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GIS-Based Assessment of Soil Erosion Using the Revised Universal Soil Loss Equation (RUSLE) Model in Morigaon District, Assam, India

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ABSTRACT

Soil erosion in the agricultural landscape of Assam has been impacting the livelihoods of millions. In administrative regions like districts, which are vulnerable to natural disasters like floods and bank erosion, GIS-based soil erosion estimating studies can help planners and policymakers identify areas of soil erosion to implement scientific conservation measures. The main purpose of this study is to estimate soil loss and to determine soil loss zones in the Morigaon district of Assam. The Revised Universal Soil Loss Equation (RUSLE) combined with GIS has been incorporated into the present study. The five parameters of RUSLE, namely, rainfall-runoff erosivity, soil erodibility, topographic factor, cover management, and conservation practices, are individually estimated from relevant and authentic data sources, and all these parameters are quantified in GIS. The research findings show that 46.89% of areas in the district are in moderate soil loss zone, eroding 0.78 ton/ha/year, 34.27% of areas are in low soil loss zone, 15.36% of areas are in high soil loss zone, eroding about 12.22 ton/ha/year and 3.47% of areas are in a very high soil loss zone, eroding 192.8 ton/ha/year. The high soil loss zones mainly cover the riverine areas and bare lands in the district. As per our estimation, there is an average of 205.85 tonnes of soil loss in the district per hectare per year.

INTRODUCTION

Soil erosion, in general, involves the removal and transport of the top layer of soil. It is a global problem affecting natural resources, ecosystems, and agricultural production over the decades (Bakker et al. 2005, Ighodaro et al. 2013, Koirala et al. 2019, Littleboy et al. 1992, Parveen & Kumar, 2012, Pimentel 2006, Thapa 2020). Soil loss due to soil erosion is more common, especially in mountainous areas. Generally, soil erosion is induced by two factors: wind (aeolian process) and water (fluvial process), of which water is considered as the primary one. In India, the soil is eroded at an average annual rate of 5.3 billion tons per year (Narayana & Babu 1983), and the average annual soil loss at the national level is 4.9 billion tons (Singh et al. 1992). However, soil loss due to erosion is more common in the Himalayan region and Western Ghats as compared to other parts of the country (Pandey et al. 2007). The surface water flow and resulting soil erosion are mainly induced by five factors, namely rainfall, soil erodibility, topography, cover management, and support practices (Renard 1997).

To estimate annual soil loss due to water erosion, the Science and Education Administration of the National Runoff and Soil Loss Data Centre developed the Universal Soil Loss Equation (USLE) model in 1954 (Wischmeier & Smith 1978), which is the most empirical method for estimating soil loss. USLE is the most widely accepted method for estimating average annual soil loss and its effectiveness in determining conservation measures. However, in 1993, the USDA Soil and Water Conservation Service introduced the Revised Universal

Soil Loss Equation (RUSLE), which is an improved and diverse version of USLE. Both the models are the same, but RUSLE includes more accurate slope length and slope gradient calculations and more detailed calculations for soil cover and conservation practices along with development in iso-erodent maps (Renard 1997). Over the last few decades, numerous studies have been carried out on soil loss estimation studies by many researchers using GIS and remote sensing techniques due to their accuracy and reliability. The majority of the literature found on the study of soil erosion is mainly on river basins or watersheds in India (Abdul Rahaman et al. 2015, Balasubramani et al. 2015, Das & Sarma 2017, Devatha et al. 2015, Ganasri & Ramesh 2016, Gelagay & Minale 2016, Kalita et al. 2018, Kalita & Bhattacharjee 2024, Krishna Bahadur 2009, Pandey et al. 2007, Thakuriah, 2023). However, there are only a few studies on soil loss estimation in the context of state, e.g., soil loss estimation studies in a broader perspective have been made on a state like Goa in India, which is a diversified state surrounded by coasts and Western Ghats (Gaonkar et al. 2024) and in districts or such administrative regions (Budhathoki et al. 2023, Das et al. 2020, Handique et al. 2023, Koirala et al. 2019, Lewis 1985, Nagaraju et al. 2011, Niyonsenga et al. 2021, Thapa 2020).

Measuring soil loss in an area or a region is necessary because it helps design soil conservation measures in an area or a river basin, designing dams and reservoirs, etc. Understanding the rate and patterns of soil loss helps in implementing effective soil conservation techniques such as contour farming, terracing, and afforestation. In the agricultural sector, such studies can help to maintain soil health and ensure long-term productivity. Against the above backdrops, the present study attempts to assess soil loss in the Morigaon district of Assam, which is predominantly an agrarian district of the state. This is the first-ever study on soil loss estimation in the district.

