

SPATIAL ANALYSIS OF SOIL EROSION AND CONSERVATION PRACTICES IN THE FOREST LANDSCAPES OF THE DOOARS REGION, NORTH BENGAL

Rinki Das¹, Dr. Meenu Sharma²

^{1,2} Research Scholar, Department of Environmental Science,

Mansarovar Global University, Sehore, MP

ABSTRACT

For forest ecosystems, soil erosion is a major concern, particularly in areas with very steep terrain and heavy precipitation. Soil erosion, sediment movement, and fertility loss are all exacerbated by the strong monsoon rainfall that falls on the Dooars region in North Bengal, which is close to the Eastern Himalayan foothills. This study examined four forest regions to determine the prevalence of soil erosion, the impact of topographic features, and the efficacy of water and soil conservation efforts. To examine soil erosion trends across the research sites, a quantitative geospatial method was used. This technique included field observations, remote sensing, GIS analysis, and data from the Digital Elevation Model (DEM). Soil loss varied significantly across different geographic areas, with the steep Himalayan foothill terrain of Buxa Forest Area resulting in the highest mean soil loss (48.9 t/ha/yr) and the gentle piedmont topography and dense vegetation cover of Chapramari Forest Area resulting in the lowest mean soil loss (15.4 t/ha/yr). An increase in erosion susceptibility was shown to be significantly associated with higher elevation, steeper slopes, and larger drainage density, according to topographic study. The conservation strategies that were evaluated showed that afforestation (62.1%), vegetative barriers (58.0%), contour trenching with check dams (55.4%), and natural regeneration (64.7% reduction in soil loss) were the most effective. The research shows that forest landscapes can be made more ecologically stable and soil erosion greatly reduced using vegetation-based restoration and appropriate structural conservation measures.

Keywords: Soil erosion, Topography, Conservation, Afforestation, Vegetation

I. INTRODUCTION

Depletion of rich topsoil and subsequent decrease in agricultural production is the result of soil erosion, which is a large-scale environmental problem. Both soil loss and sediment supply have become major worldwide problems in recent times, with more and more effort going into improving soil erosion models to better estimate soil loss at basin and watershed sizes. Determining the rate of erosion in a watershed may be done by measuring the amount of solid particles moving downstream over a long period of time. When there is a lack of hydrometric and discharge data for a specific watershed, one well-established and practicable solution is to use modelling techniques to determine the amount of erosion and discharge in that watershed.

Most forms of soil erosion entail carrying away the top layer of soil. Natural resources, ecosystems, and agricultural output have all been impacted by this worldwide problem for decades. Particularly in hilly regions, soil erosion is a more normal cause of soil loss. In most cases, water is the most important component in the fluvial process, while wind also plays a role in soil erosion. On a yearly basis, 5.3 billion tonnes of soil are washed away in India, with a national average of 5.9 billion tonnes. Nevertheless, soil erosion is more prevalent in the Himalayan area and the Western Ghats than in other regions of the nation. Rainfall, soil erodibility, topography, cover management, and support practices are the five key elements that produce surface water flow and surface area erosion.

The most empirical approach for predicting soil loss was created in 1954 by the Science and Education Administration of the National Runoff and Soil Loss Data Centre. It is known as the Universal Soil Loss Equation (USLE) model. Its purpose is to quantify yearly soil loss due to water erosion. Unified Soil Loss Estimation (USLE) has become the gold standard for calculating effective conservation measures and predicting average yearly soil loss. On the other hand, RUSLE, an enhanced and more varied version of USLE, was brought out in 1993 by the USDA Soil and Water Conservation Service. Although all models are identical, RUSLE incorporates improvements in iso-erodent maps, more precise computations of slope length and gradient, and superior predictions of soil cover and conservation techniques.

Research on soil loss estimate has been heavily favoured by GIS and remote sensing methods for their dependability and accuracy during the past couple decades. Most of the literature on soil erosion has focused on watersheds or river basins in India. Research on soil loss estimation in the context of states is limited. For instance, studies that take a broader view have focused on diverse states like Goa in India, which is bordered by the coast and the Western Ghats, as well as districts or similar administrative regions. In order to plan soil conservation measures in a river basin, build dams and reservoirs, etc., it is important to evaluate soil loss in a larger area or region.

Worldwide, water-induced soil erosion worsens nutrient loss and leads to land degradation. Natural disasters like floods, droughts, and landslides become more frequent as a result, in addition to degrading land and reducing soil nutrients. Although it occurs naturally, the intensity and breadth of its effects are determined by a wide range of environmental factors, such as weather, terrain, soil, vegetation, precipitation, and connections among these. But, human activities (like as farming and deforestation) often greatly speed up this process, which is called erosion that humans have induced or accelerated.

