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Soil erosion assessment in the Ranganadi watershed of Lakhimpur district, Assam, using GIS techniques and Revised Universal Soil Loss Equation model

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ABSTRACT

The loss of soil due to erosion is one of the most critical land degradation issues globally, representing a vital asset for both the economy and the environment. To effectively manage and regulate such a global issue, it is imperative to estimate the loss. With technological advancements, methodologies such as Geographic Information Systems (GIS) and Remote Sensing (RS) are crucial in addressing these difficulties. The primary objective of this study was to employ the Revised Universal Soil Loss Equation (RUSLE) model inside a GIS framework to quantify soil loss in the Ranganadi river basin of Assam, providing a more rapid and accurate estimate. Three distinct physiographic units, *i.e.*, Piedmont Plain, Alluvial Plain, and Flood Plain, were delineated. Collected 60 GPS-based soil samples from distinct physiographic units were collected and analyzed for different soil physico-chemical properties, in addition to taking into account a variety of criteria, such as rainfall erosivity factor (R), soil erodibility factor (K), topography factor (LS), cover and management factor (C), and conservation practices factor (P), the RUSLE approach is based on the evaluation of soil loss per unit area. Five basic RUSLE factors,

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viz., R factor, K factor, LS factor, C factor, and P factor, were used to determine soil erosion. Further, erosion ratio, dispersion ratio, and erosion index are the basic examples of erodibility indicators that were taken into consideration while used to evaluating the erodibility of the soil. The anticipated soil erosion in the above-said area varied from minimal to severe, with values between 0.01 and 27.38 t ha^{-1} yr^{-1}. Among the physiographic units, alluvial plain soils had the greatest mean soil erosion value of 8.52 t ha^{-1} yr^{-1}, whereas floodplain landscapes indicated the lowest average value of 3.39 t ha^{-1} yr^{-1}. The dispersion ratio varied between 0.08 and 0.33, with soils exhibiting a dispersion ratio exceeding 0.15, signifying their vulnerability to erosion. The erosion ratio varied between 0.04 and 0.61, whereas the erosion index fluctuated from 0.06 to 0.84. As a result, this model is particularly useful in anticipating soil loss in an area, allowing community members, legislatures, and other linked agencies to plan ahead of time for future efforts to mitigate the degradation.

1 Introduction

We all know that all living organisms that live on Earth need clean water, air, and nutrients, which all come from soil (Katsuyuki 2009; Keesstra et al. 2016). Because of the population's heavy reliance on soil resources, overexploitation causes soil degradation. In India, erosion hazards impact approximately 147 million hectares, comprising 94 million hectares of submerged erosion and 9 million hectares of wind erosion. Annually, a reduction of 1 mm of topsoil leads to a decrease of 5,334 MT in production attributable to soil erosion (Bhattacharyya et al. 2015). According to Meena et al. (2017), soil loss is a severe environmental problem that affects water body siltation, nutrient loss, and soil productivity. It adversely affects public health and the lives of marginalized communities dependent on agriculture, especially in the Eastern Indian Himalayas (Pimental 2006). The area is experiencing considerable soil erosion, with rivers transporting substantial quantities of sediment into the Bay of Bengal. The Himalayan and Tibetan regions contribute approximately 25% of the dissolved load to the world's oceans (Raymo and Ruddiman 1992). The Himalayan foothills in northeastern India, including Arunachal Pradesh, Nagaland, Manipur, Mizoram, Meghalaya, and Assam, are no exception to soil loss. However, the Himalayan rivers' sediment load has grown due to loss of forest cover, indiscriminate exploitation of natural resources, strong monsoon precipitation, and vulnerable river catchments with inadequate water retention capacity (Valdai 1985; Rawat and Rawat 1994). Thus, soil erosion needs immediate analysis since it is a significant obstacle to the long-term preservation of the environment and natural resources. The efficacy of various land management strategies, therefore, depends on measuring and evaluating the mean amount of soil erosion in arable and pastoral lands (Prasuhn et al. 2013). Soil attrition in any region may be quantified using several formulas and equations found in the literature. These have been produced during an extensive period of global experimentation. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978; Singh and Panda 2017) and RUSLE are the most commonly used methods for the computation of soil degradation (Renard et al. 1997; Fernandez et al. 2003; Srinivasan et al. 2019). The idea of associating available data sources employed with RUSLE and GIS technology is a reliable solution for computing the extent of soil erosion (Bez and Krishna 2014; Pham et al. 2018). These techniques have been widely incorporated and applied in many types of research; the RUSLE model can effectively estimate the erosion susceptibility of a watershed (Shinde et al. 2010; Ganasri and Ramesh 2016). Furthermore, GIS skills, in conjunction with satellite imaging techniques, are highly effective in modeling areas that are prone to soil erosion (Parveen and Kumar 2012). Molla and Sisheber (2017) estimated soil loss and conservation strategies under different slope classes and land uses in the Koga watershed in the upper part of the Blue Nile basin. Balakrishna and Balakrishna (2019) evaluated soil erosion and identified critical sub-watersheds. Soil erosion is instrumental in land degradation in mountain regions, with increased rainfall and surface water runoffs on bare lands, which increase soil erosion in India's northernmost region (Thapa 2020). Kandpal et al. (2018) carried out soil erodibility assessments in three forest divisions of Shivalik Hills, Punjab. They found that the Dasuya forest division exhibited maximum soil loss (31.78%), followed by the moderately dense forest of Gurdaspur (29.20%) and Garshnkar (11.28%). The Brahmaputra Valley in Assam is characterized by significant undulation, resulting in serious soil erosion issues. The depletion of soil due to runoff from the ground is one of the most prevalent types of soil damage in Assam, especially during times of heavy and prolonged rains that have a negative impact on agricultural output. According to the State Department of Soil Conservation, Assam, the Ranganadi basin, which is found in Assam's northern bank plains, is most susceptible to erosion. This watershed has many physiographic units, and the specific soils in this region exhibit numerous fundamental characteristics. Still, the knowledge about the characteristics of the soils that erode inside the watersheds is limited. The purpose of this work was to use the model developed by RUSLE and GIS analysis to explore the Ranganadi watershed's deteriorating soil features to enable the policymakers to devise strategies for watershed management to minimize soil erosion in the area.

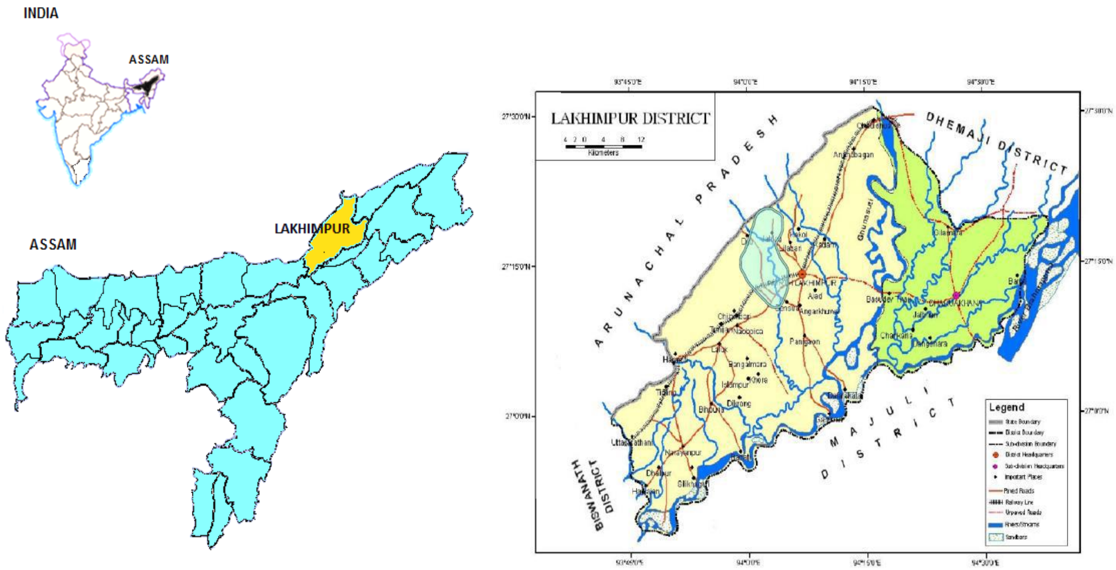

Figure 1 Location map of the study area

2 Materials and Methods

2.1 Site description and climate

The Ranganadi catchment is situated in the Lakhimpur district, in the North Bank Plain Zone of Assam. The Ranganadi watershed lies between 93°59'06.18'E and 94°05'08.55'E longitude and between 27°10' 36.40'N and 27°20' 33.68'N latitude (Figure 1). The climate in the scrutinized field is a humid sub-tropical one, with an average annual rainfall of 3194 mm, an average annual temperature of more than 22°C and the difference between the average summer temperature of 27.3°C and means winter temperature of 18°C are 5°C. Consequently, the studied area can be considered to have a hyperthermic soil temperature regime. The climate of the said field has equal concentrations of soil moisture.

