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Soil Erosion Estimation of Palasbari in Northeast India by RUSLE Model

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ABSTRACT

Soil erosion is a serious problem and its estimation at a large scale is an urgent need. This study aims to estimate the annual soil loss in Palasbari town (639 km^2) applying the Revised Universal Soil Loss Equation (RUSLE) model on a GIS platform. The study area comprising Palasbari town is located in the state of Assam in Northeast India. The annual soil loss rate varies from 0 to 3779t ha^{-1} yr^{-1} and the mean annual rate of soil loss is 42 t ha^{-1} yr^{-1}. The soil loss values are categorised into four classes of severity i.e. slight, moderate, severe and extreme soil erosion. Based on spatial analysis, it is found that areas with high slope length and steep slope with heavy and high intensity precipitation are more prone to soil erosion. It is concluded that steep slopes, frequent flooding, sandy soil, destruction of vegetation cover are the main causes of soil erosion in the study area.

KEYWORDS: *Soil erosion, RUSLE, Remote sensing, GIS, Palasbari*

INTRODUCTION

Soil erosion is a geomorphic process, which affects all types of landforms. The average rates of soil erosion throughout the world are estimated between 12 and 15tons per hectare per year (t. ha^{-1}. yr^{-1}) which means that every year the land surface loses about 0.90 – 0.95 mm of soil (FAO and ITPS, 2015). The estimation and representation of area vulnerable to soil erosion is very essential for its protection and management. Modeling provides a consistent and numerical approach to estimate soil erosion and sediment yield under various conditions, and is essential to guide the comprehensive control of soil erosion. Since scientists proposed one of the earliest quantitative soil erosion prediction equations in the 1940s, several modeling initiatives have been made to estimate soil erosion loss at different spatial and temporal scales (Merritt et al., 2003; Borrelli et al., 2021). Quantitative models proposed in the literature to assess soil erosion loss are divided into three broad categories: (i) empirical; (ii) conceptual and (iii) physics-based (Merritt et al., 2003).

Empirical models are based on the analysis of observations and seek to characterise response from these data. The computational and data requirements for such models are usually less than for conceptual and physics-based models, often being capable of being supported by coarse measurements. These models are frequently preferred than conceptual and physics-based models as they are the simplest and can be implemented with readily available data.

Conceptual models are typically based on the representation of a catchment as a series of internal storages. They usually incorporate the underlying transfer mechanisms of sediment and runoff generation in their structure, representing flow paths in the catchment as a series of storages, each requiring some characterisation of its dynamic behaviour. Conceptual models involve a general description of catchment processes but they do not include specific details of process interactions.

Physics-based models are based on the solution of fundamental physical equations describing stream flow and sediment generation in a catchment. Standard equations used in such models are the equations of conservation of mass and momentum for flow and the equation of conservation of mass for sediment. These types of models are data demanding where data on several parameters are required which are not always easily available.

The USLE model, i.e., Universal Soil Loss Equation (Wischmeier and Smith, 1978) was the first and most important empirical model; and it was based on thousands of experimental data collected by the Soil Conservation Service and the Agricultural Research Service in 37 states of the United States of America. In particular, soil loss by erosion on a yearly basis was assessed as a product of factors concerning climate, nature of the soil, soil use and morphology. A revision of the USLE model, called RUSLE (Renard et al., 1997) is applied to erosion over extended areas and in different contexts (including forests, rangeland, and disturbed areas). In order to better understand the support practice impact assessment phase and its link to minimise soil erosion rate, the RUSLE model has updated values for the USLE factors by employing new relationships and additional values. RUSLE is used to evaluate the environmental implications of water erosion by taking into account all inputs from raw parameters such as rainfall, land cover, topography, erodibility, and support methods. RUSLE has been widely applied worldwide to estimate soil loss (e.g. Dabral et al., 2008; Jain et al., 2001; Jasrotia and Singh, 2006; Millward and Mersey, 1999; Pandey et al., 2009; Shivhare et al., 2018; Zhou et al., 2014). The purpose of this study is to estimate the average annual soilloss during the water year 2019–2020 and to prepare a soil erosion map of Palasbari in Northeast India by applying the RUSLE model.

