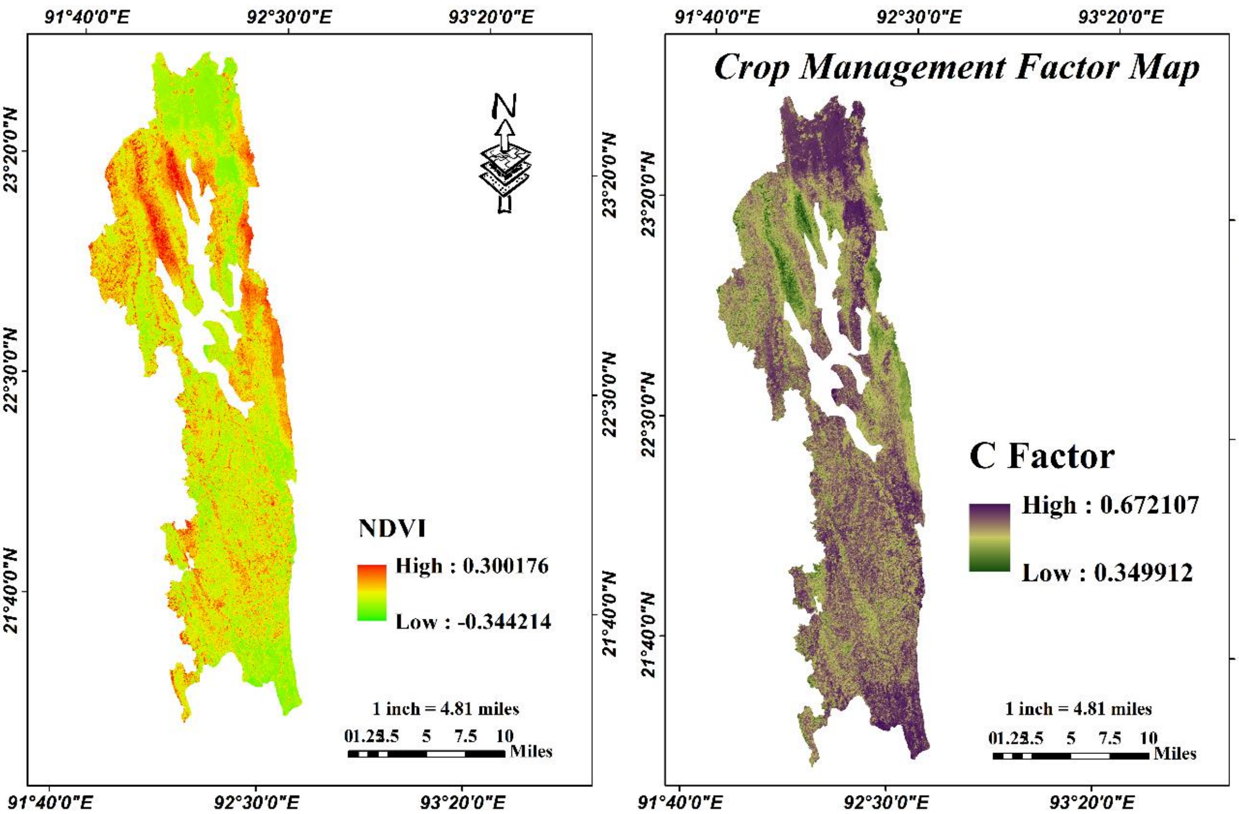

Figure 7. a) Normalized difference vegetation index (NDVI) and b) crop management map

