A STUDY ON SOIL EROSION DYNAMICS AND SPATIAL MAPPING USING RUSLE AND ARC GIS

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Abstract

The health of ecosystems, water quality, and agricultural output are all seriously threatened by soil erosion. In this work, soil erosion rates in the Budhabalanga River Basin have been analysed, and maps of erosion risk are created using the Revised Universal Soil Loss Equation (RUSLE) and Geographic Information System (GIS) technology. By shedding light on the regional distribution of soil erosion vulnerability, the study hopes to improve land management and conservation tactics. Many factors, including rainfall, soil characteristics, land use and cover, slope, and conservation techniques, are taken into account while collecting data. Soil erosion pattern visualization and geographical analysis are made easier by the integration of RUSLE with GIS. The results aid in our comprehension of the dynamics of soil erosion in theBudhabalanga River Basin and offer important data for the planning and management of sustainable land use. RUSLE play a rucial role in environmental science, land management which often intersects with computer technology in analysis od geospatial, integration, model calibration etc.

Keywords: Soil erosion; RUSLE; Arc GIS.

1. Introduction

Water quality, ecosystems, and agricultural production are all negatively impacted by soil erosion. Topsoil loss lowers agricultural production, inhibits plant development, and depletes the fertility of the soil. Additionally, clogged streams from eroded soil can cause sedimentation in reservoirs, lakes, and rivers. Water quality might be lowered, ecosystems can be upset, and aquatic behaviours can be affected by this sedimentation. Globally, soil erosion is a serious environmental problem that affects both naturally occurring and artificially created landscapes. Thus, a comprehensive study is essential to overcome such crisis. Within this framework, research efforts were undertaken to analyze the soil erosion dynamic sand to forecast rates of erosion for a particular basin [1-4].

Researchers have investigated on soil erosion dynamics. The RUSLE shows the rainfall effects on weather, soil, topographic, and LU effect rill and inter rill erosion. This study aims to determine soil loss at a scale through approach of RUSLE eq and ArcGIS. Geographic information systems allows for the integration of various spatial data horizons, like topography, land cover, soil type, rainfall patterns, and soil erosion control practices. By combining these data layers, I found a comprehensive understanding of the factors contributing to soil corrosion.

1.1 RUSLE Modelling

The RUSLE, was developed to estimate soil in a variety of settings, including urban areas, croplands, forests, and rangelands. However, the most often utilized models for assessing soil loss were the USLE and secondly the RUSLE. The effects of terrain, weather, soil, and LU on rill and inter-rill soil erosion caused by surface runoff and precipitation droplets are demonstrated using the RUSLE model. This empirical model uses five factors to anticipate soil loss. The factors are as follows: length of slope and steepness factor (LS), erodibility of soil factor (K), erosivity of rainfall component (R), cover management factor (C), and support practice factor (P).

The RUSLE is formulated on modification in different factors is written as:

$$A= \boldsymbol{R} \times \boldsymbol{K} \times \boldsymbol{LS} \times \boldsymbol{C} \times \boldsymbol{P} (1)$$

Where

A = Average yearly soil loss (tons /acre or tons/ hectare /year)
R = Rainfall-Runoff erosivity factor (mm/ hectare / year)
K = erodibility of soil factor (tons/ hectare/MJ/mm)
LS = Length of slope and steepness factor
C = Cover management factor
P = Support practice factor

2. Literature Review:

A detail literature review has been done on the available past research on soil erosion. Some of the previous studies on soil erosion are reported in this chapter.

Fallah et al. (2016) purposed a specific study which is based on recognition of erosion-prone for the sub-watershed located at Haraz. This was placed on water and soil projects by using of Multi-criteria calculation methods, RUSLE and GIS techniques.

Bhat et al. (2019) represented soil erosion rates in a micro-watershed in J & K, India. The RUSLE model is generally used empirical model that estimates soil loss rates from a watershed. This study represents the maximum mean soil loss in the micro-watershed was 2.9296 tons/hectare/year.

Kayat et al. (2018) used the RUSLE & SCS-CN methods to analyze the soil potential zone or soil loss zone. In order to analyze the effect on soil lost in the hill slope mining areas Arc GIS grids with RKLSCP factor. The hilly area is covered by low (10,025hactare), moderate (3125hactare), high (973hactare), very high (260hactare), & severe (53hactare) respectively.

Thomas et al. (2019) explored the loss of SL rates & sediment deposit in the mountainous basin in rain shadow region of the Western Ghats in India. The gross and mean soil erosion are 11.70 tons/hectare/ year and 2.92 tons/ hectare /year in the basin. This was covered by 25% the region results was found.