STUDY AREA

Morigaon district of Assam is in the middle part of Assam with a geographical extension of latitude 26°15′ N and 26°50′ N and 92° E and 92°50′ E longitude. The district is bounded by the mighty river Brahmaputra and Darrang district on the north, Karbi Anglong district on the south, Nagaon district on the east, and Kamrup district on the west (Fig. 1.). The total geographical area of the district is 1551 sq. km. The district is characterized by alluvial plains with several rivers and numerous wetlands and is mainly drained by the Brahmaputra, Kopili, Kolong, Sonai, Killing, and Pokoriya rivers. The soil of the district is alluvial and mostly loamy, comprising sand and clay. The district falls under Central Brahmaputra Valley agro-climatic zones under the Eastern

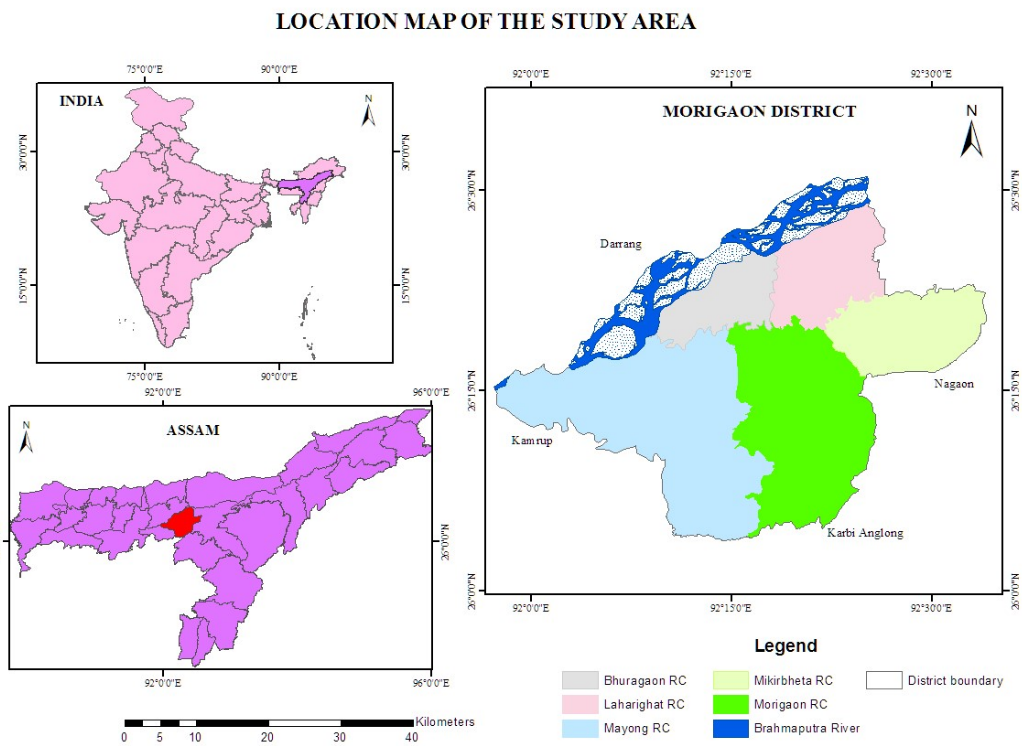

Fig. 1: Location of Morigaon district.

Table 1: Details of the database used in the present study.

Data	Year	Source	Description
Topographical maps	1963	Survey of India (SOI)	78 N15, N16,83 B (03, 04, 06, 07, 08 and 12), 1: 50000
Rainfall data	2012-2021	https://crudata.uea.ac.uk/cru/data/hrg/	High-resolution gridded datasets (CRU TS, CRU CY, CRU CL: 1901-2022 global land data for multiple variables on a 0.5° x 0.5° or finer grid)
Thematic Maps		National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur	Soil texture
Satellite image	2021	Copernicus	Sentinel 2A, 10m
	2009	JAXA and Alaska Satellite Facility (ASF)	ALOS PALSAR DEM, 12.5 m

Himalayan Region, for which it is suitable for agricultural production and agriculture is the primary economic activity of the rural households in the district.

