**Geospatial Assessment of Soil Loss using Revised Universal Soil Loss Equation (RUSLE) in the Dibrugarh District, Assam, India**

**Abstract**

Soil erosion is a critical global challenge, leading to the loss of fertile topsoil and contributing to decreased agricultural productivity, increased sedimentation in waterways, and ecosystem disruption. This environmental problem is more vulnerable in developing countries because of farmers' failure to restore degraded soil and nutrients. The depletion of soil is driven by extensive farming practices, land degradation, and various human activities that impact the environment. It is an emerging threat to sustainable land management in Dibrugarh District, Assam. This study uses the Revised Universal Soil Loss Equation (RUSLE) model, integrated with remote sensing and GIS, to quantify soil erosion that incorporates annual average rainfall, soil properties, topographic characteristics, and LULC as inputs to detect the soil erosion-prone areas. This study divides the whole Dibrugarh district into five soil erosion severity classes, i.e., very slight, slight, moderate, severe, and very severe. The results demonstrate that 91.147% of the area experiences very slight erosion (<2 t ha−1 yr−1), while severe erosion affects 0.148% and very severe erosion impacts 0.044% of the area, requiring urgent conservation efforts. Effective soil management and targeted conservation strategies are essential to mitigate erosion and ensure the region's long-term land productivity and environmental health.

***Keywords:*** Soil erosion, Remote sensing and GIS, RUSLE, soil management

**Introduction**

Among various environmental problems, soil erosion is a critical challenge for the environment that includes the detachment, transport, and deposition of soil particles, resulting in the deterioration of the topsoil layer (Jazouli et al., 2017). This process is regarded as the second dominant environmental problem the world is facing after population growth (Jahun et al., 2015), which not only strips away the upper soil and plant cover but also depletes the entire productive soil layer. Additionally, it also removes the humus, plant nutrients, organic carbon, beneficial microorganisms, and other components required for supporting soil health and fertility (Behera et al., 2023). Deforestation, agriculture, overgrazing, construction, urban expansion, and mining are some of the anthropogenic activities that worsen this natural process (Jayasekara et al., 2018). Approximately 84% of land degradation worldwide is caused by soil erosion (Opeyemi et al. 2019), while the average rate of soil erosion fluctuates between 12 and 15 tons ha-1yr-1 (Ashiagbor et al., 2013; Behera et al., 2023), causing loss of productive land. Agriculture and its associated activities caused the removal of about 5334 million tons (1653 tons/sq km) of soil annually in India (Prasannakumar et al., 2011). The importance of soil erosion goes beyond the loss of fertile soil, as it affects the quality of water, agricultural productivity, and ecosystem stability (Ayalew et al., 2020). The sediment accumulation in river basins is directly associated with soil erosion (Mohapatra, 2021), which affects artificial structures like dams and reservoirs, thereby increasing their maintenance cost and long-term usability (Samaras & Koutitas, 2014). Soil erosion is influenced by a wide range of factors such as precipitation, surface runoff, soil types, topographic characteristics, and land use/cover practices (Taye et al., 2018). Thus, a quantitative assessment is required to incorporate the scale and intensity of these influencing factors that stimulate soil erosion (Prakash et al., 2022).

Currently, the research community has concentrated on implementing remote sensing and GIS techniques to measure soil erosion and sediment yield in river basins (Benavidez et al., 2018; Sarma et al., 2021; Negese et al., 2021; Handique et al., 2023). The use of traditional methods for evaluating soil erosion is frequently time-consuming and expensive (Ganasri & Ramesh, 2016), particularly for large study areas such as district blocks. However, “precise and cost-effective assessment of soil erosion and its spatial distribution across large areas is made possible by the use of remote sensing and GIS technologies” (Milward & Mersey, 1999; Wang et al., 2002; Koirala et al., 2019). “By combining remote sensing, GIS, and the Revised Universal Soil Loss Equation (RUSLE), soil erosion losses can be estimated on a detailed, cell-by-cell basis, enhancing precision in analysis” (Milward & Mersey, 1999). In this regard, modeling supported by remote sensing and GIS provides important insights into current erosion processes and enables future predictions.

In 1968, Wischmeier and Smith developed the Universal Soil Loss Equation (USLE), revolutionizing the soil erosion prediction from cropland. This model’s simplicity and efficiency led to its worldwide popularity. The USLE model was updated and computerized in the early 1990s, resulting in the Revised Universal Soil Loss Equation (RUSLE). The Revised Universal Soil Loss Equation (RUSLE) is widely regarded as one of the most prominent empirically-based models for estimating and forecasting worldwide soil loss due to its simplicity and broader accessibility of input parameters (Perovic et al., 2013; Chalise et al., 2018; Behera et al., 2023). “This updated model provides a reliable tool for forecasting average annual soil erosion rates, incorporating remote sensing and GIS based on rainfall, soil, topography, cropping systems, and soil management” (Wijesundara et al., 2018).

The RUSLE model is used to predict the average annual loss of soil using various factors, i.e., rainfall erosivity (R), soil erodibility (K), topography (LS), cover and management (C), and support practices (P). These factors together contribute to a comprehensive understanding of the dynamics of soil erosion in a given area.

Hence, this study attempts to estimate soil erosion in the Dibrugarh district of Assam using the RUSLE model integrated with remote sensing and GIS techniques. The study area is affected by land degradation due to rapid land use changes, intensive agricultural practices, and growing anthropogenic activities. However, no such significant research utilizing data-driven tools integrating geospatial technologies has been conducted so far to assess these risks. The research aims to examine the pattern and intensity of soil loss in the study area and analyse how the topography, soil type, rainfall pattern, and land use/ cover practices contribute to it using geospatial technologies. Thus, this research seeks to provide critical insights for effective soil conservation and sustainable land management practices by evaluating the spatial distribution of soil erosion severity in the region.