2.2 Delineation of watershed

They visually interpreted the geocoded FCC of the Resourcesat-1 LISS-III data of 2015 and prepared the physiographic map in consultation with the Survey of India toposheets of scale 1:50,000. The physiographic units that have been identified following visual discernment of colour, tones, and texture differences include the Piedmont Plain, which occupied 4192 ha; the Alluvial Plain, which occupied 4808 ha; and Flood Plain, which occupied 3174 ha (Figure 2). The satellite map of the transect of the Ranganadi watershed is illustrated in Figure 3.

2.3 Soil collection and analysis

With the help of the GPS, 60 locations were selected as sampling sites in physiographic units, i.e., Piedmont Plain (soil sample 16), Alluvial Plain (soil sample 19), and Flood Plain (soil sample 25).

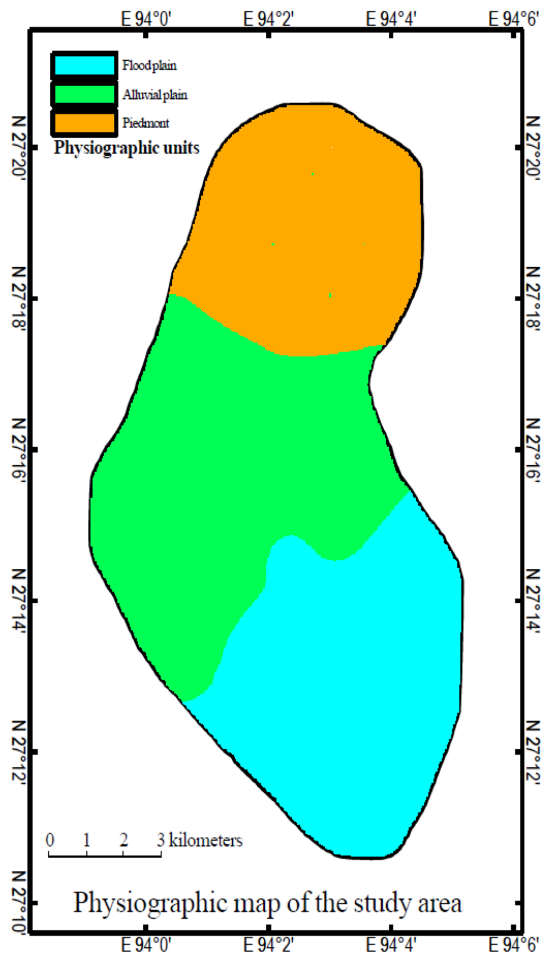

Figure 2 Physiographic delineation map

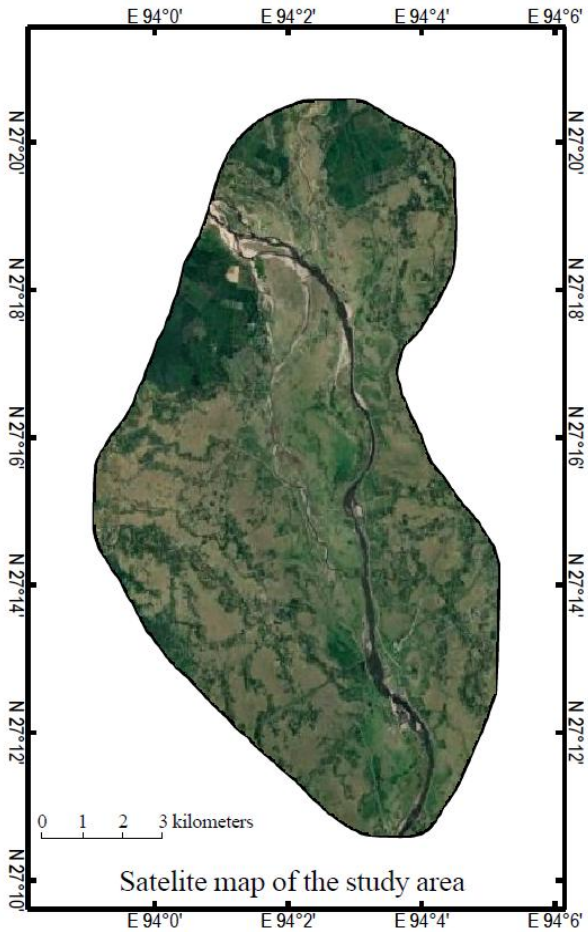

Figure 3 Satellite map of Ranganadi watershed

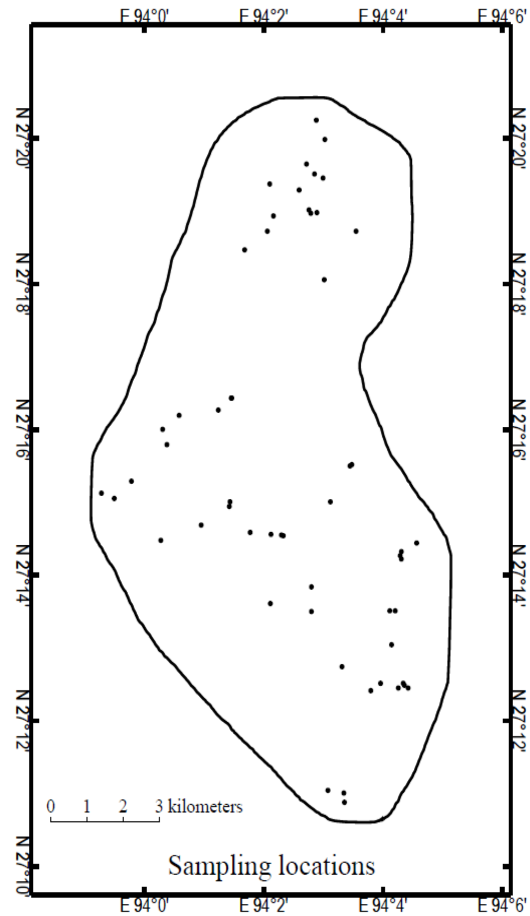

Figure 4 Sampling site map

The places that were sampled within the examined field are shown in the following figure 4. Therefore, bulk and core samples were taken from all the detected locations. The collected soil samples in bulk were dried by air, thereafter mixed and ground using a wooden mortar and pestle, and then separated using a 2mm sieve. These samples were also taken to examine some of the physical features of the soil samples obtained through the core samples, including particle size distribution by the International pipette procedure (Piper 1966), constant head approach for assessing Hydraulic Conductivity (Klute 1965), Water Holding Capacity (Piper 1966), Organic Carbon (Walkley and Black 1934), Available Water Content (Richards 1948), and Soil Aggregate (Yoder 1936).

