Soil Erosion Assessment Using the RUSLE Model and Geospatial Analysis: A Case Study of Majuli Island of Assam, India

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Abstract

Soil erosion is a major environmental issue that affects the sustainability of agricultural lands and ecosystems. The condition is more severe in the riverine areas. The RUSLE (Revised Universal Soil Loss Equation) model is a widely used tool for assessing soil erosion risk. This study aims to evaluate the soil erosion in Majuli Island, India which is situated in the mid-stream the Brahmaputra River. In this study, RUSLE Model has been paired up with Geospatial Techniques to evaluate the annual soil loss of the island. The parameters used for the assessment are the Rainfall Erosivity (R), Soil Erodibility (K), Slope Length and Steepness (LS), Crop and Management (C) and Conservation Practice (P). The results categorized the island into five classes from very high to very low. The high-class area needs immediate attentions. The results show that the highest soil loss occurs in the riverbank areas whereas it is low to very low in the central part. It indicates that bank erosion by the Brahmaputra is a major cause of soil loss in Majuli .The results of this study can help in the development of soil conservation strategies and management practices to mitigate soil erosion in Majuli Island.

Keywords: *Brahmaputra River, Erosion, Geospatial Techniques, Majuli Island, RUSLE, Soil Loss.*

1. Introduction

Soil erosion is a critical environmental issue with far-reaching consequences, impacting agricultural productivity, water quality, and ecosystem health. The process of soil erosion is when the top fertile and productive soil layer is washed away or detached

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from its original surface and is gradually deposited at a further location, resulting in the exposure of the sub-surface soil (Jain et.al. 2001). The rapid increase in the rate of soil loss poses adverse effects on the economy and environment, especially is the economy is primarily dominated by agriculture (Lal, 1998). With thorough observation, it can be noticed that the direct threat of the soil erosion is held over the developing nations as they have to feed their ever-growing population but the agricultural land gets limited (Erenstein, 1999). The problem of soil erosion is not an issue of present origin but a phenomenon persisting on the earth for a long time, but the impact is greater in the recent era due to the increased man-environment relationship and the pressure exerted by man to modify the environment (Rasool et.al. 2014). The root cause of the issue concerning the soil erosion is a combined action of change in land-use of a region and large-scale deforestation (Karamage et al. 2016; Lee et al. 2017).

Assessing soil erosion accurately is essential for effective land management and conservation efforts. The Revised Universal Soil Loss Equation (RUSLE) model, coupled with geospatial analysis, provides a powerful tool for quantifying soil erosion rates and identifying vulnerable areas. This case study focuses on Majuli Island in Assam, India, a region prone to significant soil erosion due to its unique geographical characteristics and land use practices. By applying the RUSLE model and geospatial analysis techniques to Majuli Island, the aim is to evaluate the extent of soil erosion and identify key factors contributing to erosion.

1.1. Study Area

Majuli is considered to be the largest river island situated in the course of the mighty Brahmaputra. It is the center of neo-vaishnavite culture. Majuli island extends from 93°30' E to 94°35' E longitude and 26°50' N to 27°10' N latitudes. It is the one and only island district of India surrounded by three major rivers viz. Subansiri and Kherkutia Suti to the north and the mighty Brahmaputra to the south cutting off its land routes. The elevation of this island varies from about 60 m to 85 m above the sea level (Bhaskar and Sarkar, 2013). Majuli is severely affected by bank erosion and frequent floods caused by the Brahmaputra on the southern bank of Majuli and Subansiri on the northern of the island. These hazards were not displayed with the present intensity before the great earthquake of 1950. The area of the island was recorded to be about 1249 sq.km in the year 1915 and gradually reduced to 645.49 sq.km in the year 1995 (Sarma, 2005 and

Kotoky et.al, 2005). At present the area of Majuli island measures upto only about 474.39 sq.km (LANDSAT 2023). Due to high deposition rate, the river Brahmaputra have taken the form of braided channel and anabranches and as Majuli is constituted of silty and sandy clay loam soil structures the intensity of soil erosion has also increased (Dutta et.al.,2010) and its topsoil is highly susceptible to erosion as it is composed of sandy silt mixed with clay (Sarma, 2013).

Majuli island enjoys a sub-tropical climatic condition, with average summer temperature of about 34°C and winter temperature ranging from 7°C to 18°C with average annual rainfall accounting for about 215 mm. Keeping into account all the parameters, RUSLE model have been applied with an aim to assess the soil erosion and its rate on Majuli island as it is being eroded very rapidly.