**Study Area**

Dibrugarh district lies between latitudes 27°5'38" N to 27°42'03" N and longitudes 94°33'46" E to 95°29'08" E, covering an area of approximately 3381 sq. km in Assam (Fig. 1). The district is situated in the northeastern part of the upper Brahmaputra valley. It is bordered by Dhemaji and Lakhimpur districts on the north, while to the south it is bordered by the Tirap district of Arunachal Pradesh. The Tinsukia and Sivasagar districts border it to the east and west, respectively. Geographically, the region exhibits varied features, including extensive floodplains, swamps, wetlands, and occasional hills. Agricultural land constitutes the largest portion of the area, supporting rice and oilseed cultivation. Plantation areas, predominantly tea gardens, are distributed throughout the region, reflecting the economic dependency of tea production. The Brahmaputra River runs along its northern edge, while the Burhi Dihing River, an important tributary of the Brahmaputra, traverses the district with its widespread network of tributaries and wetlands (beels). The dominant soil types are sandy clay loam and clay loam, which show moderate to high erodibility, particularly under intensive land use and poor vegetation cover. The district has a humid subtropical climate, characterized by heavy rainfall during the summer and comparatively dry winter conditions (Bora et al., 2023).

**Materials and Methods**

**Data Collection**

The study utilized multiple geospatial datasets sourced from several repositories (Table 1). The datasets comprised rainfall data, soil information, a digital elevation model (DEM), and satellite imagery, all essential for the RUSLE model implementation. A cloud-free Landsat 8 OLI satellite image (path/row- 135/041; cloud cover- 5.10 %) was retrieved from the United States Geological Survey (USGS) on 20th December 2023 to derive land cover and management details. To assess the topographical impacts on soil erosion, a 30-meter resolution SRTM 1 Arc-Second DEM, acquired on 21 December 2023. The DEM dataset was retrieved from Earth Explorer, managed by the United States Geological Survey (USGS).