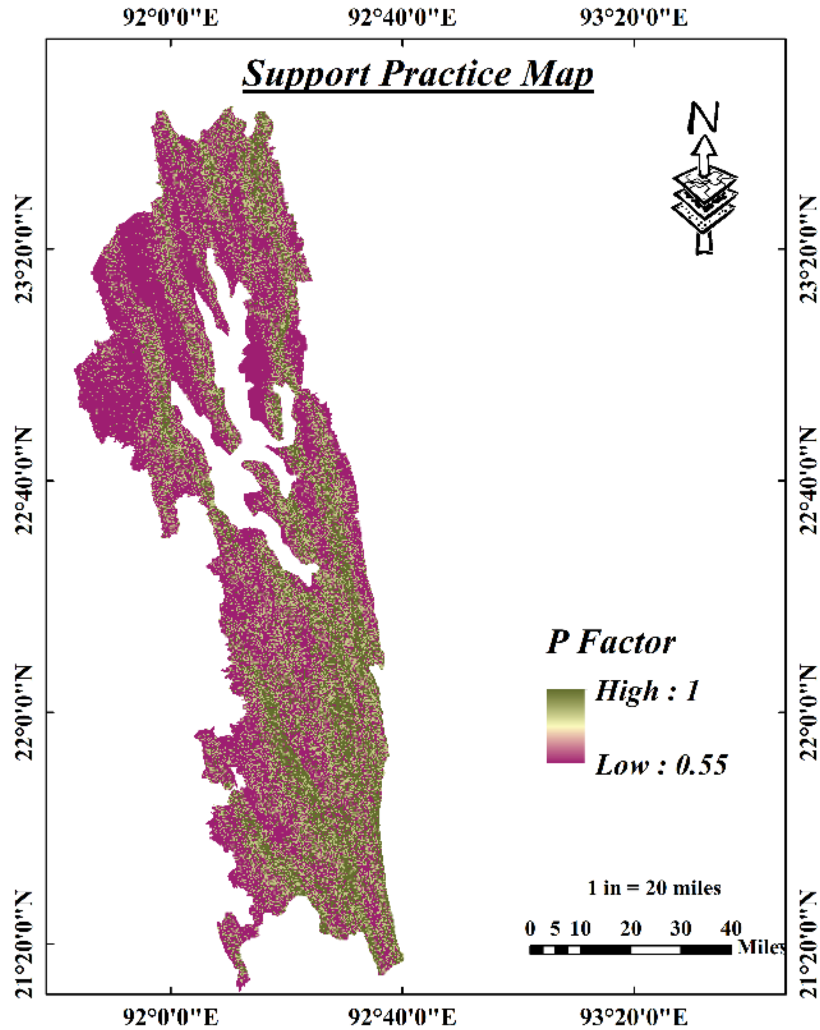

Figure 8. Conservation support practice map

Following the histogram distribution, the estimated pixel level soil loss value was divided into five classes, and Figure 9(a) shows the soil loss's spatial distribution. Approximately 76% of the study area is classified as having 'Very Slightly' erosion risk (0-2 $t.ha^{-1}.yr^{-1}$), as based on the findings from Table 5. About 4 % of the area of research is under the high to very high erosion risk (20 $t.ha^{-1}.yr^{-1}$). In accordance with the final soil loss map Figure 9(a), nearly 94% of the basin will have low erosion risk, 5.7% will have moderately severe erosion risk, and 4.4% of the basin will have extremely severe soil erosion.

The soil erosion probability zone with the final soil loss map, as depicted in Figure 9(b), was created by employing the weighted index overlay method to superimpose various layers, including land use-land cover, soil, slope, and rainfall maps. The four types of soil erosion probability zones in the study area are very slight, slight, moderately severe, severe, and very severe. Figure 9(b) shows that in Khagrachari, about 52.8 percent of the basin area produces low erosion, amounting to 1747.6 t yearly, while a very moderate probability zone covers nearly 45% of the basin area in the Rangamati and Bandarban.