The Oued Laou watershed has a major problem with soil erosion due to surface runoff, which affects flood control, agricultural output, and waterworks infrastructure both upstream and downstream. Erosion is becoming more severe and explosive due to a number of conditions and practices, particularly in the southern and central regions. A number of factors, including hilly terrain, overgrazing, ineffective farming practices, forest fires, intentional burning, and some illogical human actions, can contribute to the deterioration of land cover and the erosion of soil. Rainy seasons increase the likelihood of runoff and water erosion because the soil is more easily altered, detached, and conveyed by the water. This, in turn, affects downstream waterworks like bridges and reservoirs, making sedimentation a problem.

Since the 1930s, scientists have been concerned in soil erosion risk assessment in order to plan for and identify erosion management strategies. For the most accurate assessment of soil erosion rate from original site, quantitative techniques are needed. There are a variety of methods that have been developed to measure soil erosion caused by water on different scales, including global, regional, and local. To put a number on the rate of soil loss, several models have been constructed. The three main types of these models are physical-process-based, semi-empirical, and empirical. The US Department of Agriculture (USDA) developed the Universal Soil Loss Equation (USLE) in 1978 to anticipate the quantity of continuously eroded material; it is the most utilised.

In 1997, Renard et al. introduced a new version of USLE called The Revised Universal Soil Loss Equation (RUSLE). Extensive research has made extensive use of it to measure the quantity of soil erosion from hillslopes in a sustainable way. Numerous scientists from throughout the globe have rendered RUSLE their services in recent years. With the help of the catchment area, some of them were able to calculate the potential soil loss due to conventional farming methods.

Along with simulating the field-wide distribution of soil loss, RUSLE also gives the option to measure the rate of soil erosion at the plot extent. Due to its simplicity, adaptability over large-scale regions, improved dependability, and cost-effectiveness, the combination of geospatial methodology with RUSLE model is an ideal solution.

II. REVIEW OF LITERATURE

Manic, Milos et al., (2022) .Hilly terrain is characterised by a steep topography and a very loose soil layer; various erosion processes can significantly affect forest management in this type of terrain. A process of erosion was seen along the unstable slopes throughout the majority of the Crveni Potok catchment located in the south-east of Serbia. The results of the study reveal the presence of two types of erosion, each with its own intensity level; moderate and mild erosion are more common, while severe erosion can be observed in certain areas. Gully erosion occurs when water pressure in the pores of loose soil forces it to move away from a parent substrate, which happens in geologically predisposed places of the Crveni Potok watershed. The factors that influence gully erosion are investigated in this study. These factors include soil density, topographic surface slope, rainfall (both the amount and its distribution), and plant features. The tools used in this study combine geospatial data with nuclear and remote sensing analysis to create a holistic picture of the factors impacting erosion in unstable forest regions. Soil erosion rates in the research region are predicted using conversion models that are based on fallout radionuclide inventories. Combining airborne photogrammetry with terrestrial Structure-from-Motion 360-degree camera photogrammetry and Terrestrial LiDAR Scanning (TLS), we simulate intricate geomorphological features of forest landscapes. The present erosion level in the forest gullies, as well as the gully systems' volume, density, breadth, and length, may be measured with these approaches. The study's physiographic characteristics, which are essential for pinpointing erosion hotspots, were uncovered by the remote sensing methods. We compare and contrast the models that each approach produces, evaluate the methods, and emphasise the pros and cons of each. This strategy enables the identification of priority objectives for soil conservation and site-specific remedial operations, which enhance sustainable forest management.

Potić, Ivan et al., (2021). Soil erosion, a problem with worldwide environmental and economic implications, is greatly affected by changes in land use. Intense human pressure has been felt in several mountain locations of Serbia as a result of the surge in winter tourism in recent decades. On Kopaonik Mountain, within the boundaries of Kopaonik National Park, there is Serbia's largest ski area, and there is growing friction between conservation and commercial goals. We quantified sedimentation and surface runoff in three sub-basins in the Kopaonik ski resort region across two years (1984 and 2018) using the Soil and Water Assessment Tool (SWOT). We next looked at the changes that had happened over the time period that was observed. Surface runoff and sediment output increased in sub-basins 1 and 3, whereas sub-basin 2 showed a decrease, according to the results. When looking at the changes in land cover, we can see that evergreen forests have grown, urban areas and barren soil have emerged, mixed forests and pastures have decreased, and deciduous woods have grown. Based on these findings, the two primary processes in the studied region are the expansion of tourism and the natural regeneration of degraded agricultural land. The application of SWOT and remote sensing techniques aids in the detection and tracking of land degradation concerns, which in turn improves management and conservation efforts.