Tropike et al. (2022) analyzed the risk of soil loss in the Kosovo River basin. The RUSLE model with GIS & RS was used for soil erosion rates or soil loss. Geological process, climate state, terrain attribute, length of slope, LULC, etc. These are the important factors that contribute the soil erosion potential risk.

Biswas and Pani (2015) analyzed the soil loss in a plateau area Jharkhand region of the Barakar River basin. The revised model and GIS have been used for the estimated soil erosion rate. According to RUSLE factors shows that rate of significant soil loss is >100 t/ha/yr. The results revealed that reservoir storage capacity in both living and dead storage had been showed as well as soil erosion in higher basin areas.

Markose and Jayappa (2016) estimated the soil lost and assessment the watershed of the Kali basin using the revised model. These results showed that 42% of the region has a low erosion risk and 6.97% of the territory has a high erosion risk.

Kumar and Singh (2021) explored work on the estimated soil erosion rate using various digital elevation model and the RUSLE parameters were applied to determine the sub watershed’s soil susceptibility. Results revealed that the clay with loam soil has the highest at 0.28cm3 and glacier has the lowest water carrying capacity at 0.22cm3 respectively.

Bora et al. (2021) this study determined soil erosion in the Chisheke watershed by using the rusle equation. According the outcomes, revealed that soil losses ranged from 0-400 t/ha/yr, on average of 24t/ha/year. Settlements lost in highest (60t/ha/yr) and bare soil (45t/ha/year), while agriculture and tea plantations (8.5t/ha/yr) recorded less soil losses.

Negese et al.(2020) Integrated the RUSLE eq, ArcGIS, and RS have been access to the watershed. To determine the soil loss, the RUSLE factors such as R, K, LS, C, and P were overlarge and computed. With a mean yearly soil loss is 38 tons/hectare/year, and the range of up to 187.47 tons/hectare/years in areas of steep slope, the results revealed that the watershed as lost 487057.8 tons of soil annually. It was founded that the GIS, RS and RUSLE is necessary, accessible and useful for analyzing soil loss.

Pan and Wen 92013) studied the determination of soil erosion and its geospatial distribution in watersheds on the steep slope plateau region. The RUSLE eq and GIS models have been used to calculate the soil erosion rates. In order to these finding, the spatial mean soil erosion was 78.78 t/hec in 2002 as compared to 70.58 t/hec in 2010 respectively.

Nirmanee et al.(2019) studied the RUSLE equation and which has been used to calculate soil loss in the Kalu Ganga river basin, Srilanka. The finding revealed that the predicted mean soil loss for the entire watershed was 0.63 tons/hectare/ year.

Mukanov et al. (2019) integrated the GIS techniques of the Esil watershed, Kazakhstan by utilizing the RUSLE equation for the estimation of mean average soil loss.

Girma and Gebre et al. (2020) ArcGIS and RUSLE eq were combined to study the spatial distribution of soil erosion in the Omo- Gibe river basin and identify areas that require prioritizing soil corrosion control.

Belaynch et al. (2019) RUSLE eq and GIS techniques were used to explore the calculation of soil erosion potential zone and identification of hotspots region in the Gumara watershed. The finding research that soil corrosion brought by water erosion was issue in the watershed. 62.1% of the 42.67 tons/hectare/year in a total of average yearly soil loss came from cultivated area.

Antench and Biru (2021) estimated the spatial anticipate the rates of loss soil of the Kaffa zone the RUSLE and GIS were used. The RUSLE model customized for Ethiopian set of conditions was able to determine soil loses by empirical data on rainfall/runoff data, FAO soil map, satellite images, length and slope factor using DEM, and P factor using DEM and spatial images. Based on the paper showed that the mean yearly mean soil loss was 30 tonne /hectare /year and 36264.5 tonne /hectare /year was soil loss of potential respectively.

Ejaz et al. (2023) analyzed the rates of soil loss risk in Wadi Baysh river basin, Yemen. The RUSLE model, coupled with integrated GIS and RS approaches has been used in this paper. The finding showed that 57.91 million tons of soils were lost from the basin average on year.

Choudhary and Nayak (2003) examined the average yearly soil loss rates from the Sagar Lake catchment area in Madhya Pradesh, India. GIS techniques were utilized in concurrence with the model of RUSLE. Based on the study, the areas average annual silt deposition rate has been calculated to be 1.15 cm per year, and the mean rate of soil loss was 17840 tons per year.