DESCRIPTION OF THE STUDY AREA

The study area comprises the Palasbari town and the villages around it. The Palasbari town is located at a distance of 23 km west of Guwahati (capital city of the state of Assam) in the south bank of the river Brahmaputra. The study area is located between 25.83° North latitude to 26.18° North latitude and 91.32° East longitude to 91.73° East longitude (Figure 1). It encompasses a total area of 639 km^2 including 610.44 km^2 of rural area and 29.05 km^2 of urban area. According to the 2011 census, Palasbari has a population of 2,39,026. It is one of the most vulnerable locations in the state of Assam where heavy soil erosion occurs every year. The area is basically a low elevation area but the southern part of the area has comparatively higher elevation. The elevation ranges from 20m to 671m above mean sea level (Figure 1). Annual floods occur generally in the low-lying parts of the study area during May to August every year. The occurrence of floods is mainly due to inundation by the river Brahmaputra and its tributaries.

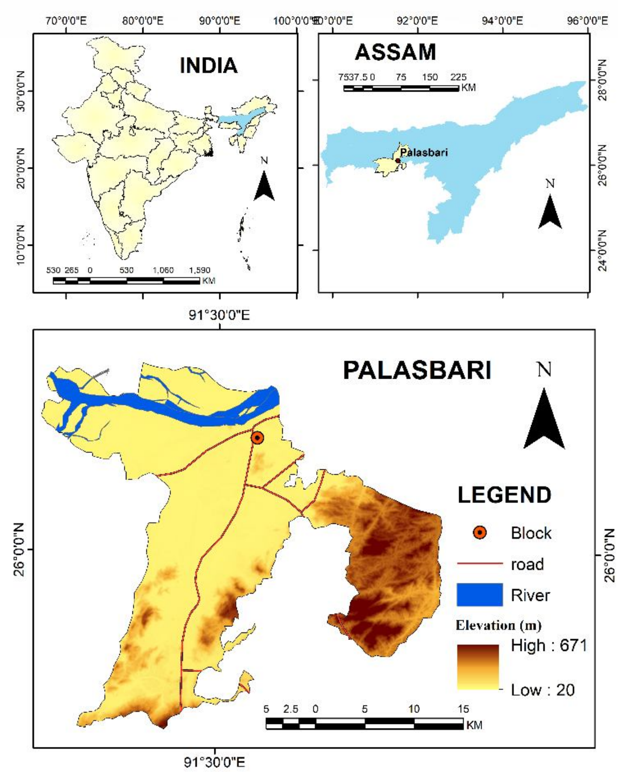

Figure 1: Location map of the study area

Vegetation covers 48% of the total study area whereas more than 26% of the total area is covered by growing settlements. The land cover map, as derived from LISS- 3 satellite sensor of NRSC/ISRO, using supervised classification, is shown in Figure 2.

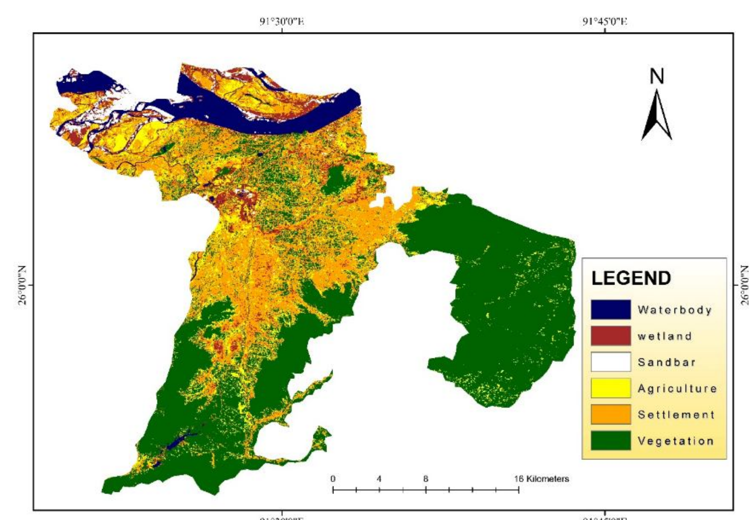

Figure 2: Land cover map of the study area

According to the Digital Soil Map of the World (DSMW) published by FAO-UNESCO, soils in the Palasbari region are of two types: Orthic Acrisols (AO) and Distric Nitosols (ND). Orthic Acrisols is the dominant soil type and found in the majority of areas. The sand, silt, clay and organic components in both the soil types range from 38.9% to 53.6%, 15.8% to 17.6%, 30.6% to 40.6% and 1.57% to 2.25% respectively. Therefore, sand is the dominating component in the soils types of Palasbari.