2.4 RUSLE Parameters Analysis

Renard et al. (1997) developed the Revised Universal Soil Loss Equation (RUSLE) model (Figure 5), which was used to evaluate annual soil loss in the Ranganadi watershed region. When assessing soil loss, this model has the advantage of taking into account all important input variables, including land use or land cover, soil erodibility, rainfall intensity and volume, and conservation practices. The Revised Universal Soil Loss Equation (RUSLE) is represented as:

$$\text{Soil loss (A)} = \text{R, K, LS, C, P}$$

Where,A = the mean annual soil loss (t ha^{-1} yr^{-1}), R = rainfall erosivity factor (MJ mm ha yr), K = soil erodibility factor (t ha MJ^{-1} mm^{-1}), LS= slope length/steepness factor, C = cover and management factor, and P = conservation practice factor

2.4.1 Rainfall erosivity factor (R)

The rainfall erosivity factor (R) was computed using the formula provided by Bergsma (1980). The established equation is:

$$R = 0.1059a.b.c + 52$$

Where a = average yearly precipitation, b = maximum 24-hour precipitation with a recurrence interval of two years, and c = one-hour maximum precipitation with a recurrence frequency of two years.

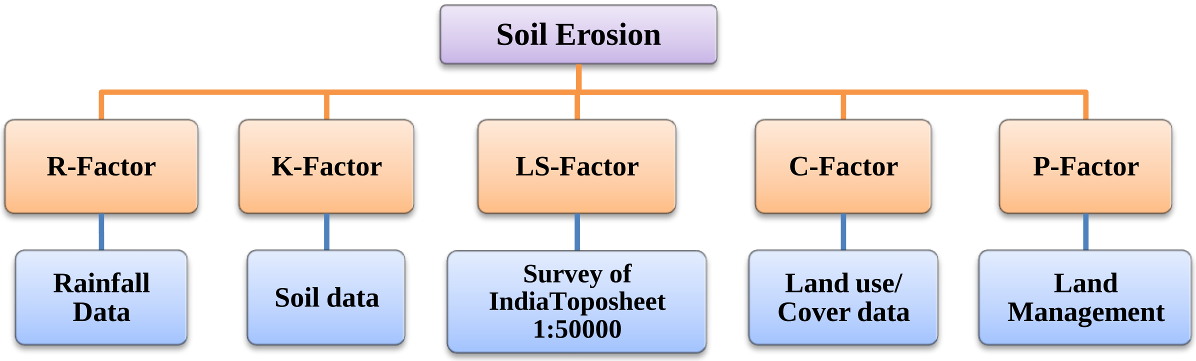

Figure 5 Flow diagram for investigation of soil erosion using the RUSLE model

2.4.2 Soil erodibility factor (K)

By measuring the rate at which soil deteriorates due to surface runoff or raindrop contact, the erodibility factor captures the variation in soil erosion per unit area as a result of external pressures. This element is profoundly influenced by soil texture, structure, permeability, and organic matter content. The volume written by Wischmeier et al. (1971) was essential in determining K values in the study area using the following equation:

$$100\ K = 2.1 \times 10\text{^} - 4 \times M\text{^}1.14\ (12 - a) + 3.25\ (b - 2) + 2.5\ (c - 3)$$

Where K = soil erodibility factor, M = percent of silt + percent of very fine sand, a = percentage of organic matter, b = soil structure code, and c = soil permeability code.

2.4.3 Slope length/steepness factor (LS)

Wischmeier and Smith's 1978 monograms and the Survey of India Topographical Map of 1:50000 were used to calculate the LS factor of each physiographic unit.

2.4.4 Cover management factor (C)

Cover management factor (C) factors were calculated using the primary crop growth/land use data gathered during the field survey.

2.4.5 The conservation practice factors (P)

The P factors employed in conservation practice were determined using information gathered during field surveys. Previous studies provided the 'P' cut-off values for various land usage categories (Potdar et al. 2003).

2.5 Erodibility indices & geostatistical analysis

The erodibility of soils was assessed by calculating the erodibility indices: (i) Dispersion ratio (Middleton 1930) = [% Undispersed (silt + clay) / % Dispersed (silt + clay)]; (ii) Erosion ratio (Middleton 1930) = Dispersion ratio / [Clay (%) / Available water] (iii) Erosion index (Sahi et al. 1977) = Dispersion ratio / [Clay (%) / 0.5 Water holding capacity].

2.6 Geostatistical analysis

Using these data, a GIS environment constructed the map showing soil loss. The values obtained from each sample location were extracted from the location map utilizing ArcMap 10.4. The soil parameter values at the unsampled site were determined through the application of the Inverse Distance Weighted (IDW) method, following the methodology outlined by Jensen (1986). The study employed the IDW interpolation methodology, a geostatistical method commonly utilized by several authors for estimating surface maps and forecasting soil parameters (Abdelrahman et al. 2020). The interpolated maps were reclassified to get the map units and legends displayed here. The watershed border of Ranganadi was superimposed on the interpolated maps to get the final map. The analysis of eight quantitative soil erosion variables, linked to three indices of erodibility and soil loss, was conducted using the statistical program SPSS-21 and Xlstat. The investigation yielded significant statistical parameters, including the correlation matrix, variance-covariance matrix, and Eigenvalues with corresponding Eigenvectors and loading. Each sample was assigned a 'Score', which is the computed value of the factor at that site and is referred to as 'Factor score'. The samples were graded according to the factor concerned.

3 Results and Discussion

3.1 Soil erosion related characters:

The eight soil erosional characteristics of the Ranganadi watershed for estimating soil erosion are depicted in Table 1. Various box plots were developed, as shown in Figure 6.

The watershed under study comprises a range of soil types, *i.e.*, from clayey loam to sandy soil. Single grains and subangular blocky shapes were among the different soil structures. Sand and

Table 1 Physiographic distribution soil erosional properties of Ranganadiwatershed

Parameter	Piedmont plain			Alluvial plain			Flood plain		
	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)
Total sand (%)	22-82.40	62.79	34.93	26.30-89.36	57.36	30.70	32.21-90.08	59.17	29.76
Very fine sand (%)	11.12-26.23	18.79	31.37	10.12-33.34	20.33	29.96	11.12-31.12	18.77	33.16
Silt (%)	9.72-60.28	26.13	69.28	5.68-56.80	25.28	42.24	5.44-53.83	25.09	46.69
Clay (%)	5.09-18	11.08	40.14	4.96-35.56	17.36	60.41	4.48-33.14	15.74	53.74
HC (cm hr^{-1})	0.42-5.87	3.06	69.61	0.43-6.24	2.51	87.28	0.48-6.17	2.32	86.27
WHC (%)	15.25-42.35	25.49	30.24	16.85-53.70	30.38	32.33	14.21-52.34	32.92	36.99
AWC (%)	5.25-13.19	8.32	39.23	4.36-17.97	11.59	34.99	4.64-18.33	10.53	35.84
OM (g kg^{-1})	0.88-2.02	1.45	24.71	0.53-2.83	1.53	40.97	0.28-2.97	1.49	42.79