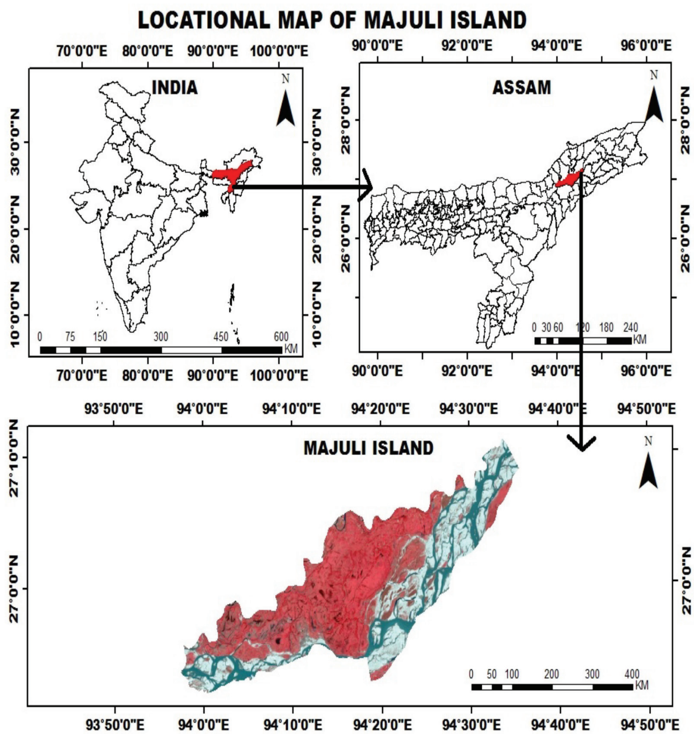

Figure 1: Location Map of Majuli Island

1.2. RUSLE Model

The working principle of RUSLE Model uses five parameters, it is a physical based empirical model that analyses the soil erosion of a region or basin. This model mainly uses the climatic data and topographic characteristics to run the analysis over a region or basin (Pathan and Sil, 2020). The input parameters of the model are Rainfall Erosivity (R) Factor, Soil Erodibility (K) Factor, Slope Length and Steepness (LS), Cover Management (C) and Support Practice (P) Factor and these factors are independent for calculating RUSLE Model. Thus the equation used for RUSLE Model is given below (Wischmeier and Smith, 1978):

A = R x K x LS x C x P (Renard et.al., 1997)

Where,

A is the Average Annual Soil Loss, usually on yearly basis (ton ha^{-1} yr^{-1})

R is the Rainfall Run-off Erosivity Factor (MJ mm ha^{-1} hr^{-1} $year^{-1}$)

K is the Soil Erodibility Factor (ton ha hr MJ^{-1} mm^{-1})

LS is Slope Length and Steepness (Dimensionless)

C is the Cover Management Factor (Dimensionless), and

P is the Support Practices Factor (Dimensionless).

With the help of GIS, these factors used in RUSLE Model can be overlapped and multiplied to acquire the result i.e., the soil loss value.

2. Methodology

This study is done for the year 2022 and for the input materials to carry out this assessment, the date required were: Cartosat DEM of 30m resolution downloaded from BHUVAN. Majuli have an elevation ranging from 60m to 85m the land-use and land-cover map have been downloaded from Sentinel Copernicus for the year 2022. The soil map is taken from FAO DSMW and extracted as per the study area shapefile. Majuli was constituted by only one soil type, Sandy Clay Loam. The shapefile of the study area has been digitized from LANDSAT-8 OLI with a 30m resolution. The rainfall data was downloaded from CRU- Climate Research Unit for the year 2022. The map projection system used for all input layers is WGS 1984 UTM Zone 46N.

Table 1: Input Data Used for RUSLE Model

DATA	RESOLUTION	SOURCE	YEAR
Cartosat DEM	30 m	BHUVAN	2022
LULC	10 m	Sentinel Copernicus	2022
Soil Data	5*5 arc minutes	FAO/UNESCO (DSMW)	
Rainfall Data	0.5*0.5º (grids)	Climate Research Unit	2022
Study Area Shapefile	30 m	LANDSAT-8 OLI	2022

The methodology that has been used in carrying out this study are as follows:

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

  The R-factor is determined on the basis of mean annual rainfall. Rainfall is considered to be significant in terms of soil loss rate and surface run-off rate (Wischmeier and Smith, 1978). R-factor is dependent upon the intensity and calculate the R-factor, the rainfall data of 2022 is considered. The equation used in this paper is Lambordi Method given as R = 1.03 x P (where, P = Mean Annual Rainfall). Using this equation in ArcGIS software by raster calculator the R-factor can be received. And the R-factor is expressed as MJ mm ha¯1 hr¯1 year¯1.