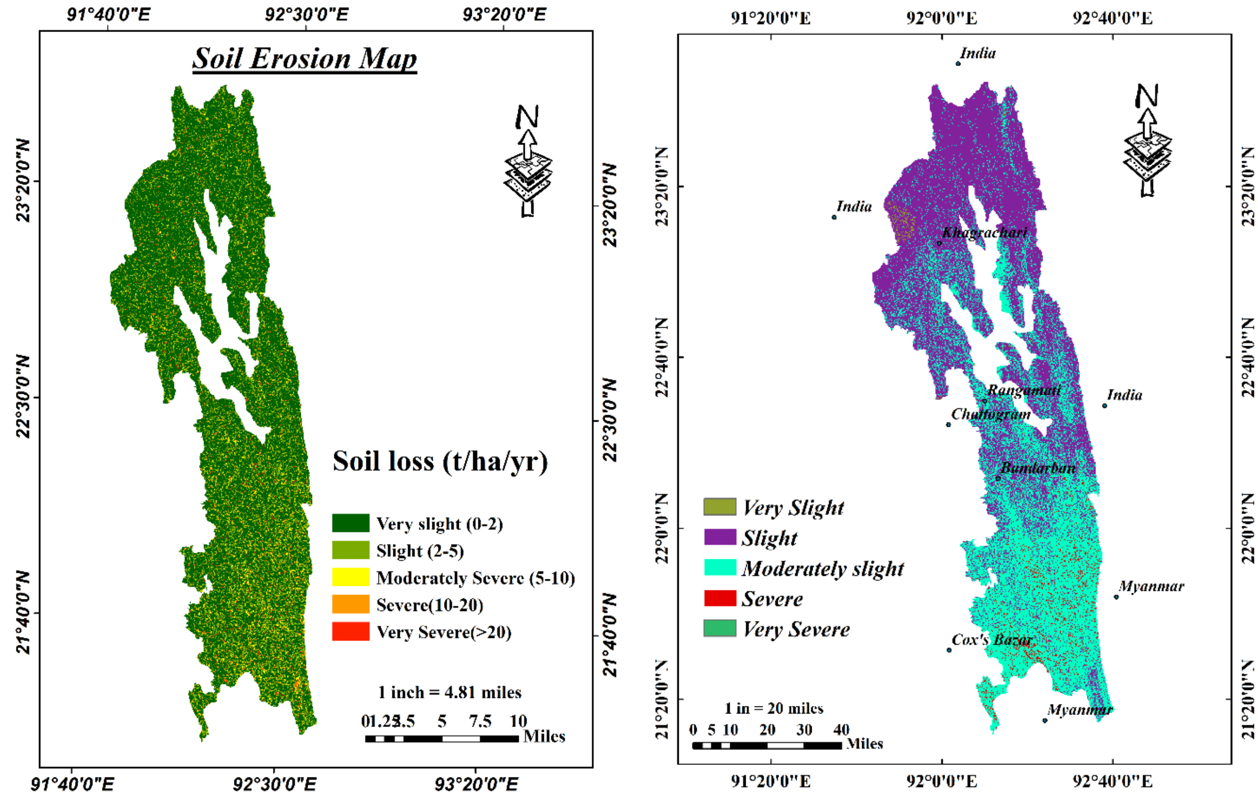

Figure 9. a) Soil erosion and b) probability zone map

Saha et al. (2022) conducted a study using RUSLE methodology in the Jamuna basin of Bangladesh and discovered comparable soil loss rates to the current study (mean soil erosion rates of 29.5 $t.ha^{-1}yr^{-1}$). About 75% of hilly areas in Bangladesh are very vulnerable to erosion, 20% are somewhat vulnerable, and 5% are moderately vulnerable (Hasan and Alam, 1970). Due to shifting agriculture, soil loss is predicted to be 4.2 $t.ha^{-1}yr^{-1}$ on 30-40 percent slopes and 7-120 $t.ha^{-1}yr^{-1}$ on 40-80 percent slopes, respectively (Malek, 2016). According to another study, inadequate 'Jhum' cultivation causes gully erosion and soil losses ranging from 10 to 120 $t.ha^{-1}yr^{-1}$ in hilly areas (Farid et al. 1992).

Table 5. Erosion risk class distribution in hectares and percentage for CHTs

Erosion Risk Classes	Range of Soil Losses ($t.ha^{-1}.yr^{-1}$)	Area (ha)	Area (%)
Very slight	0-2	875823.1	76.9
Slight	2-5	203381.9	17.8
Moderately Severe	5-10	65196.5	5.7
Severe	10-20	27530.6	2.4
Very Severe	20-65	19101.7	1.7

Numerous studies from various parts of the world with comparable climate zones revealed roughly similar mean erosion rates. A study in the southern Western Ghats of India's tropical mountain range, where 86 percent of the study region receives only slight erosion (< 5 $t.ha^{-1}.yr^{-1}$), used a reported erosion rate of 14.36 $t.ha^{-1}.yr^{-1}$ (Thomas et al. 2017). As per Prasannakumar et al. (2011), the average erosion rate for the Siruvani river watershed in Attapady valley, Kerala, India, is 14.917 $t.ha^{-1}.yr^{-1}$, with 5.76% (1,184 hectares) of the land lying under the severe soil erosion zone and 11.50% being under the high- erosion zone. A study by Tufekcioglu et al. (2018) in the Coruh River Basin of Turkey found that the Velikoy sub-watershed had an average surface soil loss rate of 3.9 t ha-1 yr-1, with 8.2% of the area at high or very high risk for potential erosion. Another study by Sheikh et al. (2011) observed that mean soil erosion rate of 12.2 $t.ha^{-1}.yr^{-1}$ at the Upper South Koel Basin, Jharkhand, India.