DESCRIPTION OF THE DATA

The data comprising of satellite images, soil, digital elevation model (DEM) and rainfall that were used in the present study to estimate soil loss are described in Table 1.

Table 1: Source and description of the dataset used in the present study

Dataset	Source	Description
Daily rainfall data	http://giovanni.gsfc.nasa.gov	Daily Rainfall data for a period of 20 years (01/01/2000-31/12/2019) with 11 grid points
Digital elevation model	https://earthexplorer.usgs.gov	SRTM 1 Arc-Second DEM (30 m resolution)
Soil Data	Digital Soil Map of the World (DSMW) by Food and Agriculture Organization (FAO) of the UNESCO	The FAO-UNESCO Soil Map of the World was published between 1974 and 1978 at 1:5 000 000 scale. 2 categories of soil based on Soil Texture.
Satellite Image	https://earthexplorer.usgs.gov	Cloud free Landsat 8 OLI satellite imagery (Date of acquisition: 25 Feb, 2020). The imagery is in GeoTiff format with 16-bit radiometric resolution (ranges from 0-65535).

Soil erosion is influenced by variety of factors such as rainfall intensity and distribution, soil types, topography of watershed, land use types, etc. For the present study, 20 years (01/01/2000-31/12/2019) of daily Precipitation data around the study area were extracted from http://giovanni.gsfc.nasa.gov. The Digital Soil Map of World (DSMW) by FAO was used to study the soil types of the area. To determine the slope length and slope gradient, SRTM 1 arc-second digital elevation model (DEM) was used. Lands at 8 OLI image was used to generate the Normalized Difference Vegetation Index (NDVI) map of the study area.

METHODOLOGY

The RUSLE model is an empirical model that is used to estimate the average annual rate of soil erosion in a watershed based on the precipitation data, type of soil, topography, crop system and management practices. The model has the following structure (Renard et al., 1997) in Eq. (1).

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where, A = Average annual soil loss expressed in ton per hectare per year ($\text{t ha}^{-1}\text{yr}^{-1}$); R = Rainfall erosivity factor ($\text{MJ mm h}^{-1}\text{yr}^{-1}$); K = Soil erodibility factor ($\text{t h MJ}^{-1}\text{ mm}^{-1}$); LS = Topographic factor; C = Cover management factor and P = Support practice factor; *L* and *S* factors represents the dimensionless effects of slope length and steepness, *C* represents the dimensionless impacts of cropping and management systems, and *P* represents erosion control practice.

An advantage of selecting the RUSLE model for application in the study area is that its parameters can be easily integrated with GIS for better analysis. The parameters of RUSLE model have been estimated based on the rainfall events, DEM, soil type and land cover. The RUSLE is applied to the study area by representing the area as a grid of square cells and calculating soil erosion for each cell in Arc GIS 10.1 software. The flowchart of the methodology used in this study is schematically represented in Figure 3.