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

  Determination of the soil type is very essential for the construction of K-factor. It is one of the factors responsible for the soil loss. The soil type that constitutes the riverine island is sandy clay loam (as per DSMW). The K-factor for RUSLE model can be calculated from the equation given as

  K-factor =fsand* fclay* forgc* fsilt*0.1317

  $$\text{fsand} = \left(0.2 + 0.3 * \exp - \left[-0.256 * m_{sand} * \left(1 - \frac{m_{silt}}{100}\right)\right]\right)$$

  $$\text{fclay} = \left(\frac{m_{silt}}{m_{clay} + m_{silt}}\right)^{0.3}$$

$$forgC = \left(1 - \frac{0.0256 * OrgC}{OrgC + exp[3.72 - 2.95 * OrgC]}\right)$$

$$fsilt = \left(1 - \frac{0.7(1 - \frac{m_{sand}}{100}}{\left(1 - \frac{m_{sand}}{100} + exp\left[-5.51 + 22.9 * \left(1 - \frac{m_{sand}}{100}\right)\right]\right.}\right)$$

given by Wischmeier and Smith, 1978

where, m_sandis the proportion (%) of sand content,

m_siltis the proportion (%) of silt content,

m_(clay)is the proportion (%) of clay content,

OrgC is the amount (%) of the organic carbon content of the layer (%)

In ArcGIS software, using field calculator to find out the values of fsand, fclay, forgc and fsilt. After obtaining the required values respectively, the K- factor is calculated again using the field calculator tool by placing equation

K-factor =fsand* fclay* forgc* fsilt*0.1317

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

This is the most influential factor while calculating RUSLE as it determines total sediment load and soil erosion. For the computation if slope length, the DEM is required from where fill sink, flow direction and flow accumulation can be calculated with the help of ArcGIS tool (Pathan and Sil, 2020). The USPED (Unit Stream Power Erosion and Deposition) method is used to compute the LS, which used the flow accumulation and slope. The equation for slope length is

$$L = (m+1)\left(\frac{\lambda_A}{22.1}\right)^m$$

Where, L is the slope length, λ_A is the area of upland flow, m is an adjustable value depending on the soil's susceptibility to erosion, 22.1 is the unit of plot length.

Again, the equation used for calculating slope is,

$$S= \left(\frac{\sin(0.01745 * \theta_{deg})}{0.09}\right)^{n}$$

Where, θ is the slope in degree, 0.09 is the slope gradient constant and n is an adjustable value depending on the soil's susceptibility to erosion.

Therefore, the equation used for calculation of the LS factor using ArcGIS raster calculator tool is given below

Power("flow accumulation"*[cell resolution]/22.1,0.4)* Power(Sin("slope degree"*0.01745)/0.09,1.4)*1.4

- **Support Practice (P)**

  After preparation of the LS factor, as the P factor is based on slope. The P factor is generated with the help of slope of the study area. It is mainly dependent on the agriculture type and slope of Majuli (study area). After confirming the cultivation type the values of the slope length is paired with the values of cultivation type. For calculation of the P-factor the values are taken from Korean Institute of Construction Technology, 1992, which is tabulated as

Table 2: P factor depending on cultivation types and slope

SLOPE	CULTIVATION TYPE VALUE
0.0-7	0.55
7-11.3	0.60
11.3-17.6	0.80
17.6-26.8	0.90
26.8 >	1

- **Cover and Management factor (C)**

  The C factor is obtained from the land-use pattern which was downloaded from the Sentinel Copernicus for the year 2022. Here, using the ArcGIS software the C values are determined depending on the land-use and land-cover classes. The C values obtained for LULC if Majuli island are tabulated below:

Table 3: Cover Management (C) factor values for the study area

FEATURES	C-FACTOR	AREA IN HA.
BUILT-UP	0.004	63.46
CROP	0.15	341.32
TREES	0.01	28.09
WATER	0	14.46
BAREGROUND	1	2.07
RANGE LAND	0.05	24.61
FLOODED VEGETATION	0.35	0.35

The C-Factor represents the effects of soil cover, productive level of crop sequence and soil-disturbing activities on soil erosion (Pathan and Sil, 2020). The C-Factors used in this paper is derived from Tiruneh, G., & Ayalew, M. (2015) and Gelagay, H. S., & Minale, A. S. (2016).