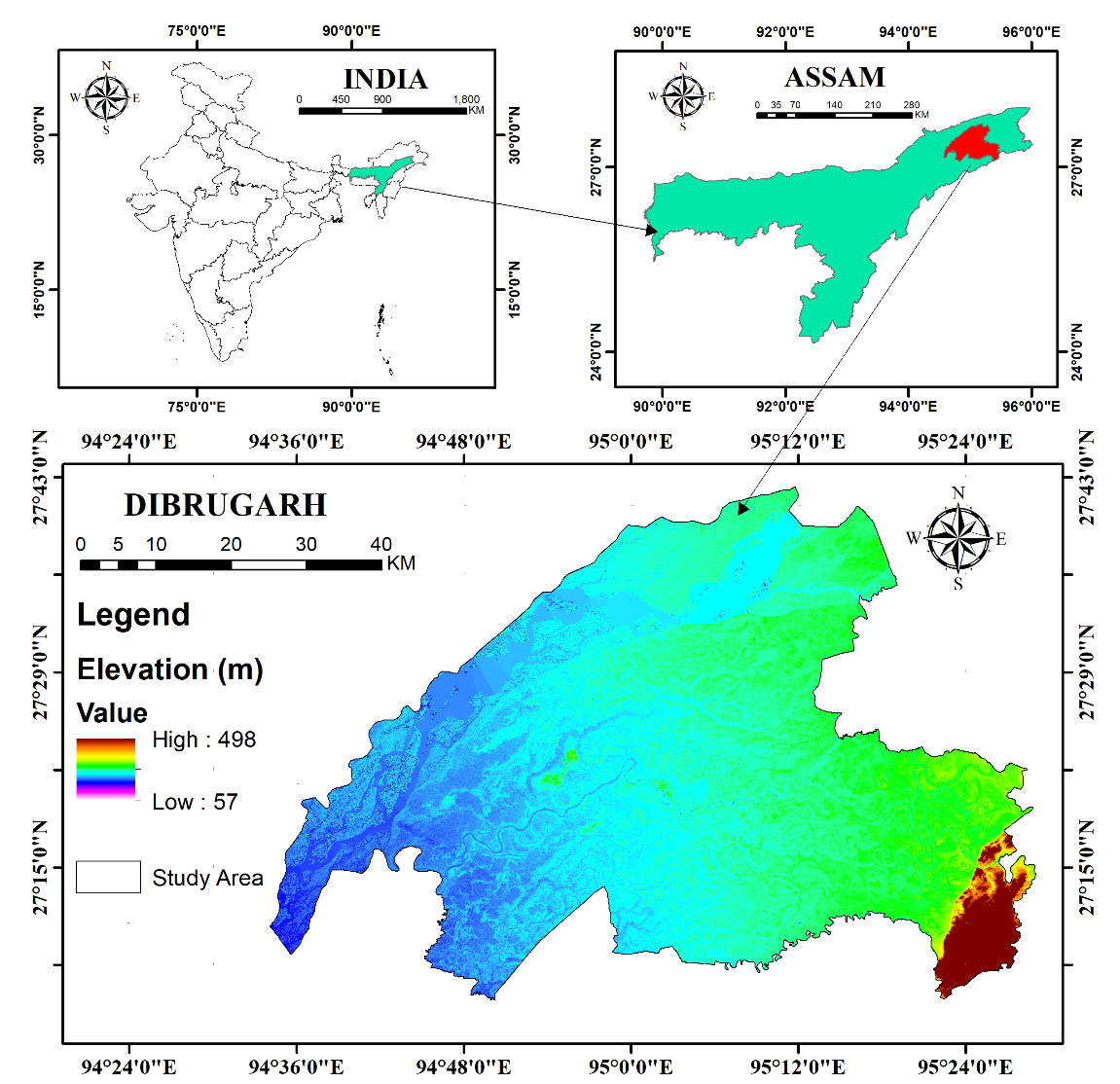


Fig. 1 Location of the study area

The study used high-resolution gridded average annual rainfall data (spatial resolution- 0.5° x 0.5°) obtained from the Climatic Research Unit (CRU) for the year 2021-22 was retrieved on 21 December 2023 for rainfall analysis. Additionally, the analysis of soil erodibility required the standardized soil profile data, which provides detailed information on soil properties such as sand, silt, clay content, and organic carbon. This data was acquired from the United States Food and Agriculture Organization (FAO) soil data portal, along with a soil map in a vector format prepared at a scale of 1:5,000,000. Fig 2 shows the methodological flow chart of the entire research.

Table 1: Sources of data used for the RUSLE model

|  |  |  |
| --- | --- | --- |
| **Datasets** | **Source** | **Date of acquisition** |
| Satellite data (Landsat 8 OLI) | <http://earthexplorer.usgs.gov/> | 20-12-2023 |
| DEM | SRTM DEM (30 m resolution) <http://earthexplorer.usgs.gov/> | 21-12-2023 |
| Rainfall data | Climate Research Unit (CRU), <https://crudata.uea.ac.uk/cru/data/hrg/> | 21-12-2023 |
| Soil data | FAO, UN <https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/en/> | 20-12-2023 |

**Application of the RUSLE Model**

The average annual soil loss (A) can be estimated through RUSLE model using five factors: rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and conservation practices (P) (Renard et al., 1997), expressed as:

(1)

where, A = average annual soil loss (t ha−1 yr−1), R = rainfall erosivity factor (MJ mm ha−1 h −1, yr−1), K = soil erodibility factor (t h MJ−1 mm−1), LS = slope-length and slope steepness factor (dimensionless), C = land management factor (dimensionless), and P = conservation practice factor (dimensionless).

**Computation of causative factors**

***Rainfall Erosivity Factor (R)***

The R factor quantifies the erosive power of rainfall, measured in MJ mm ha¹ h¹ yr¹. Due to data limitations, the empirical equation by Singh (1981), favorable for the Indian context, was used:

R = 79 + 0.363 AAP (2)

where 'AAP' is the average annual precipitation in mm. A rainfall map was generated using gridded rainfall data (1921-2022) and IDW interpolation techniques in ArcGIS 10.8.

***Soil Erodibility Factor (K)***

The K factor measures loss of soil per rainfall erosion index unit, influenced by soil texture, structure, organic matter, and porosity. Using soil data from the FAO, and extracting it with the area of interest (AOI), K values were calculated with the formula from Sharpley & Williams, 1990:

(3)

(4)

(5)

(6)

(7)

Where SAN, SIL, and CLA represent the percentages of sand, silt, and clay, respectively; C is the organic carbon content. SN1 is derived from the sand content by subtracting it from 1 and dividing by 100. Fcs and indicates a low soil erodibility factor for soils with coarse sand and a high factor for soils with low sand content. Fsi-cl reflects a low soil erodibility factor with a high clay-to-silt ratio. Forgc reduces soil erodibility for soils with high organic content, while Fhisand reduces soil erodibility for soils with extremely high sand content.

***Slope Length and Steepness Factor (LS)***

The LS factor reflects terrain influence on soil erosion, calculated using SRTM DEM data and the Wischmeier & Smith (1957) equation:

(8)

where λ is flow path length, Ψ is 22.13 for SI units, and S is the average slope.

***Cover and Management Factor (C) and Conservation Support Practice Factor (P)***

The C factor accounts for vegetation's impact on soil erosion. A LULC map was created using the Support Vector Machine (SVM) algorithm in ArcGIS 10.8. The LULC classes were identified using training samples on a pixel-by-pixel basis, where representative training samples were utilized to train and prepare the final LULC map. The C values were assigned based on land cover types (USDA-SCS, 1972; Wischmeier & Smith, 1978; Pandey et al., 2007). The P factor reflects conservation practices' effects on runoff and soil erosion, with values ranging from 0 (high conservation) to 1 (no conservation) (Wischmeier & Smith, 1957; Renard et al., 1997). The validation of the LULC map was achieved using a confusion matrix, which compared the ground truth data generated from Google Earth Pro and field verification, and the generated LULC map classes. Statistical information about the overall accuracy (OA), user’s accuracy (UA) and producer’s accuracy (PA), and Kappa coefficient was used to validate the classification accuracy (Mishra & Rai, 2016).