Pavisorn et al. (2019) explored the Langcang-Mekong Basin to influence the soil erosion rates. In this research, RUSLE and GIS techniques have been used. The results of the study showed that total annual soil loss rates range from 700-10000 tons per km^2 per year.

3. Study Area

The study area for the investigation is Budhabalanga river basin, situated in the northern region of Odisha and the eastern section of India. Its coordinates are 87.06902º or 87 º 4'9" E longitude and latitude 21.47031° or 21°28'13"N. The drainage area's basin is around 175 km long and 4669 km^2.

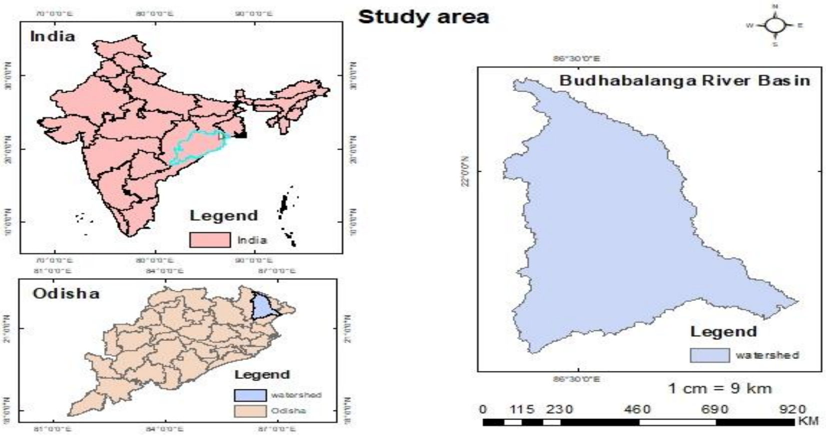


Fig. 3.1 Study map of the Budhabalanga River Basin

3.1 Topography:

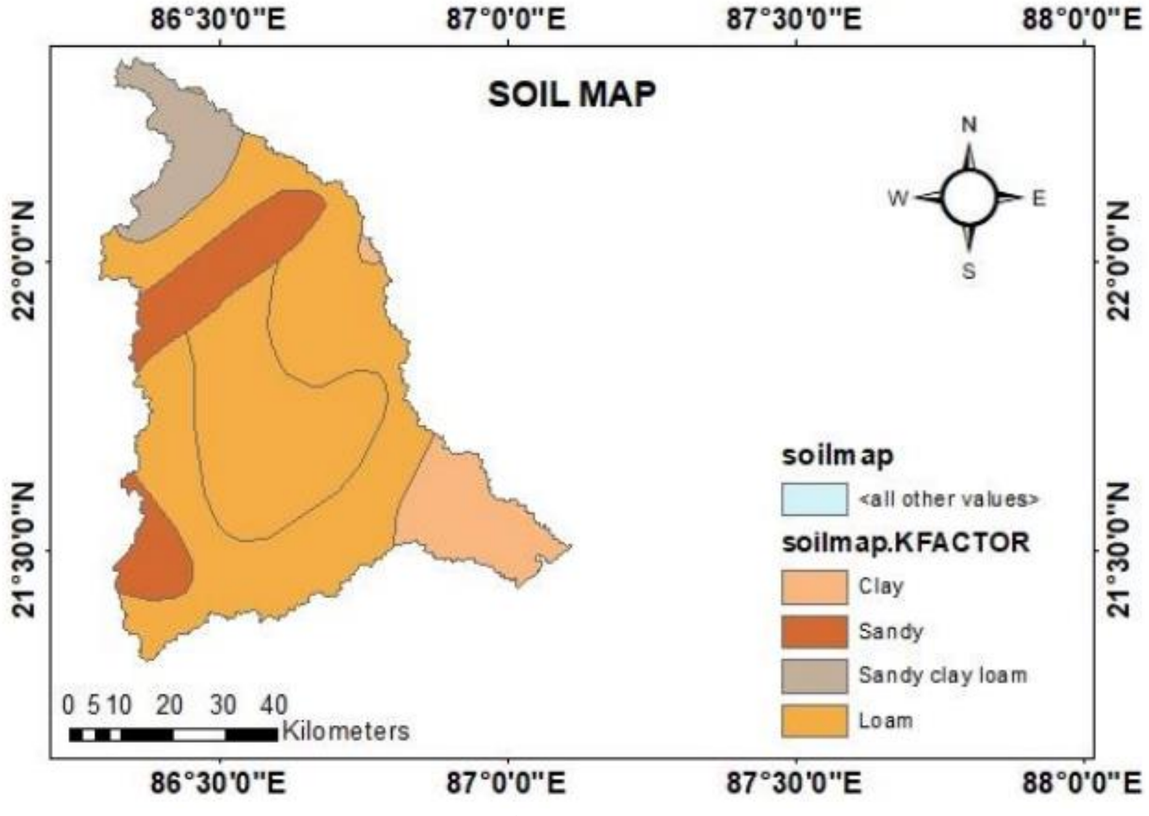
The topography of the Budhabalanga basin is identify by diverse landforms, including hills, plateaus, plains, and valleys. The River basin nears its end, it forms a deltaic region. Deltas are formed by sediment deposition and consist of fertile land and a network of distributaries.