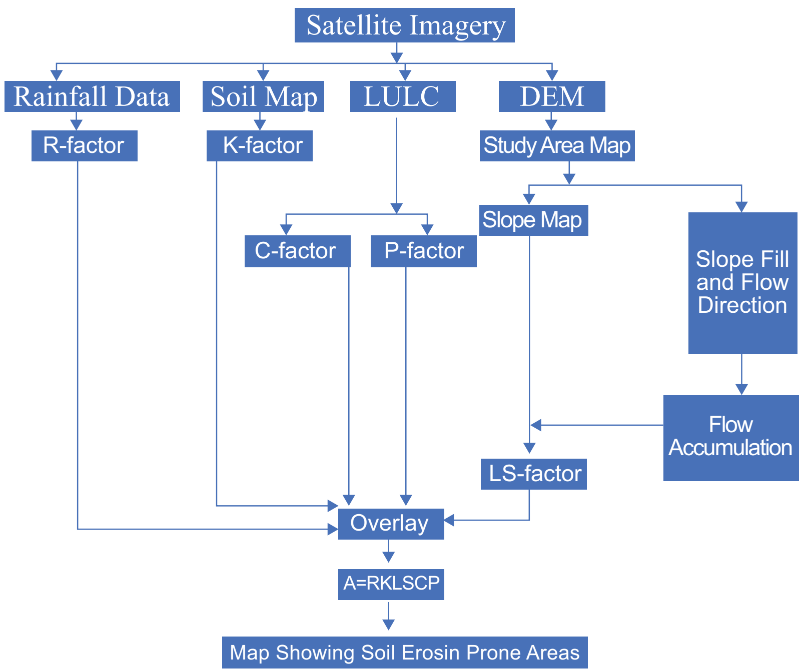

Figure 2: Methodological Framework of RUSLE Model

3. Results and Discussion:

3.1 Change in Area

As Majuli island is prone to severe flood and devastating act bank erosion, the area of the island is gradually shirking over the years. The area of Majuli island was estimated to be about 425.03 km^2. in the year 2000. But it can be seen to have certain changes like erosion in major parts along the bank as well as some sediment deposition as well. With all these changes, the area of Majuli island has been reduced to around 380 km^2 by the year 2023-24.

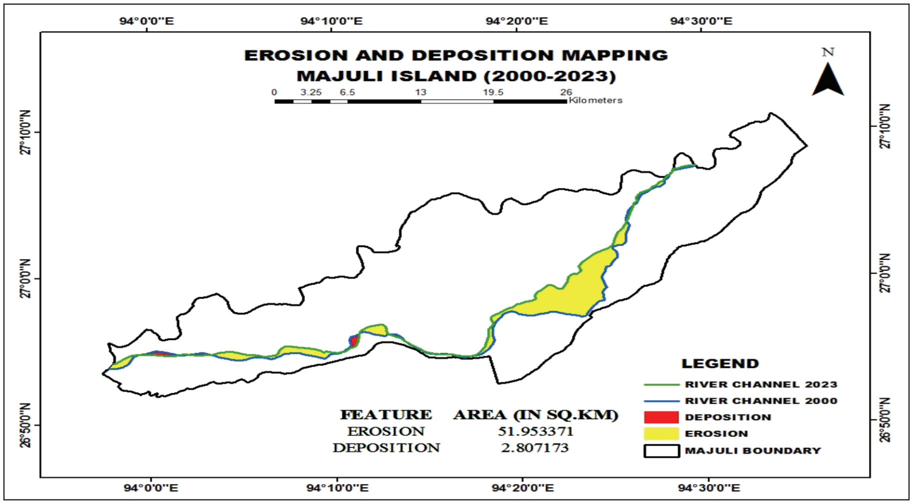

Figure 3: Pattern of Bankline Shifting (2013-2024)

3.2 Land use and Land Cover

The term "land use" and "land cover" (LULC) is used to depict the maps that describe about the types of landforms found on the surface of the earth (land cover) and the anthropogenic activity that is associated with them (land use). Land cover is an important parameter for a number of models associated with agriculture, hydrology and ecology which constitutes necessary tools for development, planning and management of natural resources in the region.

The GIS and Remote Sensing technology combined makes the perfect tool to identify and locate various types of land features. LANDSAT imagery year of 2000 and 2023 were used for preparation and interpretation of land use/land cover. The study area has been classified into five major categories to determine LULC. The areas identified and mapped as settlement in the year 2000 has been noticed to have gradually increased by the year 2023. This provides information the intense anthropogenic activities taking place within the island have changed the surface features. Agricultural land has been converted into built-up area. On the contrary, the continuous effect of flood and severe erosion have been cutting the land area by actions of lateral erosion. Thus with the shrinking land area and increasing population and settlement size, there is a drastic change that is noteworthy in case of the river island, Majuli.