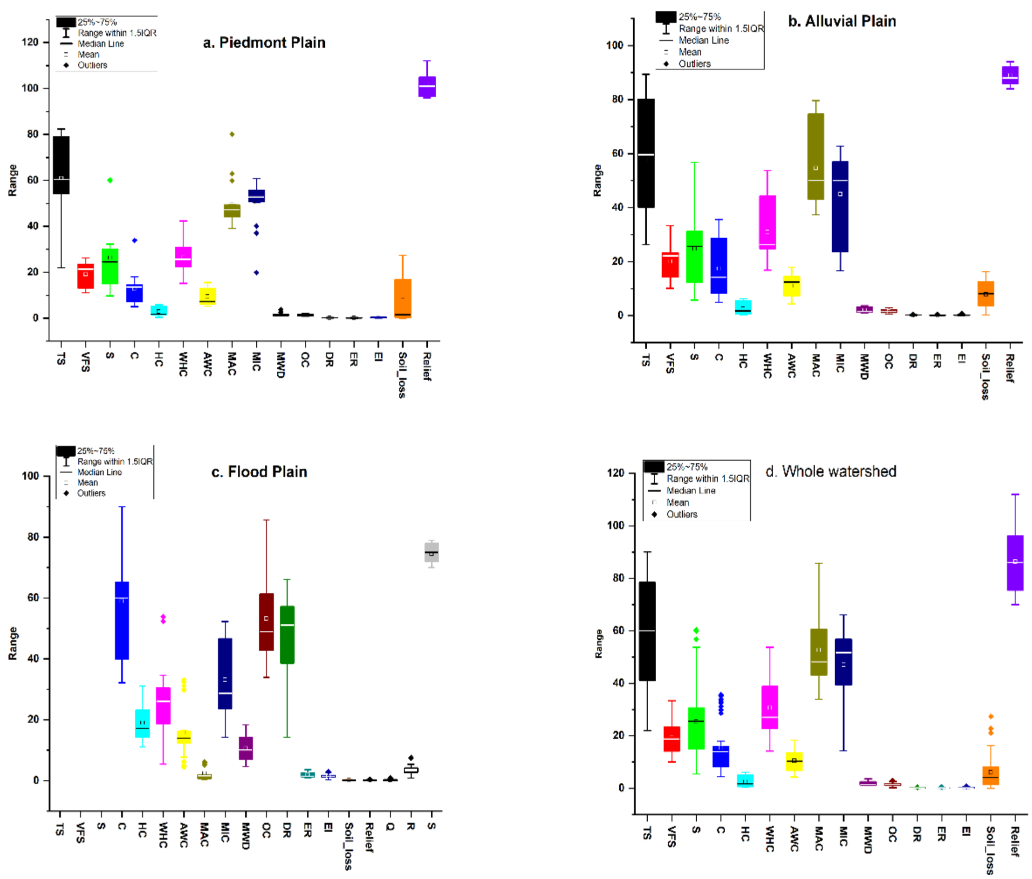

Figure 6 Box plots showing soil erosional properties of Ranganadi Watershed (a) Piedmont Plain (b) Alluvial Plain (c) Flood Plain (d) Whole watershed

fine sand contents in the examined soils ranged from 22.00 to 90.08% and 10.12 to 33.34%, respectively (Table 1). Similarly, Table 1 shows that the concentrations of silt and clay varied from 5.44 to 60.28% and 4.48 to 35.56%, respectively. The alluvial plain had the lowest percentage of sand (Mean 57.36) among the physiographic units, while the piedmont plain had the greatest percentage (Mean 62.79). The highest silt percentage (Mean 26.13) was found on the Piedmont Plain. Conversely, the highest concentrations of clay (Mean 17.36) and extremely very fine sand (Mean 20.33) are found in the alluvial plain area. The faster transit of finer materials from the Piedmont Plain to the alluvial plain and flood plain is caused by erosion, which carries these materials downstream from the Piedmont Plain and dumps them in these areas. Soil degradation is influenced by factors such as sensitivity to degradative processes, land use, duration, and management. Shifting farming has been a long-standing practice in Assam. Apart from that, the river Subansiri shows evidence of large amounts of sediment being deposited and overflowing the flood area, which leads to significant wearing away of the river bank (Sasang Guite and Bora 2016). From the results, it is seen that the area experiences soil erosion because of high slope angles. High braiding, huge water flow, and the rising of the river bottom owing to silt deposition are the main causes of the river's significant instability at numerous reaches. Recurring floods every year owing to heavy rainfall during long monsoons in the study area have led to breaches of embankments and developed areas of bars, which cause erosion. In the north bank plain of Assam, Deka et al. (2009) found that the texture of the soils is finer at lower elevations than at higher elevations. Sand's coefficient of variation is lowest in flood zones (CV = 29.76%), middle in alluvial regions (30.70%), and highest in piedmont plains (34.93%). While the amount of clay differed considerably among the alluvial, flood, and piedmont plains, the silt fraction varied significantly among the piedmont basin (CV = 69.28%), Flood plain (CV = 46.69%), and Flood plain (CV = 42.24%). These findings are supported by the results of Oku et al. (2010). The presence of a substantial positive link between relief and sand, as well as a large negative correlation with silt and clay, supports the experimental finding. Bharteey et al. (2023) observed similar findings. The hydraulic conductivity of the watershed ranged from 0.42 to 6.24 cm hr^{-1} (Table 1). Of all the physiographic units, the Piedmont Plain had the highest hydraulic conductivity, with an average of 3.06 cm hr^{-1}. The strong negative correlation (r=-0.735**) (Figure 11) between hydraulic conductivity and clay concentration can be explained by the dispersion and movement of smaller particles into the pores that allow for conductivity. Dutta and Barkakoty (1996) discovered such associations in multiple soils in Assam. The studied soils had water-holding capacities ranging from 19.88% to 63.12% (Table 1). Among the physiographic units, the Piedmont plain soils have the lowest water-holding capacity, averaging 29.14%. This could be due to the greater sand content in certain soils, which supported the gradual increases in water holding capacity of the particular area soil.

From the upper Piedmont plain to the flood plain, finer materials provide more capillary holes and a bigger surface area to store water. A considerable positive connection was found between water-holding capacity and silt (r = 0.502**), clay content (r = 0.716**), porosity (r = 0.741**), and organic matter (r =0.381**)(Figure 11). The soil type is also an important factor in determining erosional activity. Silty soils are extremely sensitive to water and wind erosion, whereas clayey soil is least prone to soil erosion (Brady and Weil 2012). Deka et al. (2017) found comparable correlations in the soil of Assam's North Bank Plains. The measured soils had available water ranging from 1.0% to 22.5% (Table 1). The alluvial plain has the highest available (mean 11.59%) among all physiographic units, owing mostly to the presence of finer materials. In contrast, the Piedmont Plain had the lowest water holding capacity (mean 8.32%). There was a considerable negative association (r = -0.663**) between the amount of water that could be stored in the soil and the sand content. However, there was a strong positive association (r = 0.764**) between the amount of water that could be stored in the soil and the concentration of clay. Borgohain et al. (2021) found a similar link between the Pabho watershed. The organic matter content of the watershed ranged from 0.28 to 2.97 grams per kilogram (Table 1). Among the physiographic units, the alluvial plain soil contained the most organic matter, with a mean of 1.53 g kg^{-1}, while the piedmont plain had the least (mean 1.45 g kg^{-1}). The floodplain soils have higher organic matter content as a result of farmers' extensive crop cultivation using organic manures. Furthermore, the migration of bases and clay particles from higher to lower elevations via transportation and leaching contributed to the increase. Debnath et al. (2009) reported higher organic matter levels in rice production soils in the West Bengal Terai region. This conclusion is ascribed to farmers in the area who use more organic manure.