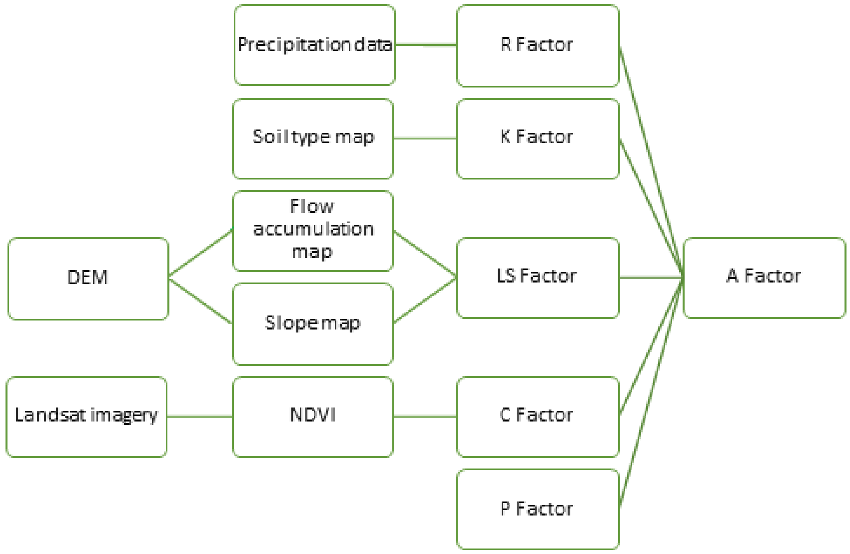

Figure 3: Flow chart of methodology

RESULTS AND DISCUSSION

Rainfall Erosivity Factor (*R*): Among the factors used within RUSLE, rainfall erosivity is of high importance as precipitation is the driving force of erosion and has a direct impact on the detachment of soil particles, the breakdown of aggregates and the transport of eroded particles via runoff. The average annual sum of individual storm erosion index values (EI30) is defined as the rainfall erosivity, where E represents the total storm kinetic energy and I30 represents the maximum rainfall intensity in 30 minutes. Wischmeier and Smith (1978) recommended that at least 20 years of continuous rainfall data are needed to compute storm EI30.

For India, Babu et al. (2004), developed an empirical method for calculating the rainfall erosivity factor from readily available rainfall data. The formula is:

$$\boldsymbol{R} = \mathbf{81.5} + \mathbf{0.38} * \boldsymbol{P} \quad (2)$$

Where, *P* is the annual precipitation for areas where annual precipitation ranges between 340 mm and 3500 mm.

The daily rainfall data were downloaded for 20 years (01/01/2000 – 31/12/2019) from the Tropical Rainfall Measuring Mission (TRMM) for 11 different coordinates, two of which are situated within the study area and the rest outside, such that it provides a more accurate interpolated result. The locations of various grid points around the study area are displayed in Figure 4. The daily rainfall data are processed in MS-Excel and the mean annual precipitation from 01/01/2000 to 31/12/2019 are calculated. The mean annual precipitation over the most recent 20 years ranges from approximately 2335 mm to 5261 mm around the study area. The rainfall erosivity factor was calculated by using Eq. (2). A spatially distributed *R*-factor map of the study area (Figure 5) was derived by ordinary kriging spatial interpolation that was performed in ArcGIS 10.1. The Rainfall erosivity factor (R) during the year 2000-2019 ranges from 1127.88MJ mm $ha^{-1}h^{-1}yr^{-1}$ to 1803.24 MJ mm $ha^{-1}h^{-1}yr^{-1}$. In the study area, the mean R value is 1462.76MJ $mmha^{-1}h^{-1}yr^{-1}$. It can be observed that the flat low-lying areas close to the Brahmaputra River experiences comparatively lesser precipitation than the sloping, thick woodland area in the southern side. Moderate amount of rainfall occurs in the central part of the region. The *R*-factor values gradually increase towards the southern part.