Table 4: LULC changes from 2000 to 2023

YEARS	2000	2023
FEATURES	AREA (IN SQ.KM)	AREA (IN SQ.KM)
RIVER	92.24	69.44
SANDBAR	175.98	143.56
VEGETATION	410.43	317.16
OPEN AREA	67.68	122.15
WATER BODIES	9.74	16.92
SETTLEMENT	30.43	117.35

Source: Calculated by author

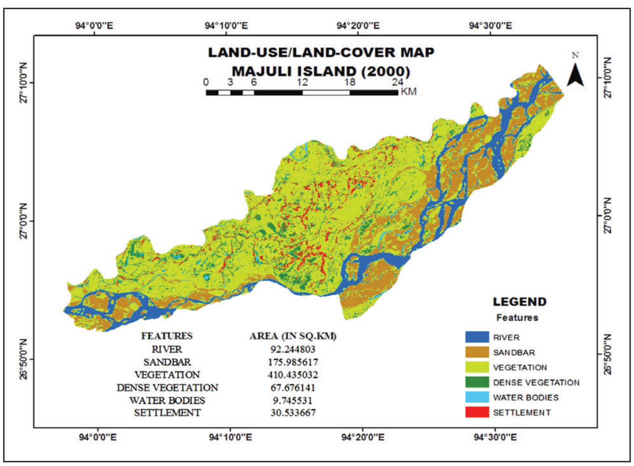

Figure 4: LULC of Majuli Island, 2016

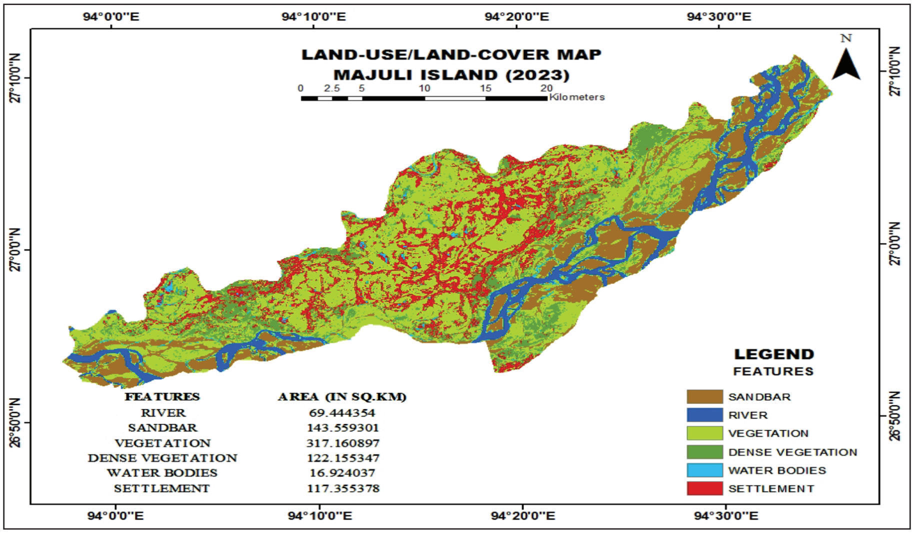

Figure 5: LULC of Majuli island, 2023

3.2 Analysis of Factors of RUSLE Model

After computation of all the required factors individually, multiplication is done to obtain the final soil loss map using ArcGIS software. The equation is calculated using the Map Algebra -Raster Calculator tool. The equation is: A = R x K x LS x C x P