3.2 LULC:

This basin area is covered by mainly forest land. It regarding 45% of area of the total geological area is covered with the dense forest. According to study GIS applications, Society and Environment, the area under forest cover in the Budhabalanga River Basin decreased from 54.5% in 1987 to 48.9% in 2008. The area under agricultural land increased from 21.8% to 29.7% during the same period.

3.3 Soil:

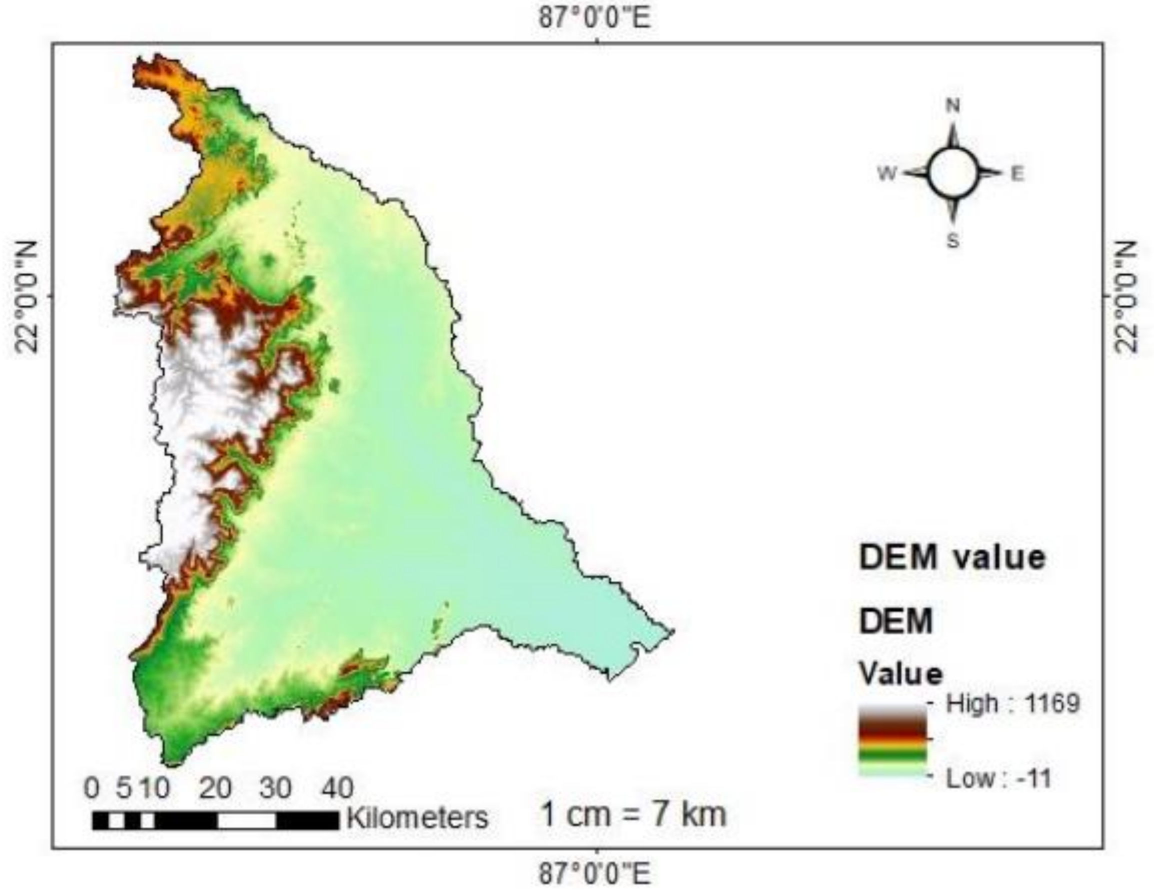
The soil category of the Budhabalanga river basin is also affected by the geology of the region. The basin is placed in the part of eastern India, and the bedrock is composed of sandstone, shale, and limestone. These rocks weather to form a variety of soils, including loamy soils, clay soils, sandy soils, and sandy clay loam soil. Figure 3.2 displays the soil map of the basin. Fig 3.2 map of soil the Budhabalanga basin area.