Fig 2 Flow chart of the methodological framework

**Results and Discussions**

The soil erosion severity classes in the study for Dibrugarh district, Assam, were determined using the Revised Universal Soil Loss Equation (RUSLE) model. The RUSLE model used several factors to assess soil erosion. The Rainfall erosivity factor (R) value was derived from the annual average rainfall of Dibrugarh district, which ranges between 3971 and 4305 mm (Fig. 3 a). The R factor derived using Eq. 2 ranges between 1520.54 to 1641.9 MJ mm ha−1 h−1 yr−1 (Fig. 3 b). The higher rainfall and K factor value were witnessed in the southeast and south-eastern portions of the region. Soil Erodibility Factor (K) is an important determinant of soil erosion derived from the study area's soil type map. The main soil categories found in the region are clay loam (Ao) covering 46.1 sq. km area (1.3%), sandy clay loam (Af) covering 2075.03 sq. km area (61.6%), and sandy clay loam (Ao) covering 1257.9 sq. km (37.3%) (Fig. 4 a). The K factor derived from Eq. 3 (Table. 2) ranges between 0.018 to 0.020 h MJ− 1 mm− 1 (Fig. 4 b).

Table 2. Soil properties and the values of ƒcsand, ƒcl-si, ƒorgC and ƒhisand and K factor

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Soil Type** | **Area (Sq. k m)** | **Sand (%)** | **Silt (%)** | **Clay (%)** | **Organic Carbon (%)** | **fcsand** | **fcl-si** | **forgc** | **fhisand** | **K Factor** |
| Sandy Clay Loam (Af) | 2075.03 | 61.7 | 14.4 | 23.9 | 0.91 | 0.2000004 | 0.993749 | 0.989864 | 0.745675 | 0.0193205 |
| Sandy Clay Loam (Ao) | 1257.9 | 53.6 | 15.8 | 30.6 | 2.25 | 0.2000029 | 0.975001 | 0.998056 | 0.723839 | 0.0185534 |
| Clay Loam (Ao) | 46.1 | 46.1 | 21.6 | 27.4 | 1.73 | 0.20001018 | 0.977640 | 0.998867 | 0.782127 | 0.0201188 |

The influence of terrain on soil erosion is represented by slope length (L) and slope steepness (S). The slope categories in the study area ranges between 0⁰ and 18.6⁰ which has been reclassed into five classes including, 0–2° covering 1833 sq. km (54.4%), 2 - 4° covering 875 sq. km (26%), 4 - 6° covering 343 sq. km (10.5%), 6 - 8° covering 152 sq. km (4.5%) and more than 8° covering 165 sq. km (4.8%) (Fig. 5. a). The LS factor generated using Eq. 8 generated an LS factor map with value ranges between 0 to 18.64 (Fig. 5. b). It was observed that with increasing slope and flow accumulation, the LS factor also increases. The type of LULC significantly affects a region's hydrologic components, including surface runoff, infiltration, and evapotranspiration. The LULC of the study area comprises river bodies covering 239.51 sq. km (7.1%), sand deposits covering 657.01 sq. km (19.5%), Forest area covering 238.74 sq. km (7.08%), agricultural land covering 967.31 sq. km (28.7%), plantation covering 731.8 sq. km (21.7%), and settlement and built-up area covering 545.54 sq. km (Fig. 6 a). The overall accuracy of 91.58% and a kappa value of 0.89 suggest that the model has performed well in accurately classifying various land use and land cover classes (Table 4) (Indraja et al., 2024). The C and P factor values assigned to each LULC class are displayed in Table 3 (Pandey et al., 2007; Dabral et al., 2008; Zonunsanga, 2016). The final C and P factor maps used in the estimation of soil erosion are shown in Fig. 6 b and 6 c.

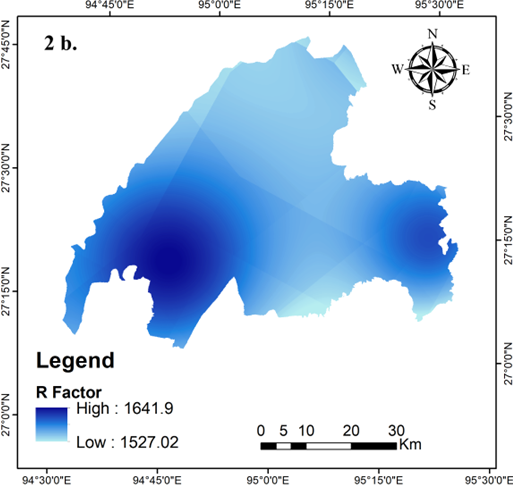
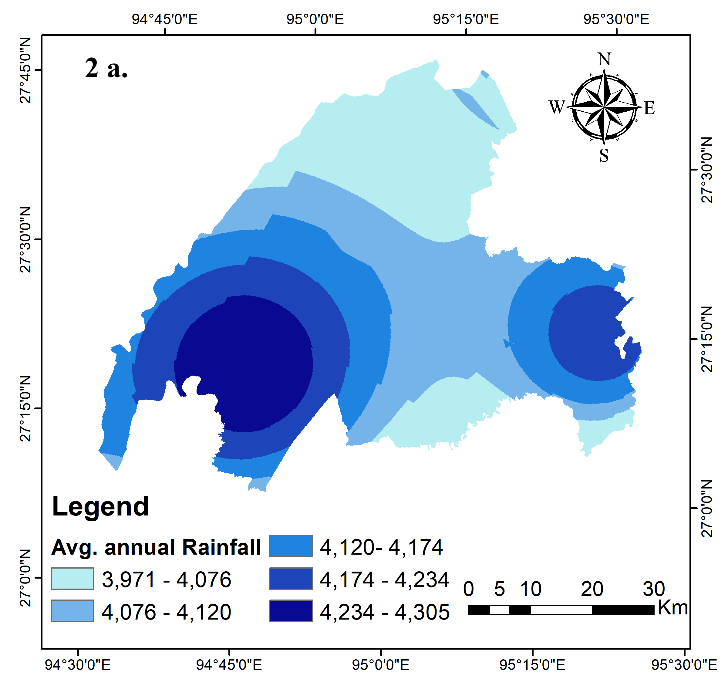