MATERIALS AND METHODS

The advent of remote sensing has made it easier to derive spatial information since they are handy and cost-effective. The integrated use of remote sensing and GIS technologies helps to assess soil loss at various scales. Table 1 indicates the data sets used to prepare thematic maps in a GIS environment. The district boundary of Morigaon is derived from the topographical maps of the Survey of India.

RUSLE Model

The RUSLE model estimates the amount of soil loss due to erosion. It is a result of the cooperative effort of scientists and users to update the age-old USLE model. Moreover, the combined use of GIS and RUSLE has been proven to be an effective approach to estimating potential soil loss in a given area (Fernandez et al. 2003, Yitayew et al. 1999). The estimated soil loss equation is very effective in soil conservation studies. The soil loss equation is:

$$A = R \times K \times L \times S \times C \times P \quad \ldots(1)$$

where, A= Amount of estimated soil eroded, R = rainfall runoff, K = erodibility of soil, L= slope length factor, S =

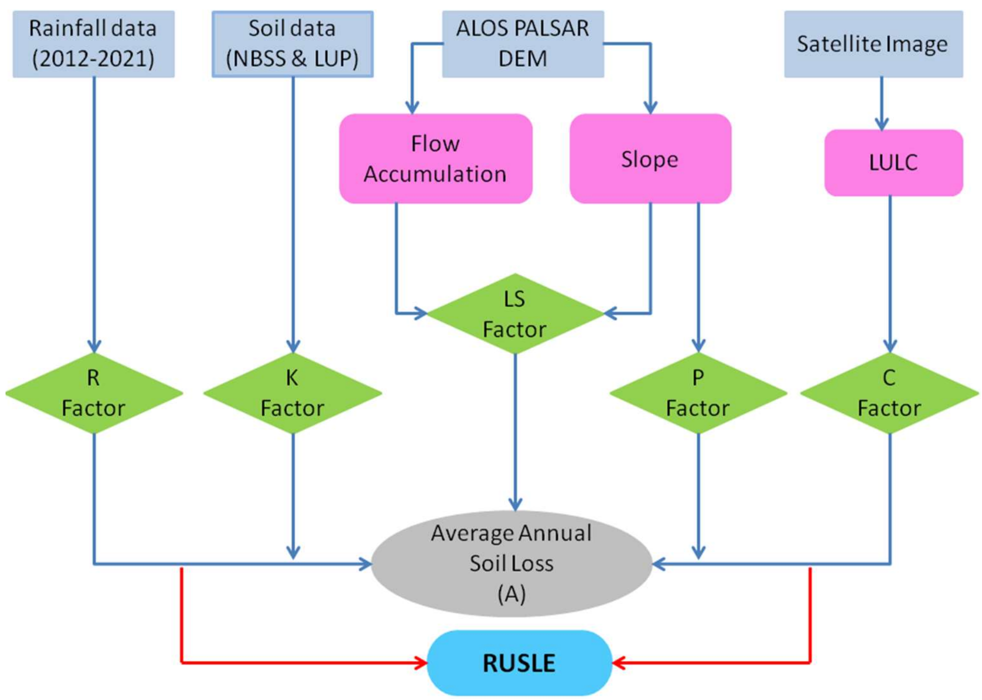

Fig. 2: Flow chart of RUSLE.

slope steepness, C = cover management and P = support practice factor.

Derivations of Parameters of RUSLE

The parameters of RUSLE can be easily integrated with GIS, for which the model acts as an advantage in the present soil loss study. The flow chart of the methodology of the RUSLE model used in this study is presented in Fig. 2.

Rainfall-Runoff Erosivity Factor (R)

Erosivity is the power of wind or water to cause erosion. The higher erosivity results in higher erosion. The rainfall erosion index is a numerical evaluation of rainfall patterns or storms that can erode the topsoil (Wischmeier 1959). It can also be regarded as *'the raindrop impact'* because raindrop impact leads to sheet erosion, which removes the top soil layers. For the R- R-factor, rainfall data has been taken for a period of 10 years i.e., from 2012 to 2021. The ten years of monthly rainfall data have been converted to average yearly data using a raster calculator in GIS. The data is in grid cells, which are further converted to point data, and an isoerodent map has been prepared by adopting the Inverse Distance Weighted (IDW) interpolation technique (Fig. 3). The R factor is calculated using the following equation: (Koirala et al. 2019, Stocking, 1984, Thapa 2020).

$$R = 38.5 + 0.35P \quad \text{...(2)}$$

Table 2: K factor values of different soil textures in the Morigaon district.