3.2 Principal Component Analysis of Soil Parameters

Variations in 11 soil hydro physical parameters besides relief, erodibility indices, and soil loss were successfully accounted for by the two major components whose Eigenvalues were more than 1.5, which accounts for 65% variation in the soil parameters (Table 2). The screen plot (Figure 7) shows the relation of the Eigenvalues with the principal component's numbers. From the factor loading matrix of the soil parameters, it is seen that silt, clay, water holding capacity, available water content, macroaggregate, mean weight diameter, Organic carbon, and soil loss had a positive factor on P1. In contrast, sand, very fine sand, hydraulic conductivity, and microaggregate had a negative factor on P1. The common P1 component that had compositions bearing a strong relationship with the inherited mechanical components was given the name of the 'Inherent Potentiality Factor'. Three parameters, such as dispersion ratio, erosion ratio, and erosion index, loaded positively in the second principal component (P2). All these erodibility parameters were more or less related to each other, and a group of parameters was therefore defined with reference to soil erosion. Thus, this second factor was termed the 'Erosion Factor'. Table 2 shows the factor loading of the soil parameters in P1 and P2; the studied parameters were distributed in all four quadrants. The PCA biplot in Figure 8 shows both the PC scores of samples and the loading of

Table 2 Eigenvalues, variance (%), cumulative variance (%), and matrix factor loading of soil parameters

Rotated Component Matrix		
Parameters	PCA 1	PCA 2
Eigenvalue	8.52	1.93
% of Variance	53.25	12.11
Cumulative variance (%)	53.25	65.36
Coarse Sand	-0.950	0.067
Very fine sand	-0.306	0.348
Silt	0.744	-0.295
Clay	0.898	0.277
Hydraulic conductivity	-0.866	0.165
Water holding capacity	0.769	0.396
Available water content	0.712	0.260
Macroaggregate	0.919	0.303
Microaggregate	-0.916	-0.321
Mean weight diameter	0.895	0.334
Organic carbon	0.367	0.239
Dispersion ratio	-0.592	0.646
Erosion ratio	-0.708	0.539
Erosion index	-0.739	0.535
Soil loss	0.527	-0.059
Elevation	-0.142	-0.186

variables. The first quadrant revealed positive loading on both the PCs, and the second quadrant had negative loadings on P1 and positive loadings on P2. Deka and Dutta (2016) also found similar findings in the Northern Brahmaputra plains of Assam.

3.3 Soil Erosion Rate Assessment

To assess soil erosion in the Ranganadi watershed, the parameters associated with the RUSLE model were initially calculated. The specifics of the assessment of the components are shown in Table 3.

3.3.1 Rainfall erosivity factor (R):

The R-factor quantifies the impact of precipitation on soil erosion. Average yearly rainfall data is necessary for calculating the R-factor. Rainfall data from 2000 to 2019 was obtained from the Regional Meteorological Centre in Northeast India. The analyzed region experienced an annual precipitation of 319.40 cm, a maximum 24-hour precipitation of 10.36 cm, and a one-hour maximum precipitation of 2.55 cm. The rainy erosivity factor (R) for the whole watershed was determined to be 945.57 mm (Table 3), and it was identified as a significant contributor to soil erosion processes in the study area. Northeast India has a higher rate of soil loss compared to the rest of the country, possibly due to excessive rainfall. Severe rainfall in the region causes acidification and loss of critical metallic minerals, including calcium, magnesium, potassium, and sodium, which are necessary for agricultural productivity. Barman et al.(2020) also got similar results in Meghalaya.

3.3.2 Soil erodibility factor (K)

The K-factor for each location was determined using field and laboratory estimates of texture, organic matter content, structure,

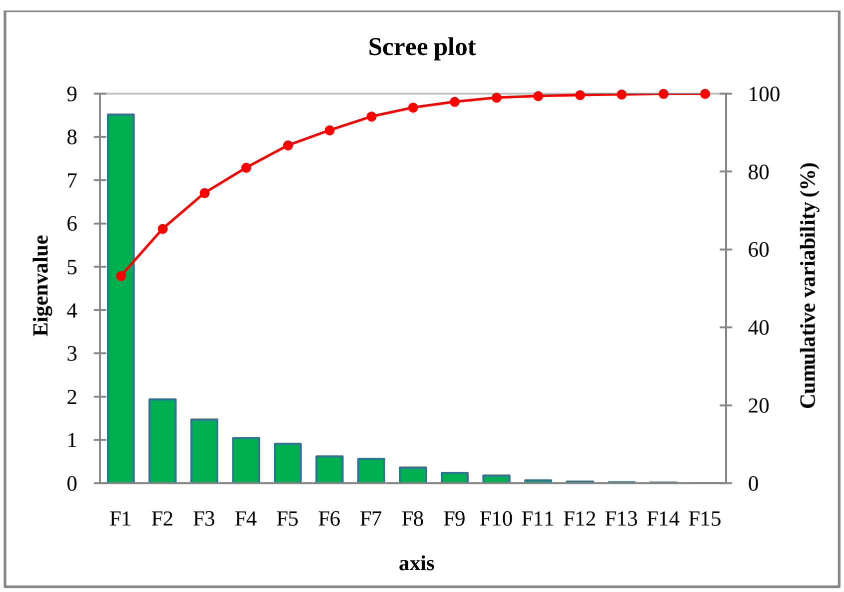

Figure 7 Screen Plot showing the relation between Eigenvalues and PC numbers

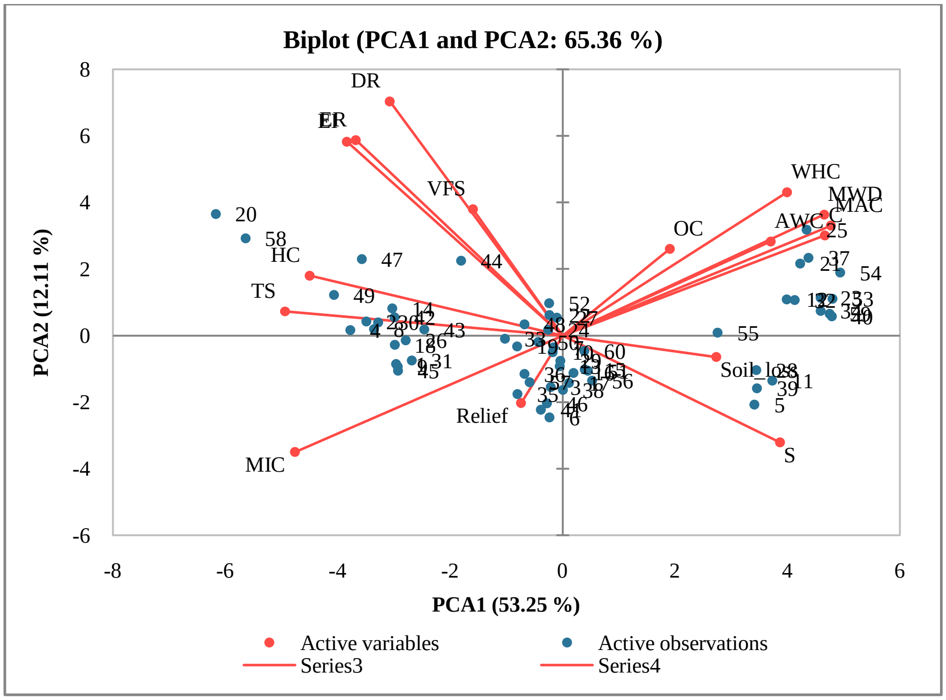

Figure 8 PCA Biplot showing factor loading of soil parameters

Table 3 Range, mean, and CV (%) values of RUSLE factors, soil loss, and elevation in diverse physiographic units of the Ranganadi watershed

Parameters	Piedmont plain			Alluvial plain			Flood plain		
	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV(%)
R	-	945.57	-	-	945.57	-	-	945.57	-
K	0.001-0.118	0.06	88.73	0.001-0.118	0.06	51.25	0.026-0.12	0.07	37.55
LS	1.63-1.63	1.63	-	0.97-0.97	0.97	-	0.32-0.32	0.32	-
C	0.02-0.50	0.24	105.24	0.02-0.50	0.44	35.55	0.10-0.50	0.47	23.17
P	0.30-0.54	0.43	29.09	0.30-0.54	0.34	27.22	0.30-0.54	0.35	27.87
Soil loss (t ha^{-1} yr^{-1})	0.01-27.38	7.37	157.85	0.33-22.77	8.52	67.76	0.53-12.61	3.39	58.02
Elevation	96-112	104.18	4.76	81-94	86.74	4.71	70-79	74.88	4.39

and permeability of surface soil samples in accordance with the monograms provided by Wischmeier and Smith (1978). The erodibility factor (K) for the examined watershed area varied from 0.001 to 0.12 (Table 3). The K value demonstrated moderate fluctuation, with a coefficient of variation of 51.94 percent. The flood plain has the greatest soil erodibility factor (Mean=0.07), succeeded by the piedmont and alluvial regions, each with a mean value of 0.06. The K factor exhibited the greatest variability (CV= 88.73%) in piedmont soils and the least variability (CV= 37.55%) in floodplain soils. A higher value of 0.51 on the basin's K factor map indicates increased susceptibility to erosion. Fine-loamy, coarse-loamy, and fine-loamy textures with a higher K value are more susceptible to erosion. Soil with a loose texture and little organic matter is especially susceptible to erosion. If the sandy Alfisol is devoid of natural surface litter, it is prone to erosion from heavy rain (Brady and Weil 2012). This K factor is mostly influenced by the amount of humus present in the soil and its texture (Getu et al. 2022).