Fig. 3 a. Rainfall map; 3 b. R factor map

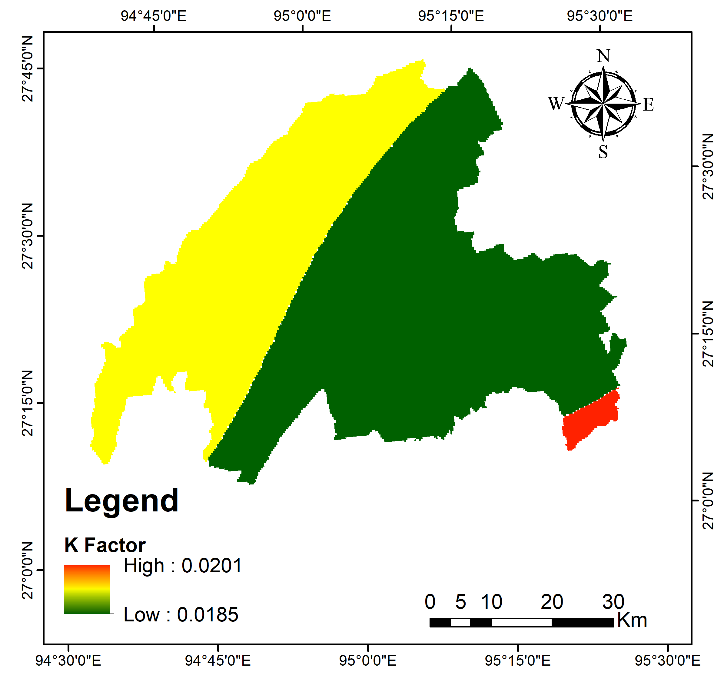
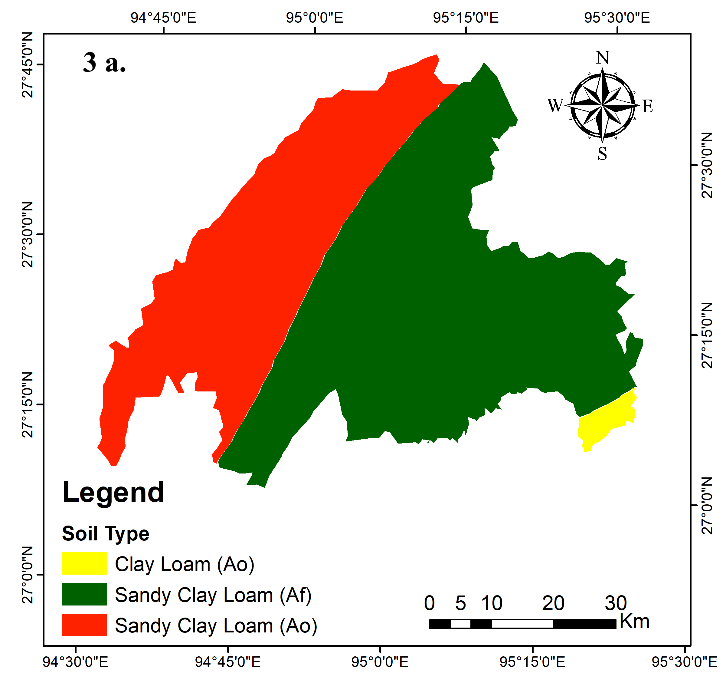


Fig 4 a. Soil map; 4 b. K factor map

Table 3. LULC types, their areal coverage, and C and P factor value

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **LULC types** | **Area (Sq. Km)** | **Area (%)** | **C Factor** | **P Factor** |
| River Bodies | 239.513 | 7.111 | 1.000 | 1.000 |
| Sand Deposits | 657.014 | 19.507 | 1.000 | 1.000 |
| Forest | 238.741 | 7.088 | 0.004 | 0.000 |
| Agriculture | 967.310 | 28.720 | 0.280 | 0.000 |
| Plantation | 731.886 | 21.730 | 0.080 | 0.000 |
| Settlement/ Built-up areas | 545.542 | 16.197 | 1.000 | 1.000 |

Table 4. Accuracy assessment results of LULC map

|  |  |  |
| --- | --- | --- |
| **LULC types** | **2023** | |
| **UA (%)** | **PA (%)** |
| River Bodies | 86.67 | 86.67 |
| Sand Deposits | 92.55 | 94.57 |
| Forest | 97.00 | 97.98 |
| Agriculture | 93.02 | 80.00 |
| Plantation | 93.68 | 98.89 |
| Settlement/ Built-up areas | 85.42 | 91.11 |
| Overall accuracy | 91.58 | |
| Kappa Coefficient | 0.89 | |