3.3 Soil map of Budhabalanga river basin

3.4 Digital Elevation Model:

A digital elev model can be used to categorize number of ways including Slope, soil type, land form, vegetation, LULC, etc. The graphics shows a dem of the Budhabalanga basin analyzed by the usgs. This data set was provided with the intention of mapping, erosion control, landslide assessment, climate change, and assessing the basins natural scheme evaluation of Budhabalanga 17 watershed, Odisha. The terrain of the Basin extends from -11 to 1169meters, with an average elevation of 579meters shows in figure. For the purposes of this study steepness factor and slope length components in the RUSLE model will be determining using this DEM. This digital elev models of river basin’s displays in figure 3.4.



3.4 model of elevation in digital of the Budhabalanga river basin

4. Results and discussions

RUSLE model factors have been analyzed using ArcGIS software.The average per year rate of soil loss has been calculated based on those factors.The research area's six rain gauge stations provided bimonthly precipitation data over a ten-year period (2010-2019). Six rain gauge stations are located at Baripada, Udala, Remuna, Balasore, Bangiriposi, and Katipada. Data on rainfall were accessible from 2010 to 2019 (Odisha Rainfall Monitoring System, source).

4.1 Rainfall erosivity factors (R)

Using GIS, the rainfall erosivity factor is estimated for this region based on the annual rainfall accumulation value from six gauging stations given in Table-1. The R factor is then calculated using the given equation (2) in the field calculator included in the attribute tables of the file in the Arc GIS.

$R = 79 + 0.363 * Xa$ (2)

Where, R is the erosivity factor of rainfall and Xa average per year rainfall in mm.

The variable is analyzed from different rainfall data for these six gauging station. It is observed that the R factor is maximum in Katipada station (814.40 mm/hectare/year) and lowest in Remuna rain gauge station (623.88 mm/hectare/year).

Table 4.1: Rainfall- Runoff erosivity factor

SL no.	Station Name	Year	R factors
1	Balasore	2010-2019	661.39mm/ha/yr
2	Bangiriposi	2010-2019	668.51mm/ha/yr
3	Baripada	2010-2019	812.51mm/ha/yr
4	Udala	2010-2019	707.49mm/ha/yr
5	Remuna	2010-2019	623.88mm/ha/yr
6	Katipada	2010-2019	814.40mm/ha/yr

Figure 4.1 examines the rainfall erosivity factor for the Budhabalanga river basin using Arc GIS. From light green (low rainfall erosivity) to blue (high erosivity factor), the color code is used.

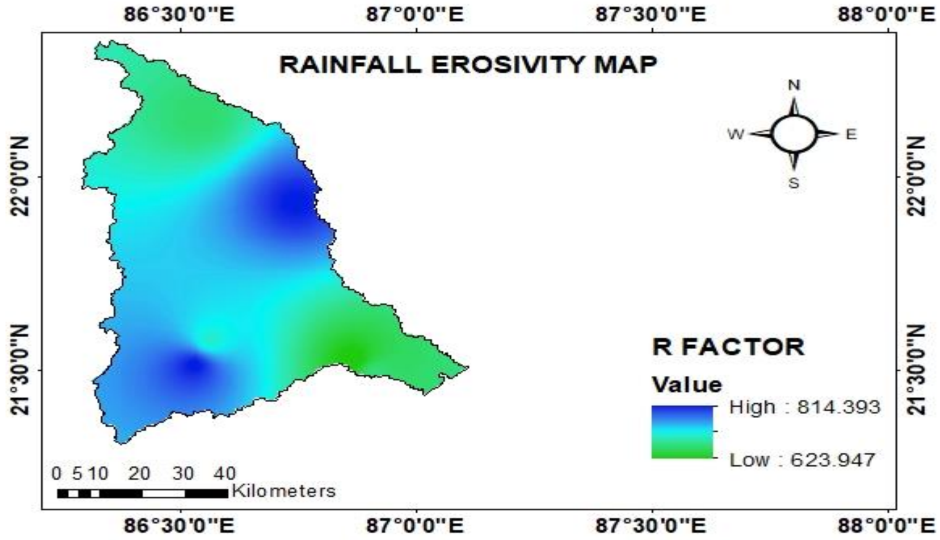


Fig. 4.1Rainfall erosivity map of Budhabalanga River Basin

4.2 Soil erodibility factor (K)

Erodibility factor deals with the overall impact of precipitation, surface runoff, and infiltration on soil loss. Figure 4.2 displays the Budhabalanga River Basin's K value data. The value of the basin is in the range of 0.017 and 0.019 mg/h/hectare/MJ/mm.