3.3.3 Slope length and slope percentage factor (LS)

The LS factor was calculated according to the methodology established by Wischmeier and Smith (1978) using nomographic computation. The LS factor in the soils of the examined watershed varied from 0.32 to 1.63, exhibiting moderate variability (CV = 60.68%) (Table 3). Erosion and landslides are strongly influenced by topography. The topographic factor (LS) reflects the impacts of topography on erosion and includes the slope's length and steepness, which influence surface runoff speed (Beskow et al. 2009; Pradhan et al. 2012).

3.3.4 Crop cover and management factor (C)

The C-factor values designated for various land use/land cover types are as follows: 0.5 for Paddy, Pineapple, Okra, and Cabbage; 0.02 for Tea cultivation; and 0.1 for Arecanut and Lemon Garden. The values were ascertained using land use/land cover data provided by Potdar et al. (2003). The crop cover and management factor (C) of the Ranganadi watershed varied from 0.02 to 0.50. The C component exhibited the greatest variability (CV= 105.24 %) in piedmont area soils and the least variability (CV= 23.17 %) in floodplain soils (Table 3). Soil erosion rate is primarily influenced by terrain and crop cover; however, other factors also have a role (Wolka et al. 2018). Crop cover acts as a barrier to land degradation, and soil loss due to excess rainfall is minimized up to a greater extent. Plant cover protects soil by enhancing infiltration, physical and chemical characteristics, and material cohesion (Tiruwa et al. 2021). Additionally, it cuts up raindrop kinetic energy and intercepts some precipitation.

3.3.5 Conservation Practice Factor (P)

The P-factor values were assigned based on field survey data. Paddy (0.5), Pineapple (0.8), Arecanut, Vegetables, and Lemon Garden (0.4) were designated. The 'P' value for tea plantations was designated as 0.8, as the cultivation of plantation crops is a form of conservation practice. The conservation practice factor (P) of the examined watershed area ranged from 0.30 to 0.54. The P component exhibited the greatest variability (CV = 29.09%) in Piedmont area soils and the least variability (CV = 27.22%) in alluvial plain soils (Table 3).

3.3.6 Estimation of Soil Loss

Assessed the input parameters for the RUSLE (R, K, LS, C, and P) and subsequently multiplied all components to compute the total soil loss (A). The soil erosion in the examined watershed ranged from a minimum of 0.01 t ha^{-1} yr^{-1} to a maximum of 27.38 t ha^{-1} yr^{-1}, with an average of 13.50 t ha^{-1} yr^{-1}, in comparison to the moderate range (10-15 t ha^{-1} yr^{-1}) identified by Potdar et al. 2003 (Table 3). Annual soil loss was highest in alluvial plain soils (Mean = 8.52 t ha^{-1} yr^{-1}) and lowest in flood plain soils (Mean = 3.39 t ha^{-1} yr^{-1}) across the physiographic groups (Table 3). Potdar et al. (2003) categorize soil loss into several erosion classes: weak (<5 t ha^{-1} yr^{-1}), fairly slight (5-10 t ha^{-1} yr^{-1}), moderate (10-15 t ha^{-1} yr^{-1}), moderately severe (15-20 t ha^{-1} yr^{-1}), severe (20-40 t ha^{-1} yr^{-1}), and extremely severe (>40 t ha^{-1} yr^{-1}). We saw soil erosion varying from little to severe in both the piedmont and alluvial plains. Consequently, the piedmont and alluvial regions exhibited greater vulnerability to soil erosion than lower-elevation locations. The positive association between height and soil loss is also noticeable (r = 0.166). Approximately 22 hectares (0.18%) are vulnerable to significant soil erosion, ranging from 20 to 40 tonnes per hectare per year. A total area of 50 hectares (0.41%) fell under the moderately severe classification, while 1047 hectares (8.60%) were categorized as moderate. The largest area of 5550 hectares (45.59%) exhibited moderate soil loss of 5–10 t ha^{-1} yr^{-1}, whereas the 5505 hectares (45.22%) had a minor erosion issue of less than 5 t ha^{-1} yr^{-1}. While it may not experience severe soil loss, it is likely to incur significant soil loss owing to erosion issues. Thus, it is essential to put measures to preserve soil into practice promptly to avert future degradation of soil quality in the region. Figure 9 illustrates the distribution of soil erosion classifications among the three distinct physiographic units. The negative correlation (r = -0.609**) (Figure 11) between sand concentration and soil loss indicates that increased sand content decreases soil loss. Sand particles possessing elevated potential energy can displace raindrops by surpassing their kinetic energy. The kinetic energy of raindrops more readily displaces tiny silt and clay particles, resulting in heightened soil loss (r = 0.610**, 0.389** for silt and clay, respectively) (Figure 11). The inverse connection of HC (r = -0.494**) with soil loss indicates that increased water transfer rates facilitate more water absorption, hence mitigating soil loss. Elevated water retention exacerbates soil erosion (r = 0.323) due to the increased weight of water-saturated soil. Similar results were also reported by Deka et al. (2011) and Das et al. (2020). A relationship between soil erosion with relief and Erodibility indices (Figure 10) smaller aggregates possess less potential energy. The positive link between soil loss and relief showed that increased removal of soil was correlated with longer and steeper slopes.

3.4 Soil erodibility indices

Soil erodibility mainly depends on the specific physical characteristics of the soil, such as the structure of the soil, which may include the elements of soil aggregates, the nature and intensity of organic matter content in the soil, and the distribution of the particle size. It is worth pointing out that the land use system significantly affects most of these physical characteristics of soils. Therefore, the diverse erodibility indices, including water-stable aggregates, dispersion ratio, erosion ratio, and erosion index under different land use systems, were predicted in this study with the aid of data on basic soil properties and by applying different empirical formulas (Table 4).

3.4.1 Aggregate status

In the Ranganadi watershed, soil macroaggregates ranged from 33.94 to 85.72 percent. Similarly, the percentage of microaggregates varied from 14.28 to 66.06 percent (Mean 47.14 percent). The mean weight diameter of the soil particles in the studied watershed ranged from