Soil texture	K- Factor
Fine loam	0.07
Fine silt	0.40
Coarse loam	0.07
Clay	0.22
Fine	0.05

Soil Erodibility Factor (K)

Soil erodibility is the susceptibility of soil to erode and is related to organic components, soil structure, texture, steepness, etc., which influence the detachment and transportation process (Panagos et al. 2014). It is related to soil infiltration as more infiltration capacity lessens the runoff volume. If runoff is less, soil erosion is also less. Soils containing a high percentage of sand and silt are more susceptible to detachment. However, an increase in the organic and clay content of the soil decreases erodibility as it aggregates the soil, and a higher raindrop impact will be required to break down the soil. Clay has a resisting capacity; however, it is easily transportable once detached. The soil texture of the district and related K factor values has been presented in Table 2. The K factor in the study area ranges from 0.04 to 0.4 (Fig. 4).

Topographic Factor (LS)

The topographic factor comprises the slope length and

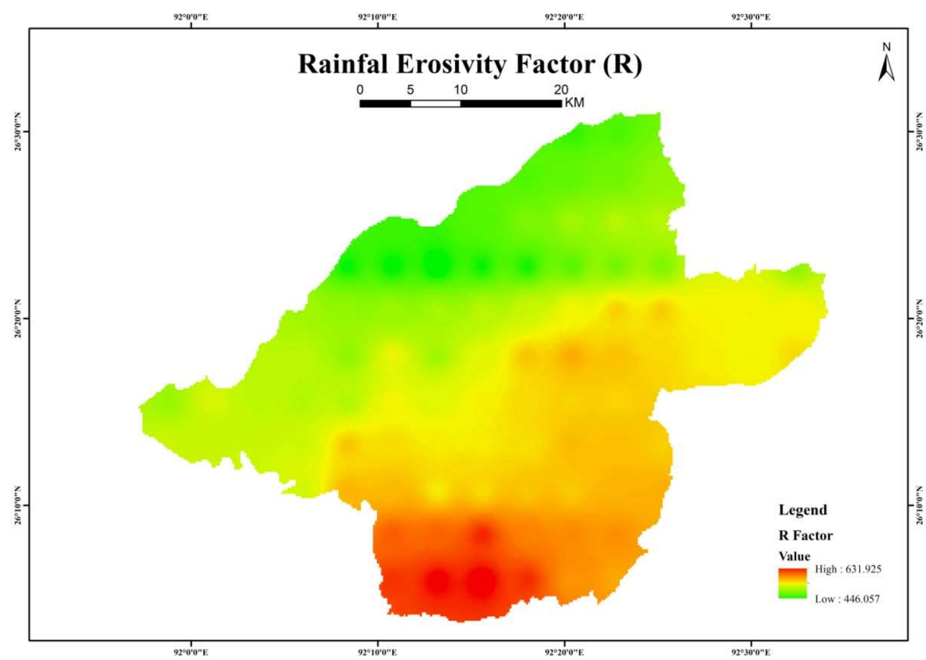

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Fig. 3: R factor map of Morigaon district.