Cimusa Kulimushi, Luc et al., (2021). The soil erosion risk assessment in South-Kivu harkens back to the colonial era, even though soil erosion has caused serious land degradation in the region. This project intends to assess soil erosion on a provincial scale by combining GIS and remote sensing data with the Revised Universal Soil Loss Equation (RUSLE). Soil erosion was projected to be 2.084 million tonnes, with an annual average of 138.2 t ha⁻¹. In addition, soil loss above 100 t ha⁻¹ yr⁻¹ constitutes 45.2% of all erosive land. Soil erosion is worsening over the whole region, with rates ranging from 87 t ha⁻¹ yr⁻¹ in Shabunda to 248 t ha⁻¹ yr⁻¹ in Uvira. Under aggressive high rainfall conditions, perennial crops, trees, and farmland experienced the greatest rate, with a mean of 1857.19 mm/y, compared to shrubs and closed forests. Reason being, whilst shrubland and closed woodland had an average slope of 17%, the previous land cover groups had a mean slope of 22%. Terracing has the potential to lessen the rate of cropland by 76%, dropping it from 162.12 t ha⁻¹ yr⁻¹ to 38 t ha⁻¹ yr⁻¹. So, it's really recommended.

Xu, Hanqiu et al., (2019). In many areas with red soil, rainwater-induced soil erosion in forests represents a distinct kind of soil erosion. In areas with red soil, such as southern China and others across the globe, identifying soil erosion is essential for developing land management strategies to reduce soil loss. To evaluate the potential for soil erosion on a large scale, remotely sensed canopy cover is often employed, albeit it is not as useful in forest environments. This article presents a case study of a forest in southern China and proposes a new remote sensing method for detecting soil erosion under the forest's canopy. Soil erosion in forests is strongly linked to five discriminators that were used to create the model. The following factors are considered: slope, bare soil index, nitrogen reflectance index, fractional vegetation coverage, and yellow leaf index. Factors such as vegetation density, vegetation health status, soil exposure intensity, and terrain steepness are quantitatively represented, and are believed to play a significant role in forest soil erosion. You can get all five of these things out of satellite images by using algorithms or linked topic indices. Soil erosion under forest model (SEUFM) was created by combining the five parts using Principal Components Analysis (PCA) or a multiplication approach. Based on a case study conducted in the forest region of Changting County in southern China using a Landsat 8 image, the first principle component-based SEUFM achieves an

overall accuracy close to 90%, while the multiplication-based model reaches 81%. Forest erosion hotspots serve as a guide for subsequent soil loss management efforts. The proposed method provides a means of understanding soil erosion, even in wooded regions where it is not usually considered an issue. Soil preservation in forests benefits from the method.

Gunawan, Gusta et al., (2013). In Indonesia's Bengkulu Province, soil erosion is a major concern for the ecosystem in the Manjuntio watershed. The ecological system and the financial system are both impacted. Assessment of the potential rate of soil erosion is important for establishing solutions for soil conservation within the framework of integrated watershed management. Using information gathered via Remote Sensing (RS) and the Geographic Information System (GIS) framework, decision-makers may save time and money while producing more precise spatial maps. For every soil mapping unit in the Manjuntio watershed, this study aims to calculate the average annual rate of potential soil erosion using remote sensing data, particularly the Normalised Difference Vegetation Index (NDVI) and Slope. The NDVI value was obtained by processing satellite data, while the slope value was obtained from processing the Digital Elevation Model-Shuttle Radar Topographic Mission (DEM-SRTM). The results showed that the area of the catchment area that was degraded increased significantly. In the Manjuntio watershed, the potential soil erosion rate rose sharply from 3.00 metric tonnes per hectare per year in 2000 to 27.03 metric tonnes per ha in 2009. Units 41–47 of the soil mapping project are under an extremely high risk of erosion. Soil mapping units 41–47 should be prioritised before water and soil conservation initiatives are launched.

Huang, Jianqin et al., (2012). Soil loss estimation using the Revised Universal Soil Loss Equation (RUSLE) has been a hot subject for a long time, but using it across a large region is challenging due to data availability and quality issues. This study used the RUSLE model to evaluate the potential for soil erosion based on soil samples, a soil type map, DEM data, and Landsat Thematic Mapper (TM) images. Using multiple regression analysis, we were able to identify the primary factors that determine the soil erosion dangers. A regression model was developed using differential elevation modelling (DEM) data and terrain mapping (TM) pictures of fractional soil and vegetation to map the distribution of soil erosion risk in a forest ecosystem in Zhejiang, China. Using the proposed approach, one can quickly examine the geographical distribution of soil erosion hazards. By integrating GIS and remote sensing, this work provides a new way to evaluate the risks of soil erosion in forest ecosystems.