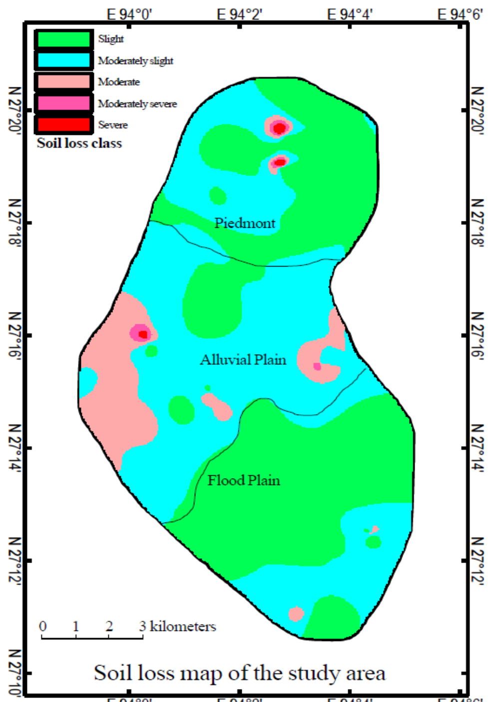

Figure 9 Distribution of soil loss in Ranganadi watershed

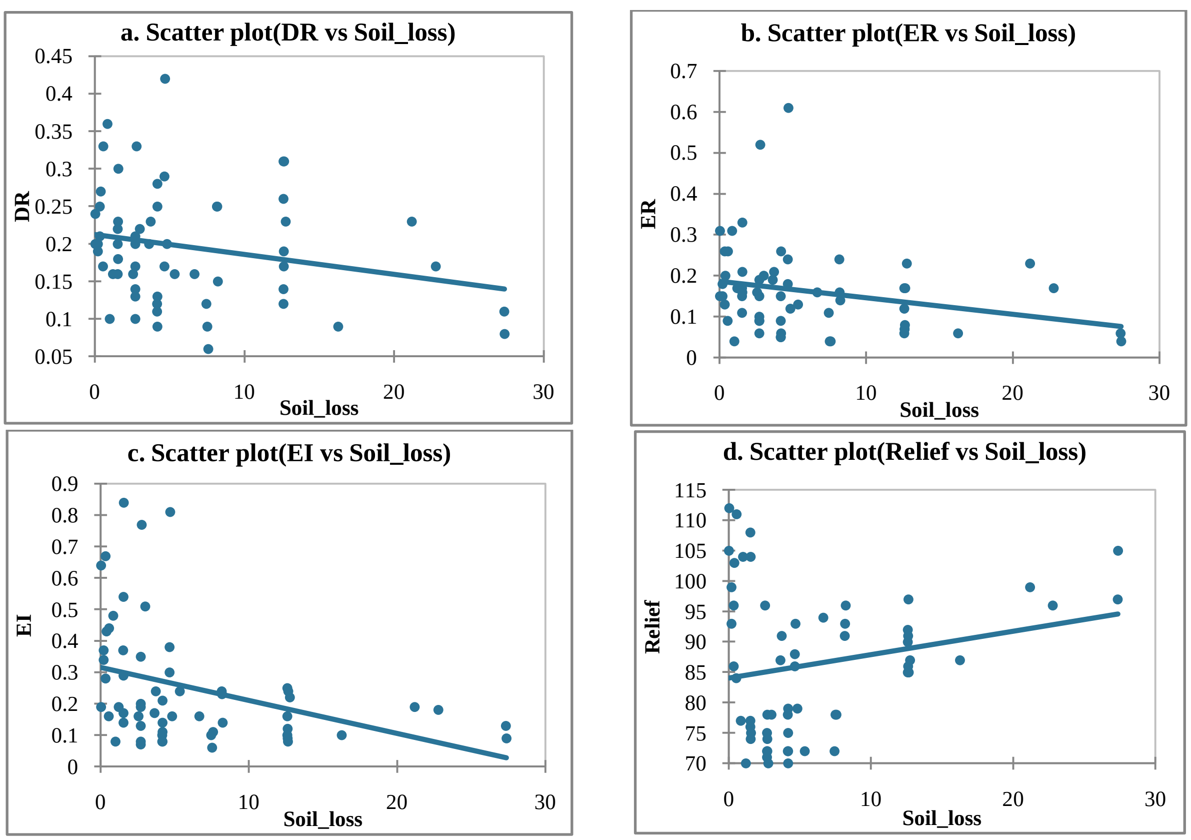

Figure 10 Relation between soil loss and dispersion ratio, erosion ratio, erosion index, and relief

Table 4 Physiographic distribution of Erodibility indices soils of Ranganadiwatershed

Parameters	Piedmont plain			Alluvial plain			Flood plain		
	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)
Dispersion ratio	0.08-0.33	0.19	39.49	0.09-0.42	0.21	34.16	0.06-0.36	0.18	42.40
Erosion ratio	0.04-0.31	0.16	54.28	0.06-0.61	0.17	64.76	0.04-0.52	0.15	72.85
Erosion index	0.08-0.64	0.26	69.33	0.08-0.81	0.25	71.99	0.06-0.84	0.25	84.64
Macroaggregate (%)	39.18-62.94	47.81	15.65	37.28-80.14	54.92	26.79	33.94-85.72	52.84	29.65
Microaggregate(%)	37.06-60.82	52.19	14.34	16.59-62.72	44.70	34.33	14.28-66.06	47.16	33.22
Mean Weight Diameter(mm)	1.06-2.58	1.55	33.83	1.07-3.69	1.96	50.55	1.03-3.58	1.84	48.09

1.03 mm to 3.69 mm. Among the physiographic units, the value of macroaggregates was highest in the alluvial plain area (Mean 54.92%) and lowest in the piedmont plain area (mean 47.81%). On the other hand, the microaggregate percentage was highest in the Piedmont Plain (Mean 52.19%) and lowest in the Alluvial Plain (Mean 44.70%). The mean weight diameter was found to be highest in the Alluvial Plain area (Mean 1.96 mm) and lowest in the Piedmont Plain area (Mean 1.55 mm). An increasing trend of macroaggregate was observed in the Piedmont plain (Mean 47.81 percent), flood plain (Mean 52.84 percent), and alluvial plain soils (Mean 54.92 percent). In the case of microaggregate, the reverse trend was followed by the alluvial plain (Mean 44.70 %), flood plain (Mean value 47.16 %), and Piedmont plain areas (Mean value 52.19 %). Mean weight diameter also exhibited a trend similar to that of macroaggregates from the Piedmont plain (Mean 1.55 mm), floodplain soils (Mean 1.84 mm), and alluvial plain (Mean 1.96 mm). The rising trend of mean weight diameter with declining elevation suggests improved aggregation due to a greater concentration of finer particles (clay and organic materials) in lower elevation regions. Furthermore, correlation analysis indicated that MWD was favorably correlated with clay (r= 0.94**) and SOM content (r= 0.42**) (Figure 11). This is evident from the chemical inactivity of sand particles, their lack of cation exchange capacity, and their bigger particle size. Consequently, MWD predominantly reflects macro-aggregation in soil due to the predominance of macroaggregate-size classes over microaggregate-size classes in its calculation. The results align with the findings of Das et al. (2020) across several watersheds in Assam.

3.4.2 Dispersion ratio (DR)

In the soils of the studied watershed, a high dispersion ratio was observed (Mean = 0.20), and the ratio varied from 0.06-0.42 (Table 4). Among the physiographic units, alluvial plain soils (Mean 0.21) were found to have a higher dispersion ratio, and floodplain soils had the lowest dispersion ratio (Mean 0.18). According to Middleton, a DR > 0.15 is categorized as erodible. From the analysis, it was observed that about 71.6 percent of the total studied area falls under the erodible group (DR> 0.15), out of which 72.7 percent of the soil samples from piedmont plain, 86.3 percent from the alluvial plain and 64 percent from the flood plain areas had DR values greater than 0.15, indicating its susceptibility to erosion. The DR exhibited a significant positive correlation with sand (r = 0.545**). At the same time, it had a significant negative correlation with silt (r = -0.560**) and clay (r = -0.327*) (Figure 11), indicating that the smaller the particles, the greater the dispersion, leading to increased vulnerability of the soils to erosion, positive relationship with HC (r = 0.503**) and a negative relationship with water retention parameters (r = -0.276* for WHC). This indicates that a higher DR will reduce porosity and, thus, water retention, leading to a higher surface flow of water and increasing the erodibility of soils. Therefore, it corroborates that a higher clay content will reduce DR (r = -0.327*) due to aggregate formation, as indicated by a significant negative correlation with MWD (r = -0.359**) (Figure 11). Similarly, it had significant positive relations with ER (r = 0.819**), EI (r = 0.726**), and soil loss (r = 0.232) (Figure 11), indicating that with higher DR, there will be more soil loss. Dabral et al. (2016) also reported similar findings in Nirjuli of Arunachal Pradesh.