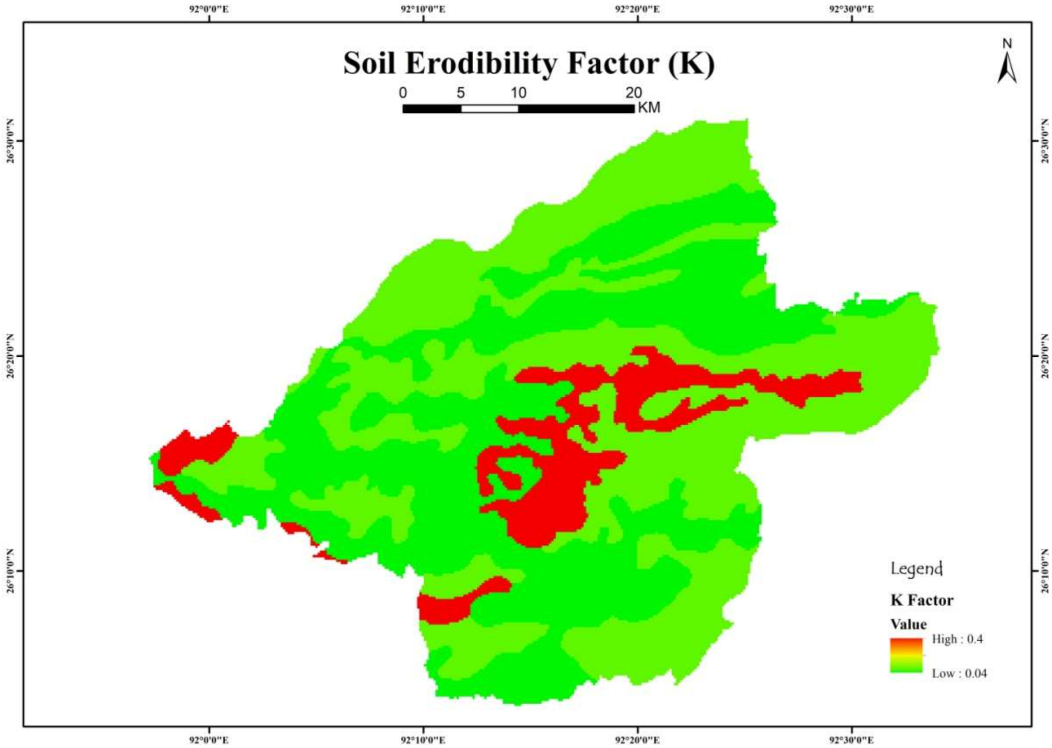

Fig. 4: K factor map of Morigaon district.

slope steepness, which directly influence the surface runoff (Koirala et al. 2019). The degree of slope is the dominant factor of soil erosion. The steeper and longer the slope, the higher the risk for erosion. In a steeper and longer slope, increased surface runoff reduces soil stability. The combined LS factor is computed by following the equation proposed by (Moore & Burch 1986). The LS factor in the study area ranges from 0 to 2.335 (Fig. 5).

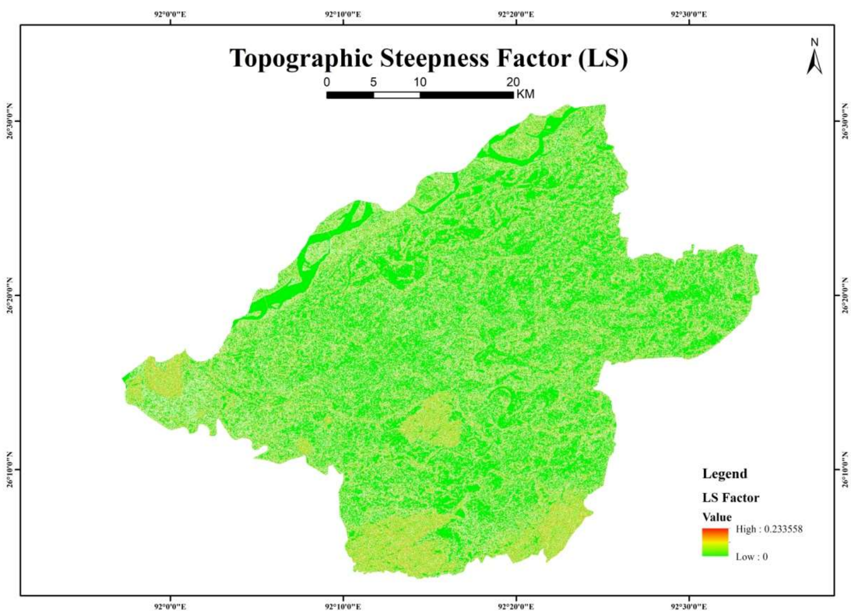

Fig. 5: LS factor map of Morigaon district.