5. Conclusion and Recommendation

Soil erosion is a serious issue in Bangladesh, with high rates of soil loss posing a threat to natural resources and biodiversity. It can have significant impacts on the ecosystem, including reduced soil fertility, poorer water quality, and increased runoff and flooding. The results of the Chittagong Hill Tracts indicate a soil erosion rate of 15.18 $t.ha^{-1}.yr^{-1}$,with around 77% of the area experiencing very slight erosion and about 2% having very severe erosion.. The high rate of soil erosion in this area is influenced by the increasing population and agricultural activities, along with the presence of sandy soil, steep slopes, and heavy rainfall. The findings of this study area emphasize the necessity for immediate action to solve this issue and prevent further soil erosion; it can be used to raise awareness among policymakers, land managers, and stakeholders about the importance of protecting soil resources and the consequences of soil erosion. A comprehensive soil management strategy can be developed and implemented for conserving soil in CHTs because of the significant soil loss assessed from this study. Therefore, the development and improvement of tools such as RUSLE play an important role for the sustainable land use and natural resource management.

References

Bai, Z. G. (2006). *Assessing land degradation in the Chittagong Hill Tracts , Bangladesh , using NASA GIMMS* (ISRIC Report 2006/06). Wageningen, The Netherlands: ISRIC - World Soil Information.

Boyce R. C., (1975). *Sediment routing with sediment delivery ratios. Present and prospective technology for predicting sediment yields and sources* (USDA ARS-S-40). Washington DC: U.S. Department of Agriculture.

Byizigiro, R. V., Rwanyiziri, G., Mugabowindekwe, M, Kagoyire, C., & Biryabarema, M. (2020). Estimation of Soil Erosion Using RUSLE Model and GIS: The Case of Satinskyi Catchment, Western Rwanda. *Rwanda Journal of Engineering, Science, Technology and Environment*, *3*(1), 14-33.

Das, B., Paul, A., Bordoloi, R., Tripathi, O. P., & Pandey, P. K. (2018). Soil erosion risk assessment of hilly terrain through integrated approach of RUSLE and geospatial technology: a case study of Tirap District, Arunachal Pradesh. *Modeling Earth Systems and Environment*, *4*(1), 373-381.

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*(2), 441-453.

Earthdata. (2022a, August 20). *Giovanni - Interactive Online Visualization and Analysis Infrastructure*. NASA Goddard Earth Sciences Data and Information Services Center. Retrieved from https://giovanni.gsfc.nasa.gov/giovanni/

Earthdata. (2022b, August 20). *Earthdata Search*. Retrieved from https://search.earthdata.nasa.gov/search

FAO. (2022, August 20). *Data Catalog.* Food and Agriculture Organization of the United Nations. Retrieved from https://data.apps.fao.org/map/catalog/

FAO-UNESCO. (1987). *Soil map of the world*. Retrieved from https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world.

Farhan, Y., Zregat, D., & Farhan, I. (2013). Spatial Estimation Of Soil Erosion Risk Using RUSLE approach, RS, and GIS techniques: A case study of Kufranja Watershed, Northern Jordan. *Journal of Water Resource and Protection*, *5*(12), 1247-1261.

Farid, A. T. M., Iqbal, A., & Karim, Z. (1992). Soil erosion in the Chittagong Hill Tract and its impact on nutrient status of soils in Bangladesh. *Bangladesh Journal of Soil Science*, *23*, 92-101.

Ganasri, B. P., & Ramesh, H. (2016). Geoscience frontiers assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin. *Geoscience Frontiers*, *7*(6), 953-961.

Gelagay, H. S. (2016). RUSLE and SDR model based sediment yield assessment in a GIS and remote sensing environment; A case study of Koga Watershed, Upper Blue Nile Basin, Ethiopia. *Journal of Waste Water Treatment & Analysis*, *7*(2), 239. doi: 10.4172/2157-7587.1000239.

Hasan, M., & Alam, A. A. (1970). Land degradation situation in Bangladesh and role of agroforestry. *Journal of Agriculture & Rural Development*, *4*(1), 19-25.

Islam, M., Bhuiyan, M., & Hossain, M. (2015). Vetiver Grass as a Potential Resource for Rural Development in Bangladesh. *Agricultural Engineering International: CIGR Journal*, *10*, 1-18.

Jahun, B. G., Ibrahim, R., Dlamini, N. S., & Musa, S. M. (2015). Review of soil erosion assessment using RUSLE model and GIS. *Journal of Biology, Agriculture and Healthcare*, *5*(9), 36-47.

Jha, M. K., & Paudel, R. C. (2010). Erosion predictions by empirical models in a mountainous Watershed in Nepal. *Journal of Spatial Hydrology*, *10*(1), 89-102.

Khosrokhani, M., & Pradhan, B. (2014). Spatio-temporal assessment of soil erosion at Kuala Lumpur metropolitan city using remote sensing data and GIS. *Geomatics, Natural Hazards and Risk*, *5*(3), 252-270.