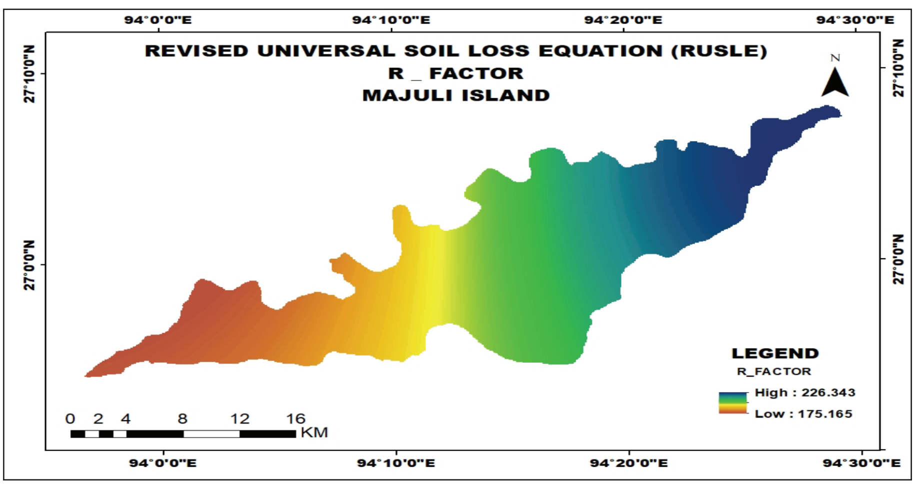

Figure 6: R- Factor obtained from the rainfall date using IDW

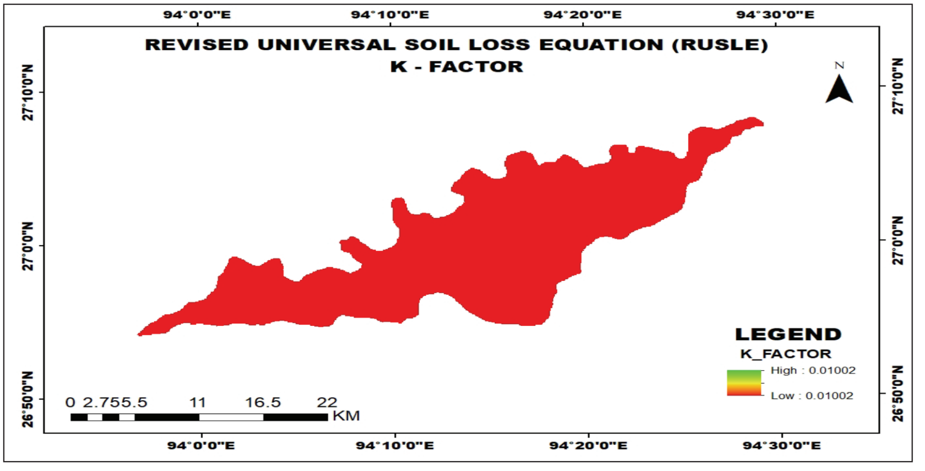

Figure 7: K- Factor obtained from soil data downloaded from FAO

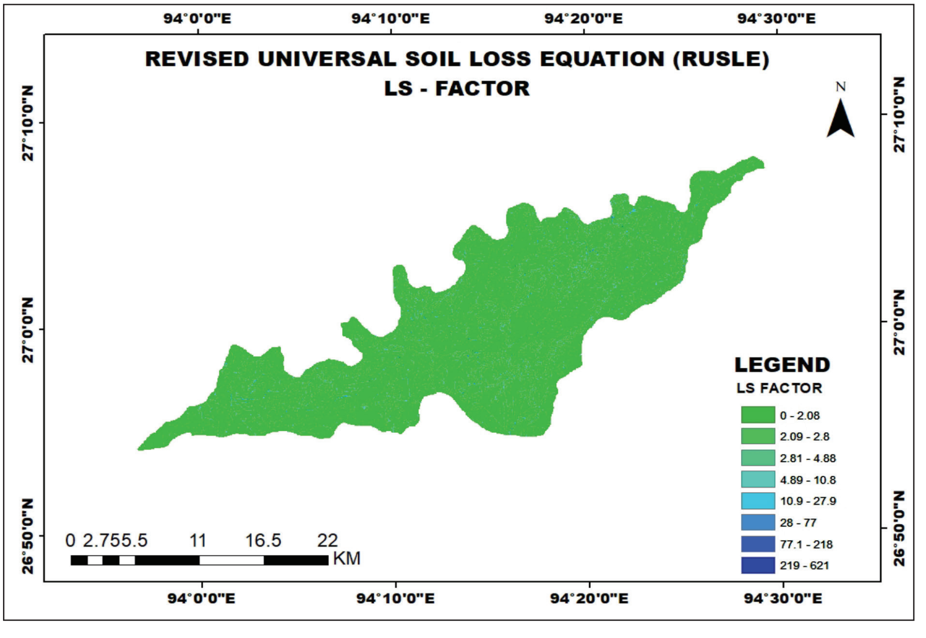

Figure 8: LS -Factor obtained from the DEM representing slope and flow accumulation