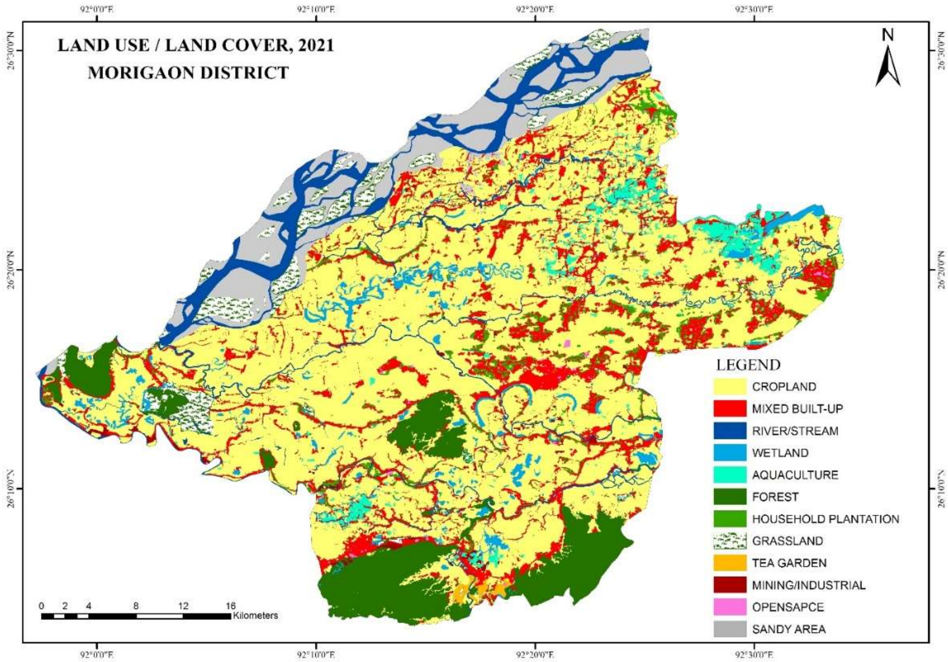

Fig. 6: Land use/land cover map of Morigaon district.

$$LS = \left\{FA \times \left(cell\frac{size}{23.13}\right)\right\}^{0.4} \times \{\sin(slope\ of\ DEM \times 0.01745/0.09)\}^{1.3} \times 1.6 \quad \ldots(3)$$

Where LS = Slope length and Steepness factor and FA = Flow accumulation

Cover Management Factor (C)

Cover management implies the ratio of soil loss from an identical area covered under specified land use. Cover management implies the vegetative cover of the area, and understanding the specific land use patterns, the risk of soil erosion can be assessed. Major land use classes of a region are an important parameter in assessing soil erosion (Erencin 2000, Folly et al. 1996). Since land use and land cover changes are the most sensitive indicators of the interactions between humans and the environment, they continue to be important areas of research (Alkharabsheh et al. 2013). Fig. 6 shows the land use and land cover map of the Morigaon district, and land cover is classified through visual interpretation techniques using Sentinel data. The C factor has been mapped from land cover classification (Fig. 7), and the C factor values used in different land use classes in the study are represented in Table 3. The C factor in the study area ranges from 0 to 1.

Table 3: Land use classes and associated C values in Morigaon district.

Land cover type	C value	Source
Cropland	0.55	(Yang et al. 2003)
Forest	0.17	(Yang et al. 2003)
Mixed built-up	0	(Koirala et al. 2019)
Mining/Industrial	0.08	(Wang et al. 2016)
Household Plantation	0.03	(Yang et al. 2003)
Agri lands	0.4	(Yang et al. 2003)
Tea garden	0.01	(Wang et al. 2016)
Grassland	0.06	(Yang, 2014)
Open Space	0.35	(Yang et al. 2003)
River/Stream	0	(Koirala et al. 2019)
Wetlands	0.05	(Yang et al. 2003)
Sandy area	1	(Bouguerra et al. 2017)

Support Practice Factor (P)

The support practice factor implies the soil loss ratio with support practices like contouring, strip cropping, or terracing in slope (Wischmeier & Smith 1978). For the study area, the P values are obtained following Table 4. P factor map (Fig. 8) has been prepared from the slope map of the district by following the equation:

$$P = 0.2 + 0.3\,S \quad \ldots(4)$$

Where S is the slope.