III. RESEARCH METHODOLOGY

Study Area

Four forest landscapes in North Bengal, India's Dooars region—the Gorumara Forest Area (Jalpaiguri District), the Jaldapara Forest Area (Alipurduar District), the Buxa Forest Area (Alipurduar District), and the Chapramari Forest Area (Jalpaiguri District)—were used for the current study.

Research Design

The study adopted a quantitative geospatial research design.

Data Collection

The study used both primary and secondary sources of information. Soil erosion characteristics, plant state, land degradation, and current conservation efforts were among the primary data points gathered by field surveys, with sample sites' geographic coordinates recorded using a portable GPS. Various secondary sources of information were consulted, including satellite imagery from Landsat-8 and Sentinel-2, a 30 m SRTM Digital Elevation Model (DEM), rainfall records from the India Meteorological Department (IMD), soil data from the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), forest cover data from the Forest Survey of India (FSI), and administrative boundary maps from the Survey of India (SOI).

Image Processing and GIS Analysis

Geometric correction, mosaicking, and clipping to the research region were applied to satellite pictures. Using supervised classification algorithms, land-use and forest-cover maps were created. We derived the elevation, slope, and drainage features using a Digital Elevation Model (DEM). In order to compare environmental features across the four forest locations, spatial analyses were performed using ArcGIS and QGIS software. Thematic layers were generated during these studies.

Statistical Analysis

To compare the four forest sites and understand the spatial variability of soil erosion and the success of conservation efforts throughout the Dooars forest landscapes, descriptive statistics were used. These approaches include minimum, maximum, mean, standard deviation, and percentage decrease.

IV. RESULTS AND DISCUSSION**Table 1. Site-wise Soil Erosion Characteristics in the Forest Areas of the Dooars Region**

Forest Site	Area (sq. km)	Minimum Soil Loss (t/ha/yr)	Maximum Soil Loss (t/ha/yr)	Mean Soil Loss (t/ha/yr)	Standard Deviation
Gorumara Forest Area	212.6	0.4	76.8	18.6	12.3
Jaldapara Forest Area	248.9	0.6	98.4	24.8	15.7
Buxa Forest Area	760.5	1.8	382.4	48.9	38.5
Chapramari Forest Area	119.5	0.3	64.7	15.4	10.1

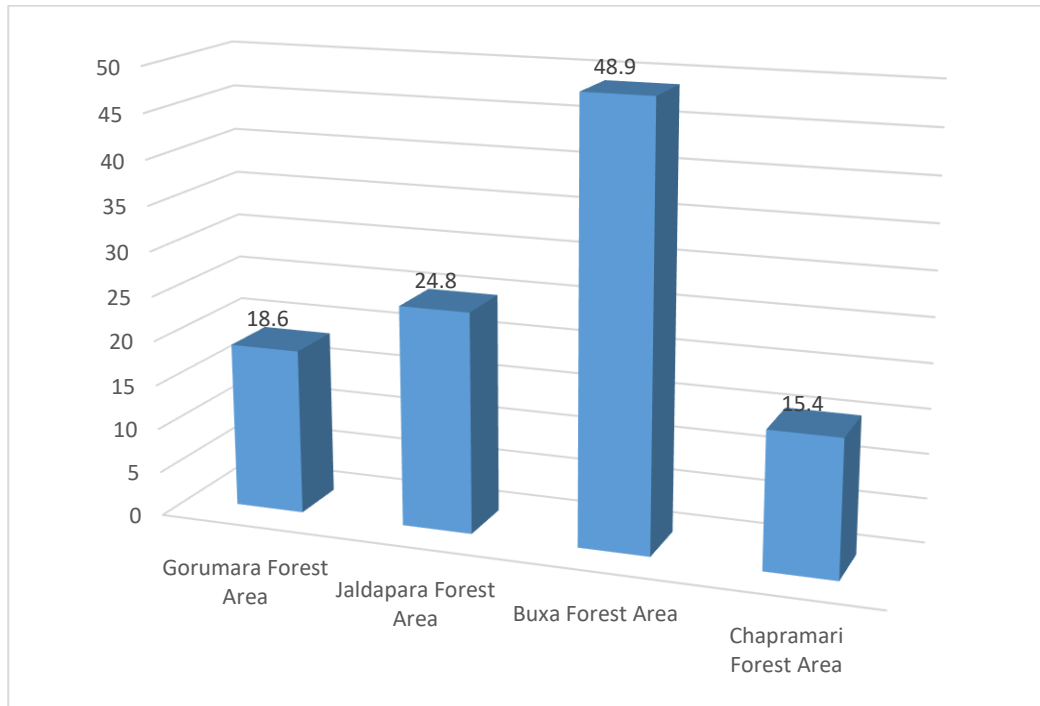


Figure 1. Site-wise Soil Erosion Characteristics in the Forest Areas of the Dooars Region