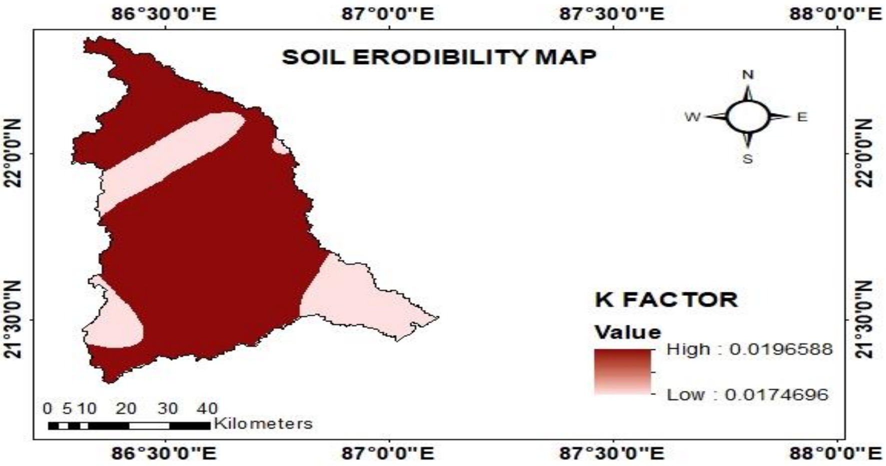


Fig. 4.2 Soil erodibility map of Budhabalanga River Basin

4.3 Slope and steepness factor (LS)

The topographic parameters slope length and slope gradient strongly influenced soil erosion. It has been observed that the rate at which soil loss increases with slope steepness as opposed to slope length. With Arc GIS, a slope and flow accumulation map are created using the SRTM DEM. The value of the variable is between 0 and 43.6088. The Budhabalanga river basin's slope length and slope steepness factor are shown in Figure 4.3.

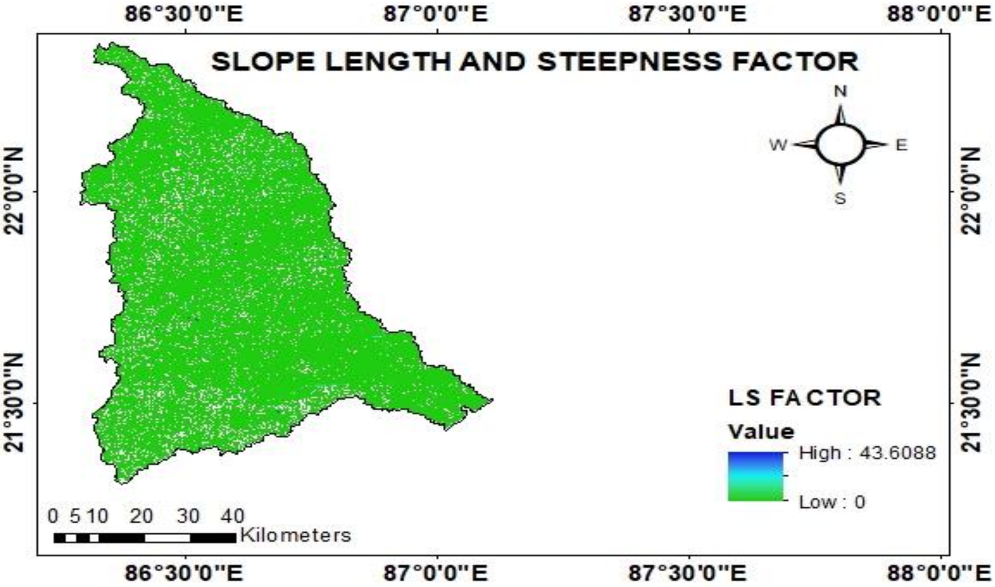


Fig. 4.3Slope and steepness factor map of Budhabalanga River Basin

4.4 Cover management factor (C)

Since soil loss occurs on field plots with variables in place over field plots without vegetation cover or practices in the vicinity, the cover management factor is dimensionless. The C factor establishes different crop varieties, plant types, and soil prevention strategies. Figure 4.4 shows the cover management factor or variable, which has a range of 0.006 to 1.