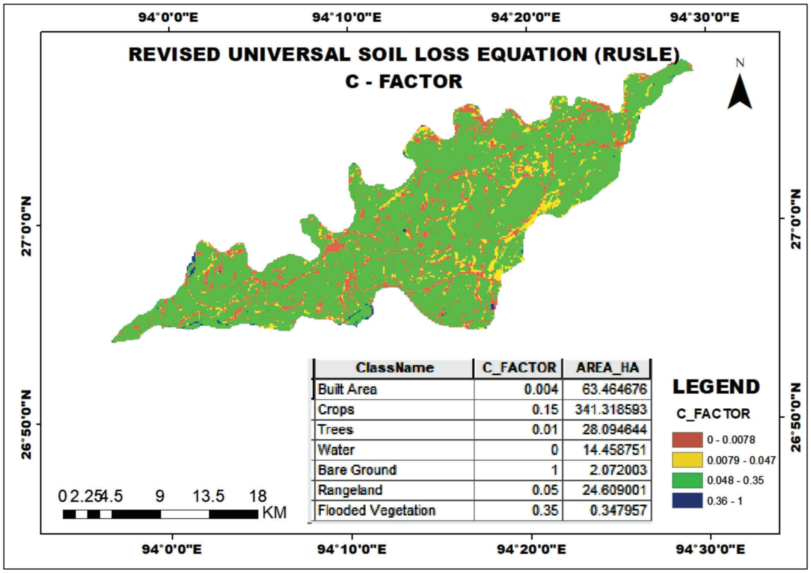

Figure 9: C–Factor is calculated on the basis of given values for each land-use class

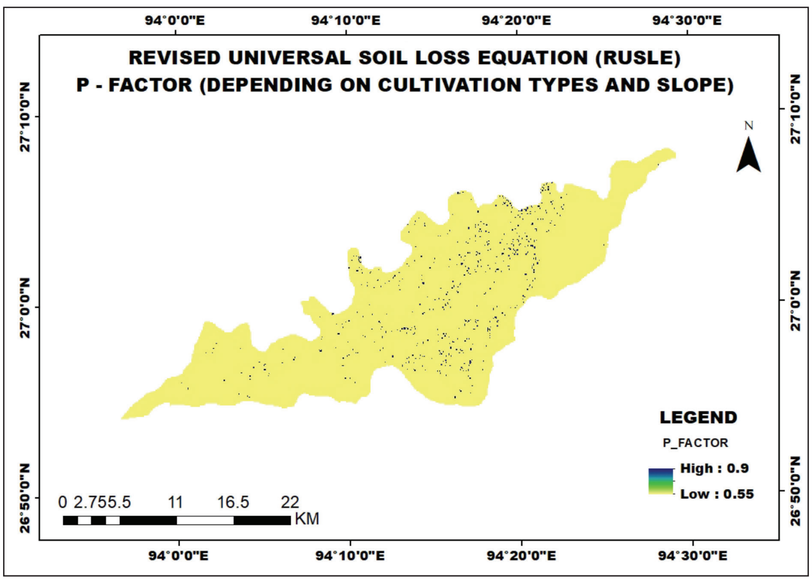

Figure 10: P-Factor is calculated on the basis of slope and cultivation type of an area.

The rainfall erosivity factor is determined by MJ mm/ha/hr/yr. Here, the R-Factor is calculated for Majuli island. The value of R-Factor is obtained to be 175.165 to 226.343 MJ mm/ha/hr/yr for the year 2022. The areas receiving relatively higher rainfall have high R-value than the areas receiving less amount of rainfall.The soil erodibility factor that is determined as K-factor. Majuli island is composed of a single soil type viz., sandy clay loam. That is why, the value of the K-Factor is not in range but a singular value 0.01002.The LS-Factor ranges from 0 to 621. The C-Factor is obtained from the LULC map from Sentinel Copernicus, where the value of C is given depending on the land-use class such as, for Built-up area the value of C is 0.004, for crops it is 0.15, for trees it is 0.01, for water it is 0, for bare-ground it is 1, for rangeland it is 0.05 and for flooded vegetation it is found to be 0.35. The P-Factor is described by the slope and type of cultivation done on the study area. The value of P usually ranges from 0 to 1, but as per calculation, here the P-Factor ranges from 0.55 to 0.90. When the value of P is closer to 1, it denoted healthy vegetation and when the value reaches close to 0, it denoted soil cover.

The output map of the above-mentioned values shows that the soil loss of Majuli island is 53.2148 ton/ha/yr for the year 2022. When the intensity of rainfall increases the soil loss also increases and with the decrease of rainfall intensity, the amount of soil loss also decreases. The value of soil loss is also influenced by the soil type. As the soil of Majuli island is sandy, it is loss in structure and is prone to be washed away by rain or river flow. Thus, these factors actively influence the outcome of soil loss.