3.4.3 Erosion ratio (ER)

The soil erosion ratios in the studied watershed area varied widely. The soil erosion ratio in the Ranaganadi watershed varied between 0.04-0.61 (Table 4). The erosion ratio was found to be highest in the alluvial plain (Mean 0.17) and relatively lower in the flood plain (Mean 0.15) soils. The presence of a high amount of sand and a low amount of silt and clay in the alluvial plain soils may be the reason for the highest erosion ratio. The results demonstrate a strong positive association with sand (r = 0.640**) and a high negative association with silt (r = -0.554**) and clay (r = -0.531**) (Figure 11), respectively. Hydraulic conductivity has a significant negative role (r = -0.588**) on ER, i.e., higher HC will reduce ER. Similarly, water retention parameters also have a negative role on ER (r = -0.396** for WHC) in reducing ER. Increased soil aggregation lowers ER (r = -0.526**), while all other erosion indices have a significant positive influence on ER (r = 0.819**

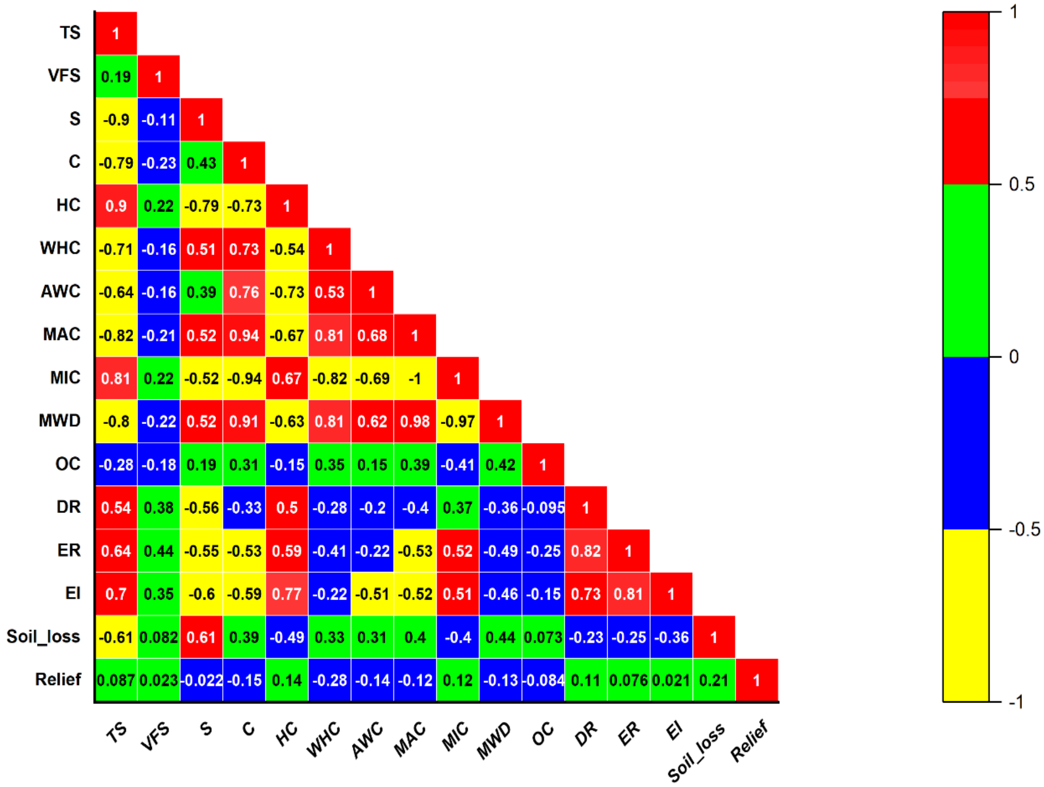

Figure 11 Correlation of soil physicochemical and soil loss (p≤0.05)

and 0.811** for DR and EI, respectively) (Figure 11). The present investigation observes a positive effect (r = 0.250) on soil loss, indicating that ER induces soil loss. Similar findings were also reported by Singh and Khera (2008) in the submountaneous of Panjab.

3.4.4 Erosion Index (EI)

It became apparent that the investigated soils' erosion indices ranged widely, from 0.06 to 0.84 (Table 4). The Piedmont plain soils had the highest value of the erosion index (Mean 0.26), whereas the alluvial plain and floodplain soils had equal mean values of 0.25. The erosion index of the studied watershed was nearly the same in all the physiographic units (EI = 0.26 in Piedmont and 0.25 in both alluvial and flood plains). The dominance of medium to lighter soil textures in the study area could be the reason for the high erosion index. The sand content had a significant positive influence on EI (r = 0.698**), while finer particles, especially clay (r = -0.588**), had a negative role. These findings followed Deka et al. (2017), which stated that the erodibility of soil varied directly with sand content. Similar to other indices, water transmission properties have a significant positive role on EI (r = 0.770**), while retention properties (r = -0.190 and -0.521** for WHC and AW, respectively) (Figure 11) have negative implications. Higher MWD reduces EI (r= -0.460**). EI had a significant positive relationship with all other erosion indices (r = 0.726** and 0.811** for DR and ER, respectively) (Figure 11), indicating that it is also on par in predicting soil erosivity. Higher EI leads to increased soil loss, as is evident from a positive correlation (r = 0.358) with soil loss. Saha et al. (2011) also reported similar findings in the hilly ecosystem of Meghalaya.

3.5 Suggested erosion control measures

Taking into account the severity of the extent of soil erosion in the discussed area, it can be assumed that the area requires the implementation of serious soil conservation measures to decrease the impact of soil loss downstream. The Piedmont plain soils indicated low to very high levels of erosion rate. This is due to high elevation, low organic matter, coarse-textured soils, and lower clay. For such conditions, vegetative bunds, contour bunds, terracing, mulching, use of farmyard manure, intercropping, and growing nitrogen-fixing crops with fibrous root systems would help reduce erosion and improve the productivity of these soils. Moreover, these soils may be used for bamboo cultivation as bamboo has a strong potential to reduce soil loss as well as to improve the economic status of the farmers. The alluvial plain soils were affected by slight to severe erosion. Good agronomic practices can be adopted to reduce probable soil loss in these soils, such as conservation tillage, crop rotation, mulching, farmyard manure, cover crops, leguminous crops, etc. The floodplain soils showed slight to moderately slight erosion, and as such, the adoption of selective agronomic practices in a location-specific manner would help reduce soil loss.

Conclusions

It was also found that the RUSLE model and the GIS were effective in estimating the extent of soil abrasion and identifying areas vulnerable to erosion. The variables that were estimated include different parameters affecting water erosion. Some of the studies employed spatial information data on physiographic, slope, land use/land cover, and soils obtained from satellite remote sensing and supporting data. The study also showed that the whole watershed was found to moderate soil erosion and, among the physiographic units, is subject to various levels of soil erosion. Soils of the Piedmont plain and alluvial plain, which are on relatively higher slopes, show a spectrum of erosion ranging from moderately to slightly eroded. Measures that should be put into practice to minimize the extent of soil erosion involve vegetative bunds, contour bunds, terracing, mulching and the use of farmyard manure, intercropping, and adoption of crops with nitrogen-fixing capability that have fibrous root systems. On the other hand, downslope landforms such as alluvial plains have varied to some extent in terms of erosion. Finally, for such conditions, it is possible to apply conservation tillage, crop rotation, mulching, farmyard manure, and the cultivation of cover crops and leguminous crops. Likewise, the floodplain soils with an almost gentle slope possess slight to moderate FF deterioration. Those limited and special forms of tillage and other management practices applied at particular places would be favorable in checking the soil loss, noting that the intensity of soil erosion is least in the low-lying areas, which have low elevation.

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The work does not contain any studies involving human and animal subjects.

Conflict of interest

The authors declare no competing interests.

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