RESULTS AND DISCUSSION

In this study, geospatial techniques are incorporated to

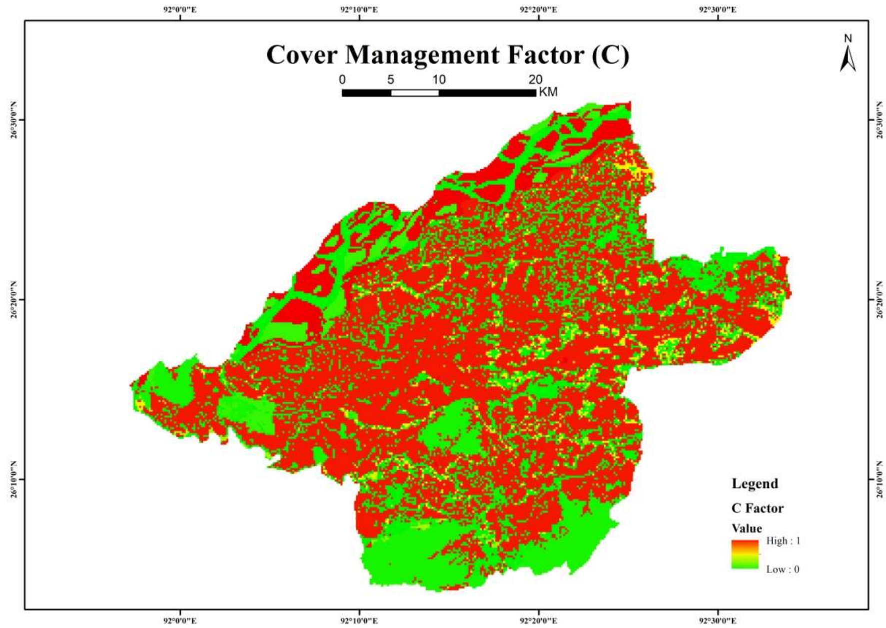

Fig. 7: C factor map of Morigaon district.

Table 4: Support practice factor according to slope (Balabathina et al. 2020, Budhathoki et al. 2023, Koirala et al. 2019).

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

estimate soil erosion using the RUSLE model. The soil erosion or estimated soil loss map was generated (Fig. 9), and the erosion map of the study area is categorized into four soil loss categories, namely, low, moderate, high, and very high. The estimated results show that 3.47% area in the district is in a very high category of soil loss, where about 192.8 tons. ha^{-1} of soil is being eroded annually. The maximum soil loss category in the district lies in the moderate soil loss category (46.89%), followed by the low soil loss category (34.27%

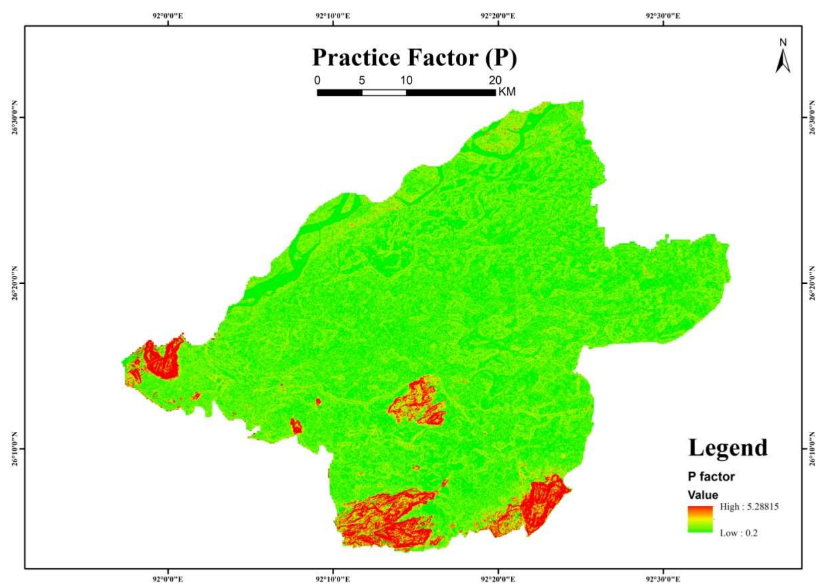

Fig. 8: P factor map of Morigaon district.