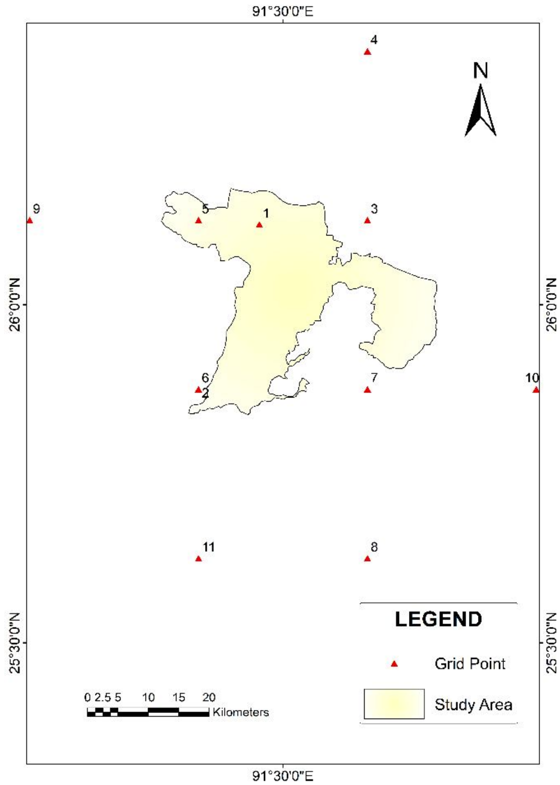

Figure 4: Locations of various grid points around the study area

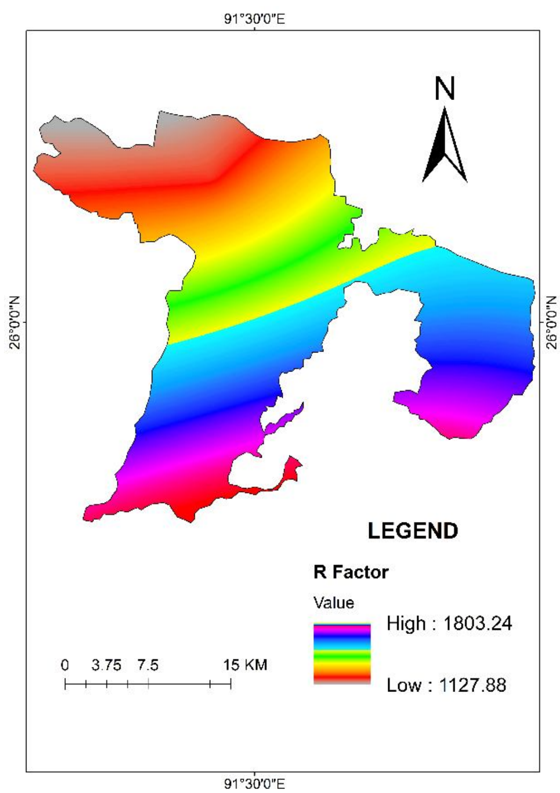

Figure 5: R-factor map

Soil Erodibility Factor (*K*): The inherent susceptibility of the soil to erosion depending on the soil profile characteristics is represented by the soil erodibility factor (*K*). In this study, the soil type map was extracted from the digital soil map of the world (DSMW) published by the Food and Agriculture Organization (FAO) of the UNESCO and the *K* factor is estimated using the equation of Williams (1995).

$$K = f_{csand} \times f_{cl-si} \times f_{orgc} \times f_{hisand} \quad (3)$$

Where, f_{csand} is a factor which lowers the *K* indicator in soils with high coarse-sand content and higher for soils with little sand; f_{cl-si} gives low soil erodibility factors for soils with high clay-to-silt ratios; f_{orgc} reduces *K* values in soils with high organic carbon content, while f_{hisand} lowers *K* values for soils with extremely high sand content:

$$f_{csand} = \left(0.2 + 0.3.exp\left[-0.256.m_s.\left(1 - \frac{m_{silt}}{100}\right)\right]\right) \quad (3a)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \quad (3b)$$

$$f_{orgc} = \left(1 - \frac{0.0256.orgC}{orgC + exp[3.72 - 2.95.orgC]}\right) \quad (3c)$$

$$f_{hisand} = \left(1 - \frac{0.7.\left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9.\left(1 - \frac{m_s}{100}\right)\right]}\right) \quad (3d)$$

Here,
m_s = Percent sand content (0.05-2.0 mm diameter particles)
m_{silt} = Percent silt content (0.002-0.05 mm)
m_c = Percent clay content (<0.002 m)
$orgC$ = Percent organic carbon content of the layer (%)

The percentage of sand content (m_s), percentage of silt content (m_{silt}), percentage of clay content (m_c) and Percentage of organic carbon content ($orgC$) are collected from the generalized soil unit information report included with the soil type map published by FAO-UNESCO. The soil unit information and the computation of the f_{csand}, f_{cl-si}, f_{orgC} and f_{hisand} for each type of soil of the study area are presented in Table 2.

Table 2: Soil unit information and the computation of f_{csand}, f_{cl-si}, f_{orgC} and f_{hisand} of the study area

Soil types	Percent sand content (m_s)	Percent silt content (m_{silt})	Percent clay content (m_c)	Percent organic carbon content ($orgC$)	f_{csand}	f_{cl-si}	f_{orgc}	f_{hisand}
AO	53.6	15.8	30.6	2.25	0.200003	0.723839	0.975001	0.998056
ND	38.9	17.6	43.6	1.57	0.200082	0.688063	0.979618	0.999911

The soils of Palasbari are of two types with varying characteristics: Orthic Acrisols (AO) and Distric Nitosols (ND). The eq. (3*a*), eq. (3*b*), eq. (3*c*) and eq. (3*d*) are calculated using the values of m_s, m_{silt}, m_c and $orgC$ (Table 2). The *K* value of AO ranges from0.134851 to 0.140876 t h MJ $^{-1}$mm^{-1} and for ND, it is 0.134851 t h MJ $^{-1}$mm^{-1}. The soil erodibility of areas with AO soil is higher and a large amount of this soil type is getting eroded annually. The spatial occurrence of the two soil types is shown in Figure 6.