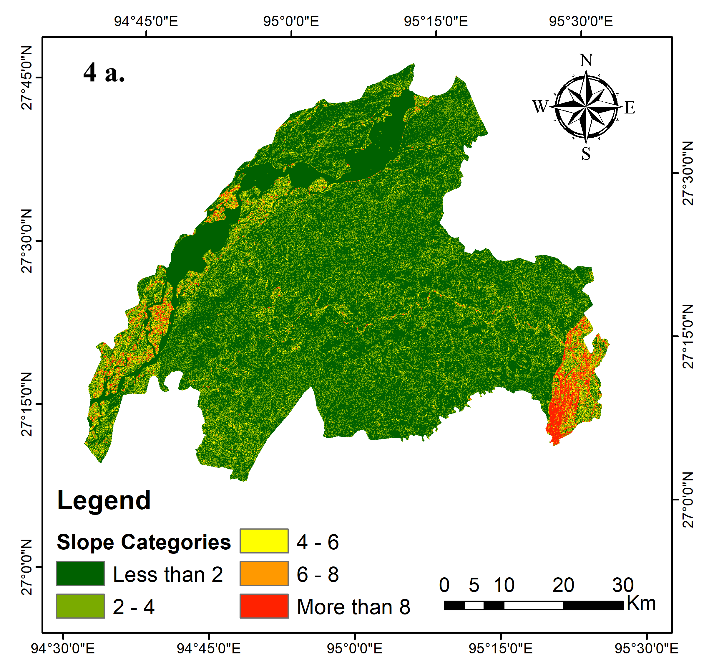
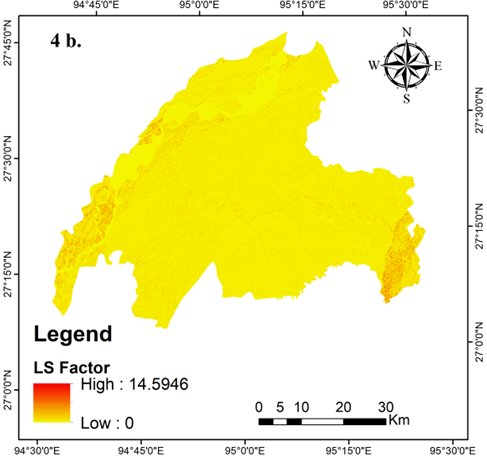
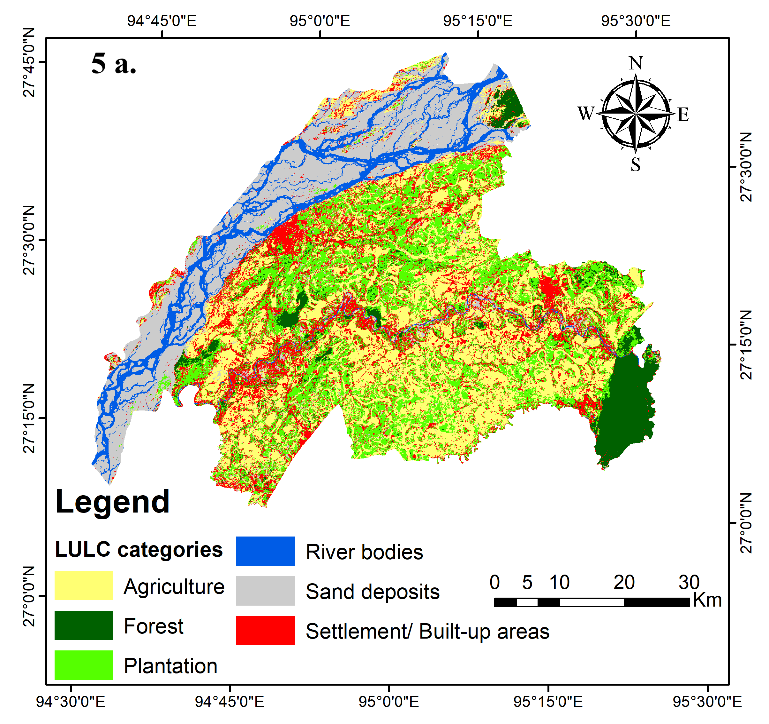
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Fig. 5 a. Slope map; 5 b. LS factor map



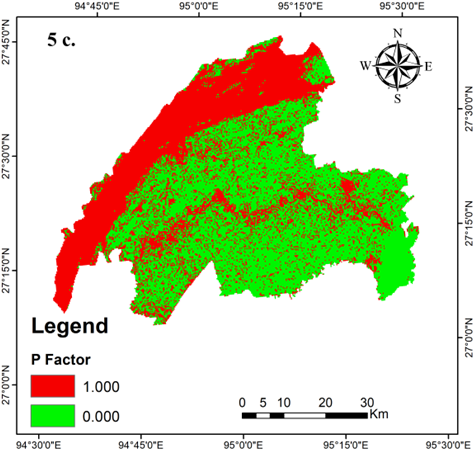
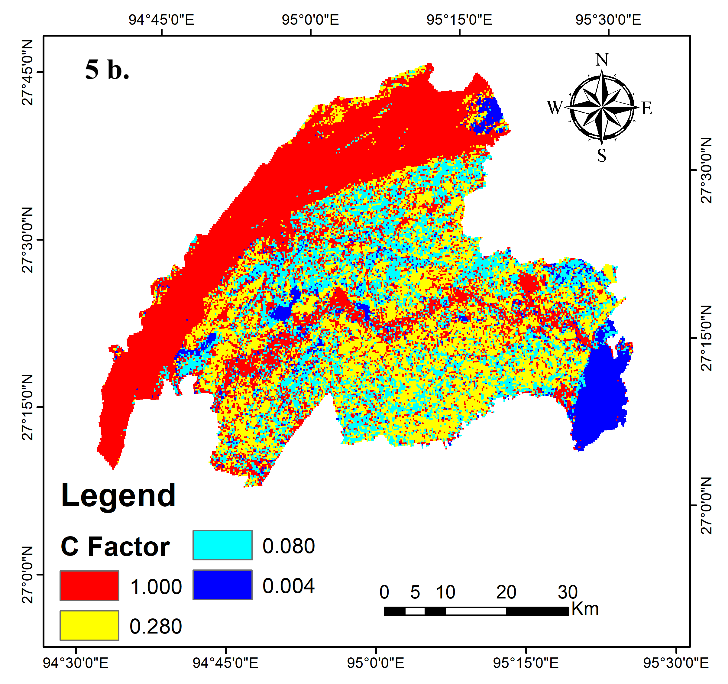