Kim, J. B., Saunders, P. & Finn, J. T. (2005). Rapid assessment of soil erosion in the Rio Lempa Basin, Central America, using the universal soil loss equation and geographic information systems. *Environmental Management*, *36*(6), 872-885.

Lu, D., Li, G., Valladares, G. S., & Batistella, M. (2004). Mapping soil erosion risk in Rondônia , Brazilian Amazonia : Using RUSLE , remote sensing and GIS. *Land Degradation & Development*, *15*(5), 499-512.

Malek, A. (2016). *Alluvial land reclamation process of Bangladesh with special reference to historical geography, Geo-politics and Environment since the Colonial Rule* (Doctoral dissertation)*.* Kansai University, Osaka, Japan.

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*(5), 1294-1289.

Mukanov, Y., Chen, Y., Baisholanov, S., Amanambu, A. C., Issanova, G., Abenova, A., Fang, G., & Abayev, N. (2019). Estimation of annual average soil loss using the Revised Universal Soil Loss Equation (RUSLE) integrated in a Geographical Information System (GIS) of the Esil River basin (ERB), Kazakhstan. *Acta Geophysica*, *67*(3), 921-938.

Ostovari, Y., Ghorbani-Dashtaki, S., Bahrami, H. A., Naderi, M., & Dematte, J. A. M. (2017). Soil loss prediction by an integrated system using RUSLE, GIS and remote sensing in semi-arid region. *Geoderma Regional*, *11*, 28-36. doi: 10.1016/j.geodrs.2017.06.003.

Prasannakumar, V., Shiny, R., Geetha, N., & Vijith, H. (2011). Spatial prediction of soil erosion risk by remote sensing, GIS and RUSLE approach: A case study of Siruvani river watershed in Attapady valley, Kerala, India. *Environmental Earth Sciences*, *64*(4), 965-972.

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1997). *Predicting Soil Erosion by Water: A guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)* (Agricultural Handbook Number 703). Washington DC: US Department of Agriculture.

Saha, M., & Sauda, S. S. (2019, October). Estimation of annual soil erosion rate using RUSLE : A study on the Jamuna River sub-basin in Bangladesh. In *European Space Agency's Living Planet Symposium*, *2019*. *Proocedings.* (pp. 1-4). ESA.

Saha, M., Sauda, S. S., Real, H. R. K., & Mahmud, M. (2022). Estimation of annual rate and spatial distribution of soil erosion in the Jamuna basin using RUSLE model: A geospatial approach. *Environmental Challenges*, *8*, 100524. doi: 10.1016/j.envc.2022.100524.

Sheikh, A. H., Palria, S., & Alam, A. (2011). Predicting Soil Loss by Water Universal S oil Loss Equation (USLE). *Recent Research in Scince and Technology*, *3*(3), 51-57.

Shi, Z. H., Cai, C. F., Ding, S. W., Wang, T. W., & Chow, T. L. (2004). Soil conservation planning at the small watershed level using RUSLE with GIS: A case study in the Three Gorge Area of China. *Catena*, *55*(1), 33-48.

Singh, G., Chandra, S., & Babu, R. (1981). *Soil loss and prediction research in India* (Bulletin No. T-12/D9). Dehradun, India: Central Soil and Water Conservation Research and Training Institute.

Shin, G. J. (1999). *The analysis of soil erosion analysis in watershed using GIS* (Doctoral dissertation). Gang-won National University, Department of Civil Engineering, Gang-won, South Korea.

Thomas, J., Joseph, S., & Thrivikramji, K. P. (2018). Assessment of soil erosion in a tropical mountain river basin of the southern Western Ghats, India using RUSLE and GIS. *Geoscience Frontiers*, *9*(3), 893-906.

Tufekcioglu, M., Yavuz, M., Vatandaslar, C., Dinc, M., Duman, A., & Tufekcioglu, A. (2018). Çoruh Nehri Havzası'nda Bulunan Veliköy Alt Havzası'nın Yüzey Erozyon Riskinin Belirlenmesi ve Haritalandırılması. *Doğal Afetler ve Çevre Dergisi*, *4*(2), 210-220.

USGS. (2022, August 20). *Earth Explorer*. U.S. Geological Survey. Retrieved from https://earthexplorer.usgs.gov/

Wischmeier W. H., & Smith D. D., (1978). *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning* (USDA Agriculture Handbook No 537). Washington DC: U.S. Department of Agriculture.

Zhang, H., Yang, Q., Li, R., Liu, Q., Moore, D., He, P., Ritsema, C. J., & Geissen, V. (2013). Extension of a GIS procedure for calculating the RUSLE equation LS factor. *Computers and Geosciences*, *52*, 177-188.