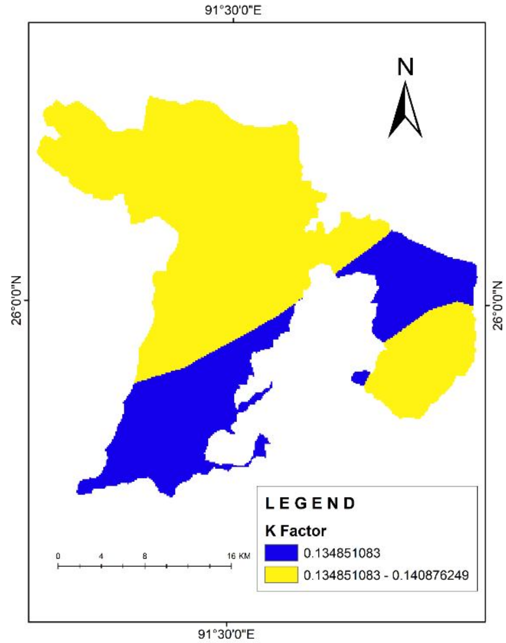

Figure 6: K-factor map

Slope length and Steepness Factor (*LS*): The slope length and steepness factor accounts for the effect of topography on erosion. Many workers have used the *L* and *S* factors as a combined *LS*-factor. The *LS* factor has been computed by an empirical formula as suggested by Moore and Wilson (1992):

$$LS = (Slope\ length/22.13)^{0.4} \times (0.01745\ sin\ \theta / 0.0896)^{1.4} \times 1.4 \quad (4)$$

Where, *Slope length = Flow accumulation × cell resolution of the DEM* and θ = Slope in degrees.

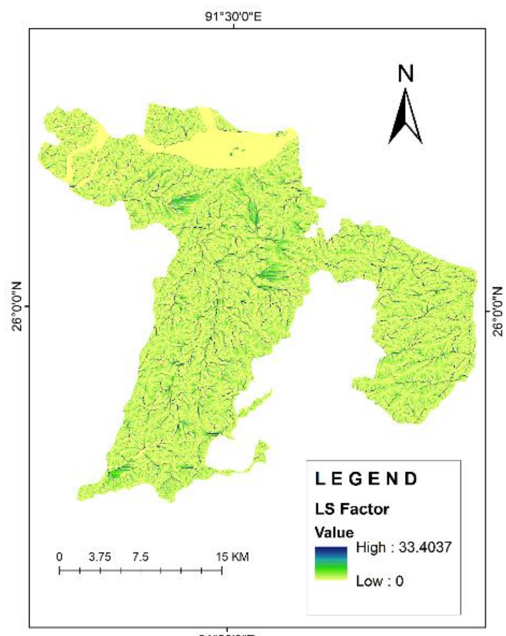

Figure 7: LS-factor map

The *LS*-factor varies from 0 to 33.4037 over the study area. The spatial variation of the *LS*-factor is displayed in Figure 7.

Cover Management Factor (*C*): The influence of vegetation cover on soil erosion is accounted by the cover management factor. The ratio of soil loss from an area with certain cover and management practices to the similar soil loss from a clean-tilled and continuous fallow land is defined as cover management factor (*C*). The value of *C* is dependent upon the vegetation type; vegetation growth stage and vegetation cover percentage. The *C*-factor was derived from the Normalized Difference Vegetation Index (NDVI) and formulated using the equation developed by Sulistyo (2016):