Fig. 6 a. LULC map; 6 b. C factor map; 6 c. P factor map

**Potential Soil Loss in Dibrugarh District**

The map of soil erosion (Fig. 7), prepared using Eq. 1 in ArcGIS 10.8, indicated that a vast majority of the area, approximately 91.147%, experiences very slight erosion with a soil loss rate of less than 2 t ha−1 yr−1, encompassing 3006.860 sq. km. This suggests that these areas are relatively stable with low slope gradients, dense vegetation cover, and stable land use, resulting in minimal soil degradation. A similar erosion pattern was found in the Bhandara region of Maharashtra, India, where very slight erosion was observed due to forest cover and stable terrain (Kashiwar et al., 2022).

Slight erosion, characterized by soil loss rates between 2 and 10 t ha−1 yr−1, affects 7.638% of the district, covering 251.982 sq. km. A similar distribution was observed in the Peddavagu watershed, where cultivated lands with moderate slopes experienced slight to moderate erosion (Shekar & Mathew, 2024). Although not critical, these areas may benefit from basic soil conservation practices to prevent further degradation. Moderate erosion, with soil loss rates between 10 and 29 t ha−1 yr−1, was observed in 1.023% of the district (33.738 sq. km). These regions require attention and implementation of soil conservation measures to mitigate erosion. Severe erosion, identified by soil loss rates ranging from 29 to 71 t ha−1 yr−1, affects a smaller portion of the area, making up 0.148% or 4.866 sq. km. These areas are at high risk and require immediate intervention to prevent significant land degradation. Severe soil loss, associated with higher rainfall and loose soil, was also observed in the Barakar River basin, Jharkhand, India (Biswas & Pani, 2015); in the Chinese Loess Plateau (Kang et al., 2024). Lastly, very severe erosion, with rates exceeding 71 t ha−1 yr−1, was found in only 0.044% of the district near the southern hill zone, equivalent to 1.466 sq. km (Table 5). A similar observation was also made in the Markham catchment, Papua New Guinea (Samanta et al., 2016), and the Jiadhal river basin, Assam, India (Borgohain et al., 2019). These regions face extreme soil erosion and demand urgent and intensive soil conservation efforts to avoid irreversible damage to the land. The study area supports high population density, tea plantations, and well-pronounced agricultural practices; however, in recent years, land use change and expansion of urban areas have led to land degradation and soil loss, which requires thorough assessment and analysis using geospatial technologies. The study highlights the importance of targeted soil conservation strategies to manage and mitigate soil erosion effectively across the district**.**

Table 5. Soil erosion severity classes and their areal coverage

|  |  |  |
| --- | --- | --- |
| **Severity classes** | **Area (sq. km)** | **Percentage Area** |
| < 2 (Very slight) | 3006.860 | 91.147 |
| 2 - 10 (Slight) | 251.982 | 7.638 |
| 10 - 29 (Moderate) | 33.738 | 1.023 |
| 29 - 71(Severe) | 4.866 | 0.148 |
| > 71 (Very Severe) | 1.466 | 0.044 |