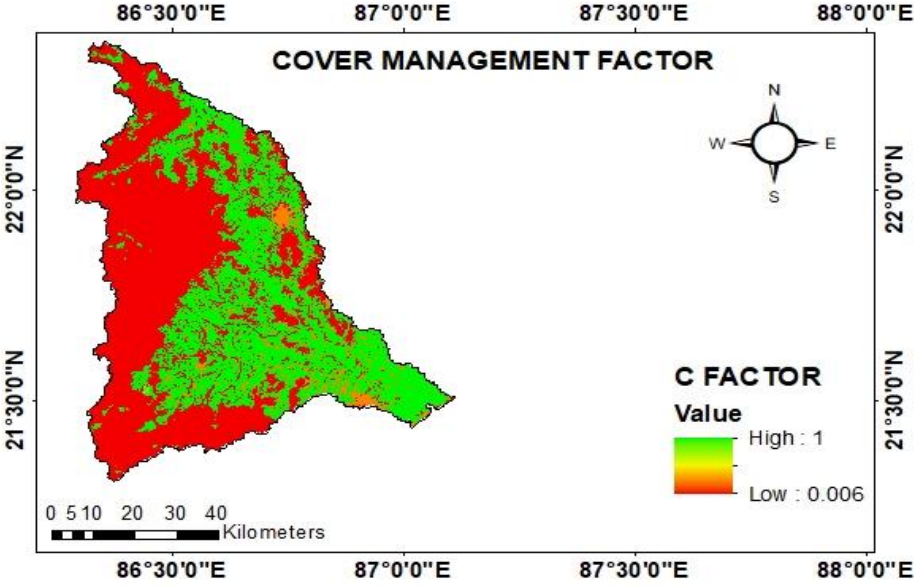


Fig. 4.4Cover management factor map of Budhabalanga River Basin

4.5 Support practice factor (P)

The range of the P factor is 0.55 to 1. The Budhabalanga River basin is depicted in figure 4.5 as the factor of support practice.

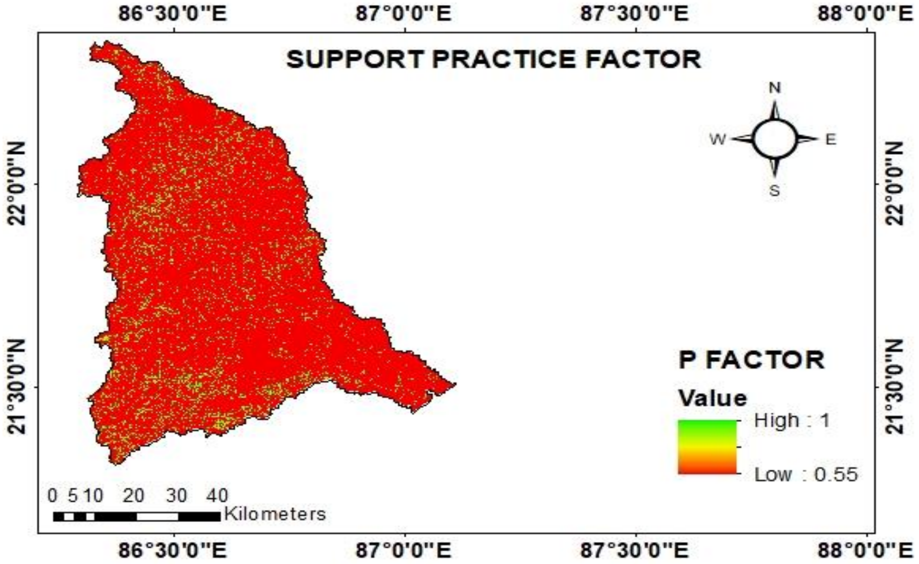


Fig. 4.5 Support practice factor map of Budhabalanga River Basin

4.6 Estimation of Yearly Average Soil Loss Rate (A)

The average per year rate of soil loss is calculated by using the RUSLE model's five different factors in ArcGIS.Figure 4.6 displays yearly average soil rates map for the river basin.

Based on observations, the annual soil loss in the basin ranges from 0 to 244.99 tons/hectare/year. In the basin's area, the average annual soil loss is 81.6926 tons/hectare. The soil loss calculation for that pixel is shown below; 30 meters by 30 meters is the pixel size. Pixel size area = 900 m^2 = 0.09 hectares Thus, the amount of soil lost annually is that pixel = 244.99 × 0.09 = 22.04 tons. The total amount of soil lost in the basin is equal to the following: basin area × mean area = 466900 hectare × 81.6926 tons/hectare/year = 5715.3229 tons/year

The yearly average soil loss rate for the Budhabalanga River Basin was obtained by multiplying the five factors mentioned above using the raster calculator tool. Based on studies, the average annual soil loss is 5715.3229 tons/year.