$$C = 0.6 - 0.77\ \mathrm{NDVI} \quad (5)$$

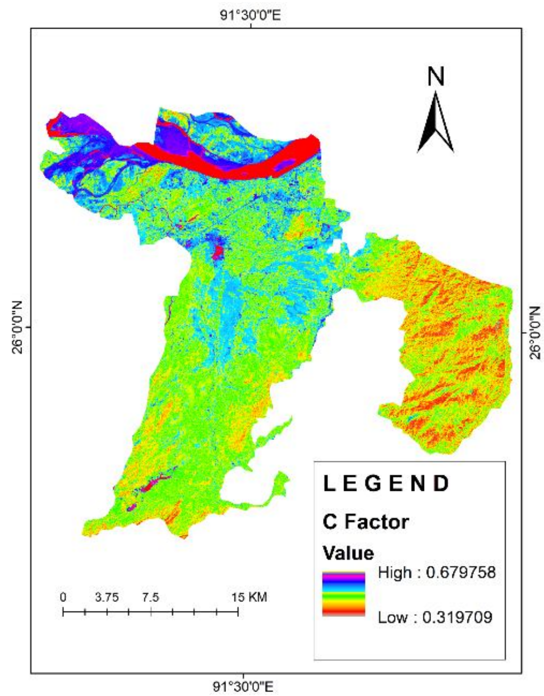

Figure 8: C-factor map

The *C*-Factor varies from 0.319709 to 0.679758 over the study area. The spatial variation of *C*-factor is shown in Figure 8. There is an inverse relation exists between the *C*-Factor and NDVI. The forest areas have low *C* values whereas the riverine areas, agricultural areas, or areas with less vegetation exhibit high *C* values.

Support Practice Factor (*P*): The support practice factor (*P*) represents the proportion of soil loss under given support practices for the corresponding soil loss with the presence of upward and downward cultivation. The *P* values are obtained using the *P*-factor classification table of Shin (1999). The *P*-factor values range from 0 to 1, where, the highest value 1 is allotted to the areas with no conservation practices, and the minimum value 0 is given to plantation areas with contour cropping and built-up land. In the study area, the low-lying areas near the river has a *P* value of 0.55 while other parts have a value ranges from 0.55 to 1 (Figure 9). The mean *P* value of the study area is 0.97.

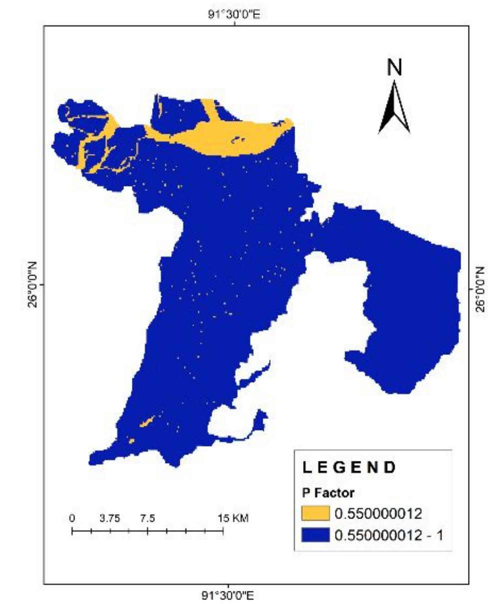

Figure 9: P-factor map

Potential Annual Soil Erosion Estimation: GIS analysis has been carried out for RUSLE to estimate the annual soil loss on a pixel-by-pixel basis in the study area. The RUSLE parameters were multiplied in the raster calculator tool of ArcGIS to estimate the annual soil loss during the water year 2019–2020. The estimated annual soil loss rate in the study area ranges from 0 to 3779.02 t ha^{-1} yr^{-1} and the mean annual soil loss rate are 42 t $ha^{-1}yr^{-1}$. The soil erosion in each pixel was classified into four classes of severity as *slight*, *moderate*, *severe* and *extreme* following the recommendations of FAO (Jahn et al., 2006). The classes of soil loss severity and their spatial distribution of soil loss in the study area are presented in Figure 10 and Table 3 respectively.

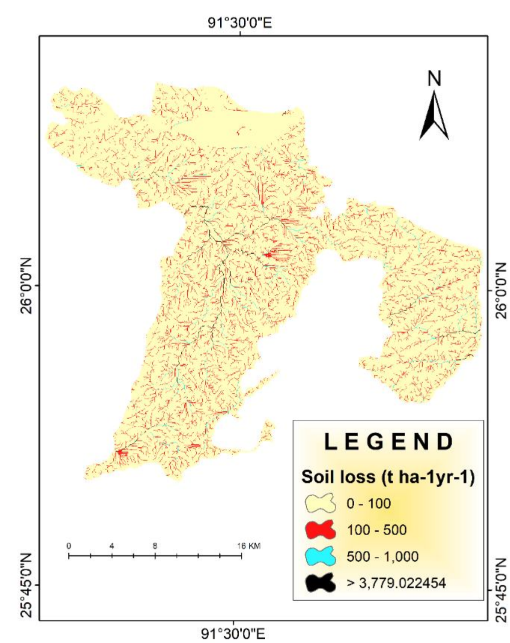

Figure 10: Annual soil loss map of the study area

Table 3: Classes of soil loss severity with loss rate and percentage of area covered