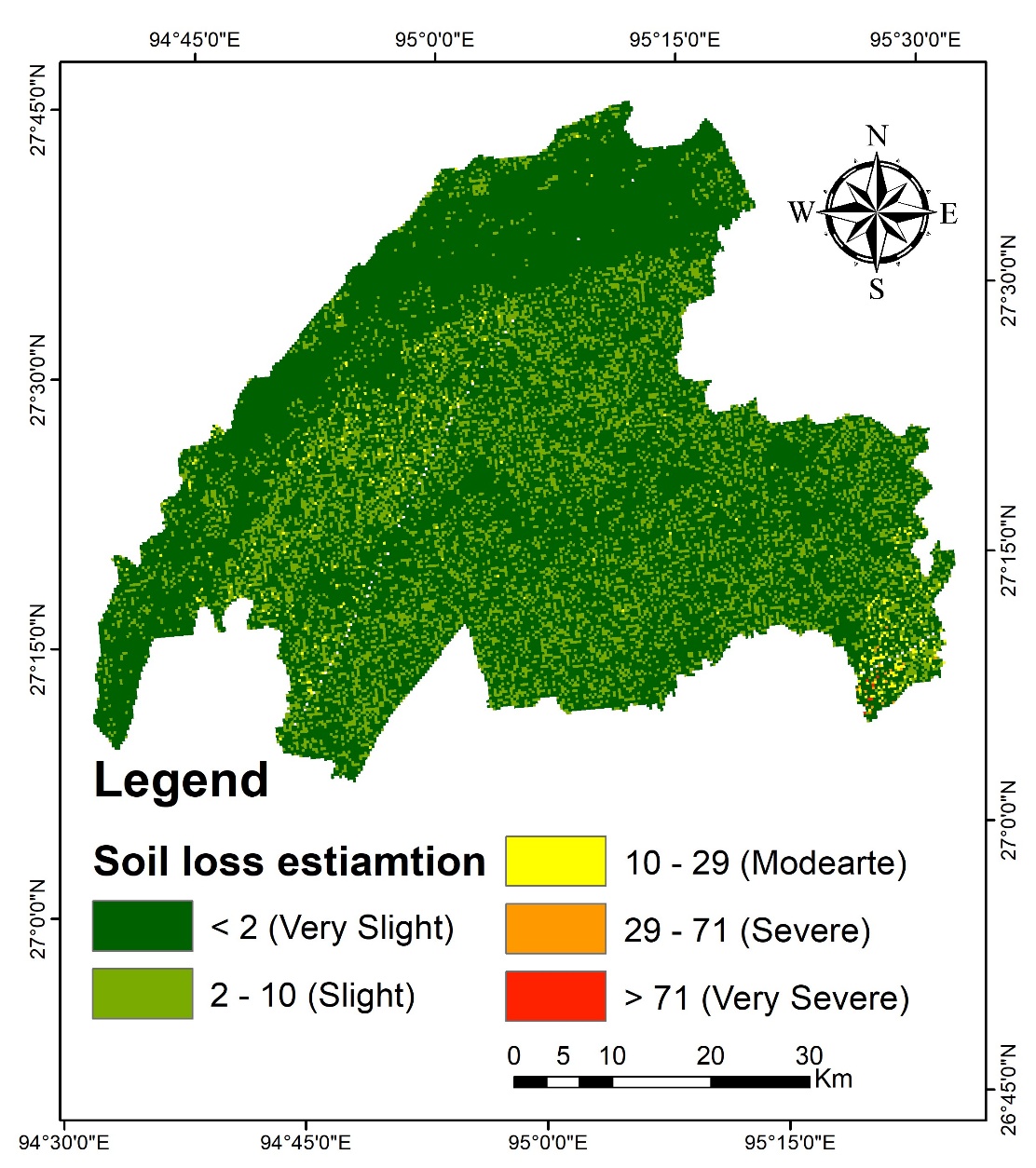


Fig. 7 Soil loss severity classes of the study area

**Implications of this study for policy and soil loss management**

“The long-term average annual rate of soil erosion can be predicted using RUSLE, an empirically based modeling method that uses five factors, i.e., rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover and management factor (C), and support practice factor (P)” (Thapa, 2020). Fayas et al., 2019 conducted a study using the RUSLE model in the Kelani River basin in Sri Lanka and reported that “the higher rate of soil erosion is attributed to steeper slopes and high annual rainfall (R and LS factor)”. Similarly, Ghosh et al., 2022 also observed in their study on the Mayurakshi River basin that the areas with steeper slopes are most vulnerable to soil erosion. The RUSLE model can be used to estimate the average annual rate of soil loss for a site of interest for a variety of scenarios related to cropping systems, management strategies, and erosion control measures (Lee & Lee, 2006). Thus, the soil erosion model is an essential tool for forecasting excessive soil loss and supporting the implementation of erosion control strategies (Ismail & Ravichandran, 2008; Kamaludin et al., 2013). The present study used the RUSLE model to evaluate the soil erosion and its spatial distribution in the entire Dibrugarh district of Assam using remotely sensed data. It divides the entire Dibrugarh district into five soil erosion severity classes, such as very slight, slight, moderate, severe, and very severe. The results revealed that severe and very severe erosion were found in the high-altitude areas with steep slopes, whereas the low-altitude areas had low rates of soil erosion, namely, the southeastern part of the study area, where the elevation is high, contributes to high potential loss of soil. Such intense erosion leads to loss of productive topsoil and agricultural productivity, siltation of the river bodies and wetlands, which may result into food insecurity and increased flooding along the river banks in the region, respectively. Conversely, in the northern part, the elevation is low, which contributes to very slight soil erosion. The rainfall and K factor value were also higher in the southeastern part of the study area, which also significantly contributes to the loss of soil. Hence, the outcome of this study would be helpful to take suitable erosion control measures in the severely affected areas, as well as assist in evolving management scenarios and provide opportunities to policymakers for managing soil erosion hazards most effectively.

Although this study utilized comprehensive tools and techniques in identifying potential soil loss severity zones, it still has limitations that could be addressed in future research. Future studies in the region should consider the multi-temporal analysis of soil loss to better understand how the soil erosion pattern changes over time. The research will also benefit from intensive field-based sediment measurement and validation processes to enhance the accuracy of the model output. Moreover, the impact of climate change, particularly changes in the pattern of rainfall, on soil erosion can be studied to explain future soil loss scenarios using projected climatic data. Lastly, the socio-economic factors affecting soil degradation and effective soil erosion control measures can be included in estimating soil loss for a more holistic understanding of soil erosion severity in the region.

**Conclusion**

In the present study, the RUSLE model was applied in the GIS environment to evaluate soil loss status in the Dibrugarh district of Assam. The RUSLE model used several factors such as rainfall erosivity (R), soil erodibility (K), topography (LS), cover and management (C), and support practices (P) to identify the areas prone to soil erosion. The soil erosion severity map was prepared and categorized into five different soil loss severity classes. The results indicate that a majority of the study area (over 91%) experiences a very slight rate of soil erosion, with most areas having erosion rates of less than 2 t ha−1 yr−1. However, small pockets, particularly near riverbanks, exhibited moderate to severe erosion, with rates ranging from 10 to 71 t ha−1 yr−1. The study highlights the importance of utilizing models like RUSLE, integrated with remote sensing and GIS techniques, for effective management of soil erosion. These models help identify critical areas requiring intervention and promote sustainable land use and land cover practices.

**Disclaimer (Artificial intelligence)**

**Option 2:**

Author(s) hereby declares that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1. The author(s) hereby declare using Grammarly (v1.2.164.1672), an AI-powered tool for correcting any grammatical errors and spelling mistakes.

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