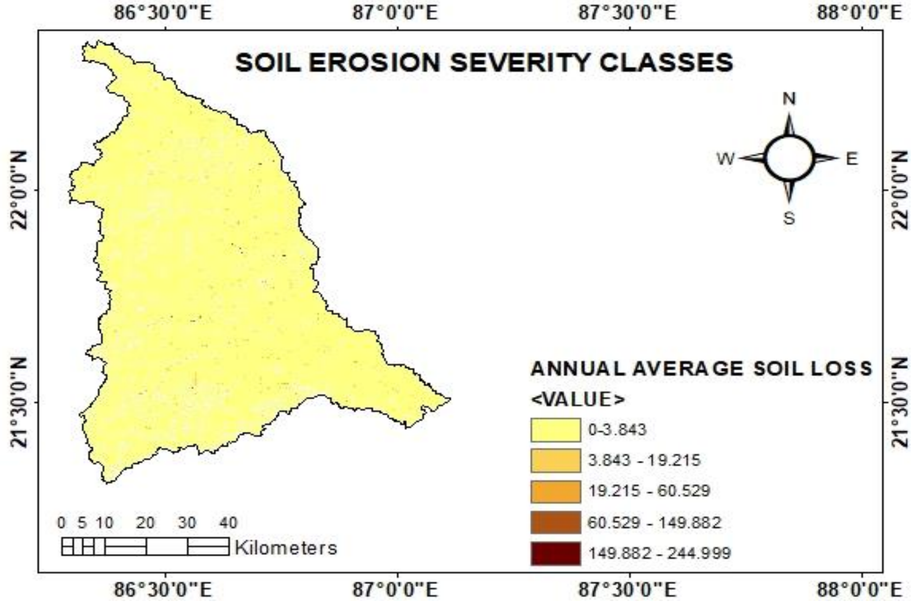


Fig. 4.6 Soil erosion severity classes map in the Budhabalanga River Basin

Table: 2 severity classes of soil loss with area and % of area

Classes of soil loss	Range (t/ha/yr)	Area (Km^2)	% of area
Low	0-3.843	2013.7	43.12
Moderate	3.843-19.215	1015.2	21.73
High	19.215-60.529	688.4	14.74
Very high	60.529-149.882	373.8	8
Severe	149.882-244.999	578.8	12.39

The majority of the study area (43%) has low soil risk, with soil loss rates between 0 and 3.843 tons/hectare/year. In contrast, 21.73% of the region has moderate erosion, with soil loss rates between 3.843 and 19.215 tons/hectare/year. Just 14.74% of the research area has high soil loss risk assessed, with soil loss occurring between 19.215 and 60.529 tons/hectare/year. With a loss of soil range of 60.529 to 149.882, 8% of the research area is deemed to have a very high risk of erosion. It is estimated that just 12.39% of the region will be severely at risk from erosion, with soil loss occurring in 149.882 and 244.999, respectively. Erosion control has been given a higher emphasis in the study regions experiencing considerable soil loss.

4 Conclusion

In this study, the dynamics of soil erosion has been presented using RUSLE model with a Geographical Information System software namely, Arc GIS.The following points illustrate the conclusions drawn from the investigation and analysis of soil erosion rates.

- A quantitative study of the average annual soil loss for a section of the Budhabalanga river basin that accounts for nearly 45% of precipitation was carried out using GIS methods, taking satellite datasets, geography and soil into account.
- Using the RUSLE method with GIS techniques, a quantitative analysis of the average annual soil loss for a segment of the Budhabalanga river basin that accounts for roughly 45% of precipitation was conducted. considering soil, terrain, and satellite datasets.
- The regionally distributed maps of the yearly average soil rate loss were produced by multiplying the raster maps of each parameter using the raster calculator in the GIS procedures.
- The Budhabalanga River Basin's annual average soil erosion rates are anticipated to range from 0 to 244.99 tons/hectare/year between 2010 and 2019. It was determined that the river basin's total annual soil loss was 5715.3229 tons.
- The primary source of soil loss in the river Basin, accounting for 39.04% of annual soil corrosion, was shrubby lands. The arid regions, which generated about 23.58% of the basin's total soil rate loss, were the secondary contributors.

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