Severity Classes	Soil Loss ($t\ ha^{-1} yr^{-1}$)	Number of Pixels	Area (*ha*)	Area (%)
Slight	0 - 100	673252	60592.68	92.06311005
Moderate	100 - 500	51691	4652.19	7.068429387
Severe	500 - 1000	4449	400.41	0.60837365
Extreme	1000 - 3779	1902	171.18	0.260086914

The estimated total annual potential soil loss for the whole study area was found as 2785233.37t yr^{-1}. Approximately, 92.06% of the study areas have a soil loss less than 100 t $ha^{-1}yr^{-1}$ while more than 7% of the total areas face soil loss from 100t $ha^{-1}yr^{-1}$ to 500t $ha^{-1}yr^{-1}$. Almost 0.6% of the total areas come under severe soil loss while only 0.26% of total areas face major soil loss, which comes under the extreme category of soil loss. The areas with moderate and severe soil loss should be given more importance in terms of erosion control. The study indicates severe soil erosion occurs mostly in areas with less vegetation and agricultural areas. While slight erosion is mostly observed in areas with low slope values or in the water bodies. Moderate soil erosion can be seen in all over the areas with moderate to high slope values. It is observed that moderate to Extreme level of erosion is seen in areas incised by water bodies and streams.

The soil erosion rate in the study area has a close relationship with land cover of the study area. It is observed that the agricultural areas and the settlement areas experience moderate to extreme soil erosion whereas the forest cover area and the water body experiences slight to moderate soil erosion. The destruction of wetlands in the central part of the area has led to moderate to severe soil loss per year. The areas with forest cover experience less soil erosion as compared to the areas that practices agriculture and the areas that has settlement. The increase in soil loss was found mainly due to the agricultural activities and increasing built up areas.

CONCLUSIONS

Soil erosion is a serious issue in agrarian countries like India that receives plenty of rainfall all through the monsoon and also home to numerous rivers. In the Palasbari area, river bank erosion by the river Brahmaputra and numerous small streams due to seasonal floods have resulted in extensive soil erosion. Empirical soil erosion models require minimal resources and can be worked out with readily available inputs to precisely map the areas exposed to high erosion risk. This paper demonstrates the application of the RUSLE model, integrated with GIS, to estimate soil erosion zones in the Palasbari area. Also, an attempt has been made to study the impact of topography and land cover on erosion rate. High soil erosion probability zone is observed in the high slope length areas with steep slopes. Precipitation plays significant role in the erosion process. Heavy and intense precipitation during monsoon disintegrates the soil, besides causes frequent flooding. Highly erodible soil and low NDVI zone also influence the soil erosion in the area. It was found that steep slope, high intensity precipitation, sandy soil, frequent flooding, destruction of vast wetlands are the main causes of soil erosion in the study area. The results conclude that the average annual soil erosion rate in the study area is 42 t $ha^{-1}yr^{-1}$, which varies from 0 to 3779 t $ha^{-1}yr^{-1}$and the estimated total annual potential soil loss is 2785233.37t yr^{-1}. It is also observed that the quantity of erosion varies mainly on topography and land cover. The erosion severity map revealed that about 92% area comes under *slight* soil loss category and less than 1% of the area comes under *severe* and *extreme* erosion category; and the rest of the area comes under *moderate* soil loss category. It is necessary to implement suitable soil conservation practices in such areas. This study demonstrates that GIS is an efficient tool in the estimation of soil erosion loss. The outcome would help to take suitable erosion control measures in the severely affected areas. The results obtained from the study can assist in developing management scenarios and provide options to policy makers for managing soil erosion hazards in the most efficient manner for prioritization of different parts of the study area for treatment.

Abbreviations

USLE − Universal Soil Loss Equation
RUSLE − Revised Universal Soil Loss Equation
GIS – Geographic Information System
NDVI − Normalized Difference Vegetation Index
FAO − Food and Agriculture Organization
ITPS− Intergovernmental Technical Panel on Soils
DSMW − Digital Soil Map of the World
UNESCO − United Nations Educational, Scientific and Cultural Organization
NRSC– National Remote Sensing Centre
ISRO– Indian Space Research Organisation
SRTM– Shuttle Radar Topography Mission
DEM – Digital Elevation Model
TRMM – Tropical Rainfall Measuring Mission

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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