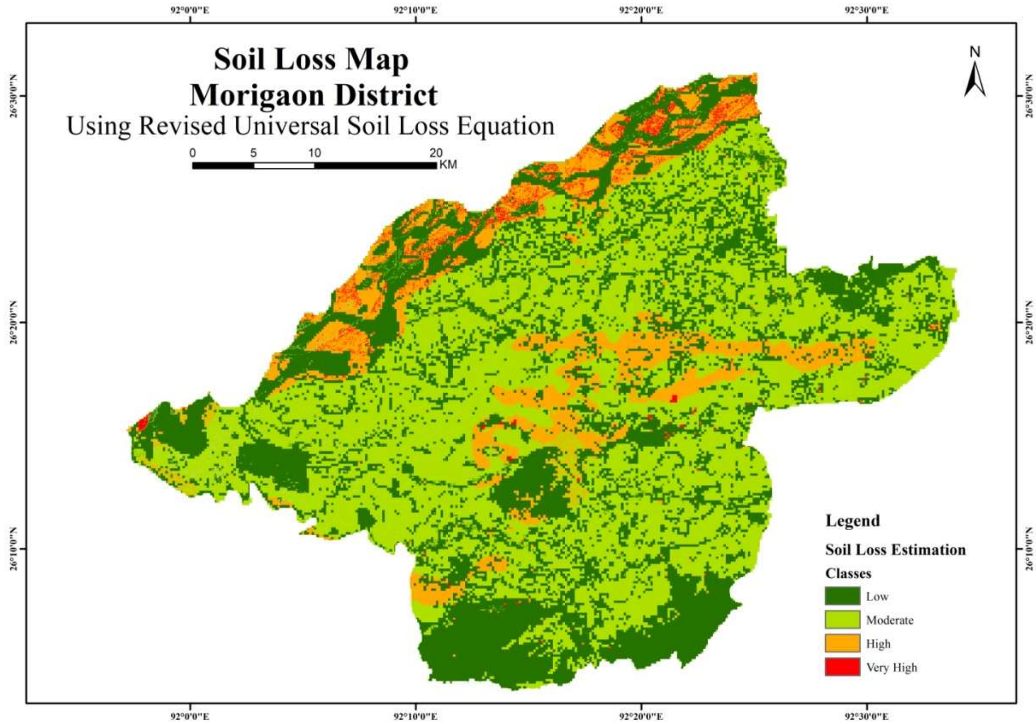

Fig. 9: Annual soil loss estimation map based on RUSLE in Morigaon district.

Table 5: Estimated value of soil loss in Morigaon district.

Soil loss category/zone	% of area within each category	Average soil loss (ton/ha/year)
Low	34.27	0.05
Moderate	46.89	0.78
High	15.36	12.22
Very high	3.47	192.8

area). In the moderate soil loss, about 0.78 ton/ha of soil is being eroded annually (Table 5).

The high and very high soil loss zone has been seen in the Brahmaputra riverbed in the northern part of the district comprising Laharighat Revenue Circle, Bhuragaon Revenue Circle, and Mayong Revenue Circle. These three revenue circles are more vulnerable to flood hazards and bank erosion. Due to detachment and transportation of top soils and the deposition of silts, it reduces the carrying capacity of the rivers which leads to flooding. In addition, the soil type of these revenue circles is of fine loamy of typic udifluvents origin. The soil of these revenue circles is moderately well-drained fine soils that occur on the level and active flood plains having loamy surfaces with erosion and severe flooding. Erosion hazards are more common in these three revenue circles, affecting the populations by permanently displacing them from their place of origin. However, a high erosion zone is also seen in the central part of the district, where there are several wetlands along the Sonai and Pokoriya river courses. The soil type of that area is fine silty, which mainly occurs in gently sloping floodplains with moderate flooding.

The low erosion zones are seen in the hilly areas of the district. Morigaon district is mainly an alluvial plain with some isolated residual hillocks. The minimum slope of the district is 2.36°, and the maximum slope is 60.19°. It can be said that the district has a gentle slope ranging from 2.36° to 7.8°. The hilly terrain of Burha Mayong Reserved Forest in the extreme west of the district indicates a low erosion zone area. Likewise, Sonai Kuchi Reserve Forest in the southwest, Kholahat Reserved Forest in the southeast, and Tetelia Baghara Reserved Forest in the south-central part of the district show a low soil loss zone area. These zones are mainly covered with a canopy of vegetation, which influences the interception of rain. The thick canopy absorbs raindrop impacts on the ground. Although steepness is high in these areas, the expected higher erosivity is reduced by the forest land use type. The thick canopy of these areas has also increased the soil stability. In addition, these residual hills have clayey soil, which is very deep and fine with slight stoniness and, therefore, is moderately susceptible to erosion.

The soil loss vulnerability map shows that soil loss is higher in the riverine areas and degraded forest areas of the district. Similar findings have also been found by other researchers in their respective studies (Das et al. 2020, Kalita & Bhattacharjee 2024). Studying soil loss over a long period, i.e., spatio-temporal variations like the soil loss study made in Chengde city of China for fifteen years (Yan et al. 2022), the spatio-temporal study will give a better vision of the pattern of soil loss, changing process of soil loss from emergence to extinction and the identification of the most influential factor of soil loss.

CONCLUSIONS

The present study attempts to apply the RUSLE model in an administrative unit like a district, and this is the first-ever study on soil loss estimation in the Morigaon district of Assam, India. It is believed that soil loss studies of this kind on administrative units will be helpful for land use planners and policymakers to formulate effective soil conservation measures. Soil erosion vulnerability map helps to identify erosion-prone areas to implement scientific soil conservation measures. The soil loss estimation maps of the study area reveal that about 46.89% of the district is in the moderate zone of soil loss, and 15.36% area is in the high soil loss zone. The moderate soil loss zone has the sensitivity to falling in the zone of high soil loss. So, proper conservation strategies are needed. In addition, the high soil loss zone, if not conserved immediately, will lead to extreme land degradation in the district.

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