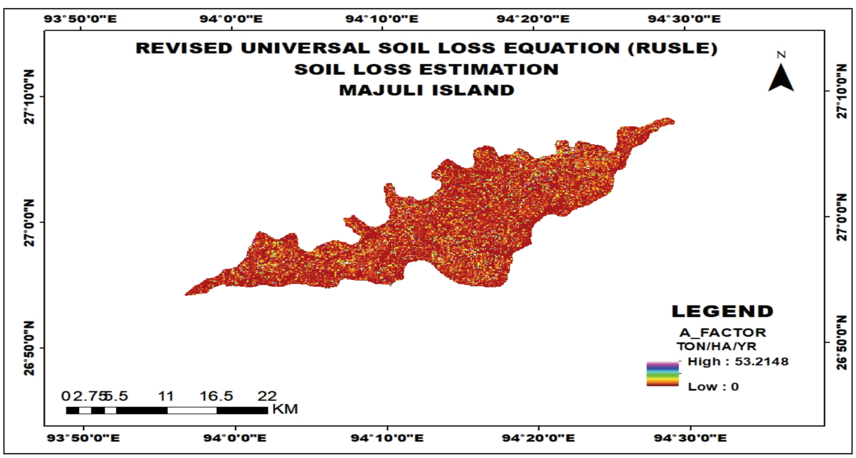

Figure 11: Soil Loss Map of Majuli Island (2022)

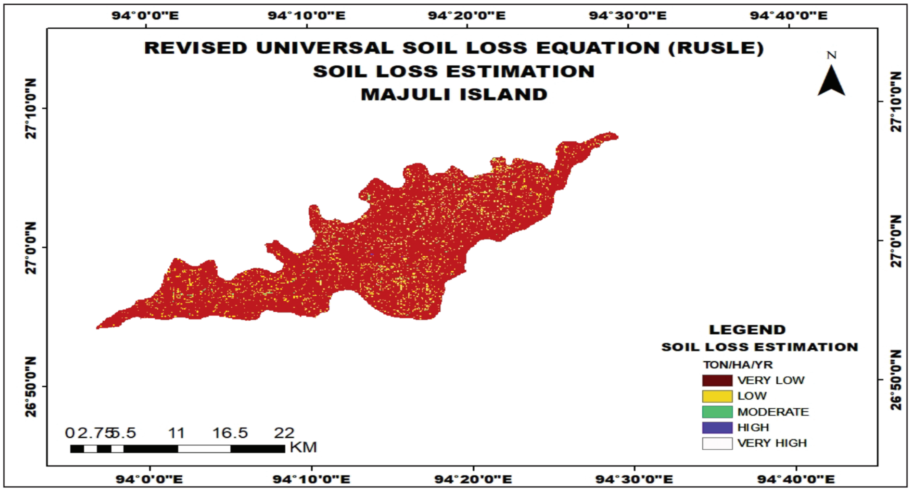

Figure 12: Soil Loss Estimation Map of Majuli Island

Table 5: Showing Soil Erosion in different classes with Area and Percentage

SOIL EROSION CLASS	RANGE (ton/ ha/yr)	AREA (in SQ.KM)	PERCENTAGE (%)	PRIORITY CLASS
VERY LOW	0-0.417	444.277939	95.38412	V
LOW	0.418-2.92	19.396025	4.164224	IV
MODERATE	2.93-9.39	1.809983	0.388594	III
HIGH	9.40-20.9	0.241398	0.051827	II
VERY HIGH	21-53.2	0.052333	0.011236	I

4. Conclusion

The application of the Revised Universal Soil Loss Equation (RUSLE) model, coupled with geospatial analysis, is instrumental in estimating annual soil loss and prioritizing erosion-prone areas in the region. The study emphasizes the significance of GIS-based RUSLE models in assessing soil erosion dynamics, particularly in Majuli Island, which are susceptible to significant erosion due to various factors especially geographical characteristics. Soil erosion is the prevailing hazard in the periphery regions of Majuli island as the soil structure is very loose and does not have a thick vegetation cover along its bank. Rainfall is another significant factor. In Majuli island the higher range of soil loss occurs along the bank and places with high elevation. Majuli island accounts to a total of 53.2148 ton/ha/yr of soil loss in the year 2022. Thus, the preventive measures are needed to be adopted along the bank of Brahmaputra primarily and also along river Subansiri and Kherkutia-Lohit suti.

4.1 Preventive Measures

There must be certain activities that are to be taken into account for implementing preventive measures from soil loss. Some cautions have been mentioned below:

a) Identification of the most vulnerable areas is the first essential step to prevent soil loss and soil erosion.

b) As the island is mostly constituted with sandy soil, the washing out of the top soil with heavy rainfall or frequent flood inundation is very common. Thus, plantation of vegetations with deep roots should be helpful in minimizing the soil loss in runoff.

c) Concrete blocks and pillars must be laid out near the bank to control the bank erosion as well to hold the loose soil from slipping away.

Thus, there are some preventive measures that can be looked upon for minimizing the impact on soil loss and soil erosion.

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