There was a lot of geographical variance across the four research locations when it came to evaluating soil erosion in the Dooars region's forest landscapes. Soil loss rates varied greatly throughout the terrain, with the greatest average (48.9 t/ha/yr) and standard deviation (38.5) measured in the Buxa Forest Area. Erosion intensity estimates ranged from 1.8 to 382.4 t/ha/yr. Because of the excessive rainfall, steep slopes, rough Himalayan foothill terrain, and patches of deteriorated vegetation, which hasten runoff and soil detachment, this is the case.

Soil erosion and seasonal floods are common in the riverine plains, meadows, and agricultural margins of the Jaldapara Forest Area, which contribute to the moderate mean soil loss of 24.8 t/ha/yr (0.6-98.4 t/ha/yr; SD = 15.7). The Gorumara Forest Area has a much reduced average soil loss rate of 18.6 t/ha/yr, with a standard deviation of 12.3, suggesting that the deep Sal forest cover and relatively moderate slope work together to effectively prevent soil erosion. The Chapramari Forest Area had the least soil loss (15.4 t/ha/yr) and the smallest standard deviation (10.1) of all the research sites, indicating more stable environmental conditions and effective natural plant cover. The values of the other sites ranged from 0.3 to 64.7 t/ha/yr.

Table 2. Topographic Characteristics of the Four Forest Sites

Forest Site	Mean Elevation (m)	Mean Slope (°)	Drainage Density (km/km ²)	Terrain Characteristics
Gorumara Forest Area	95	6.8	2.18	Gently undulating alluvial plains

Jaldapara Forest Area	112	8.4	2.56	Flood plains with river terraces
Buxa Forest Area	485	24.6	3.84	Steep Himalayan foothills
Chapramari Forest Area	128	7.2	2.31	Piedmont plains with gentle slopes

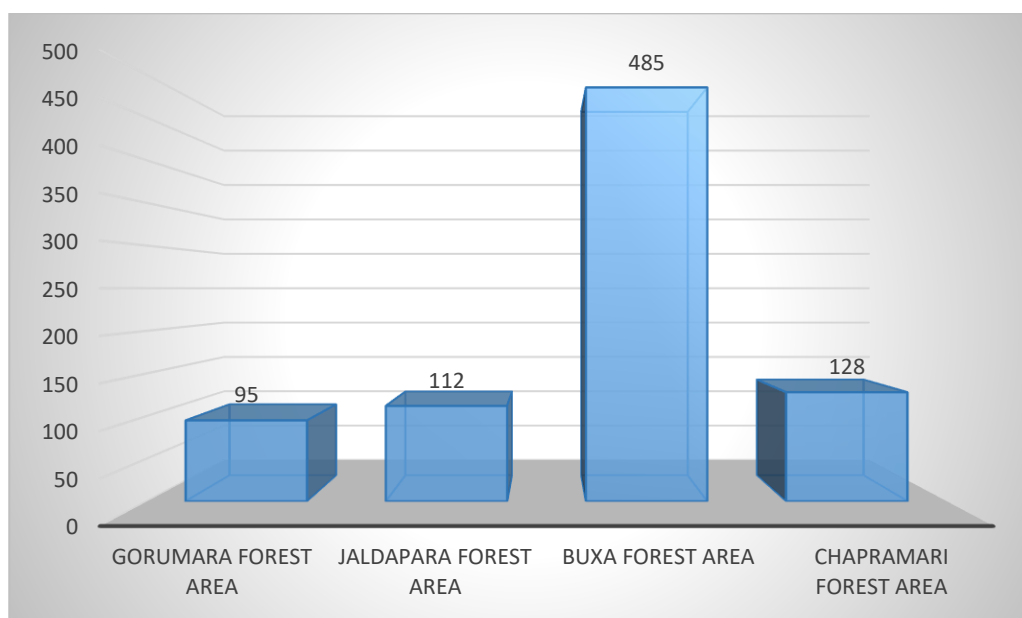


Figure 2: Mean Elevation of the Four Forest Sites

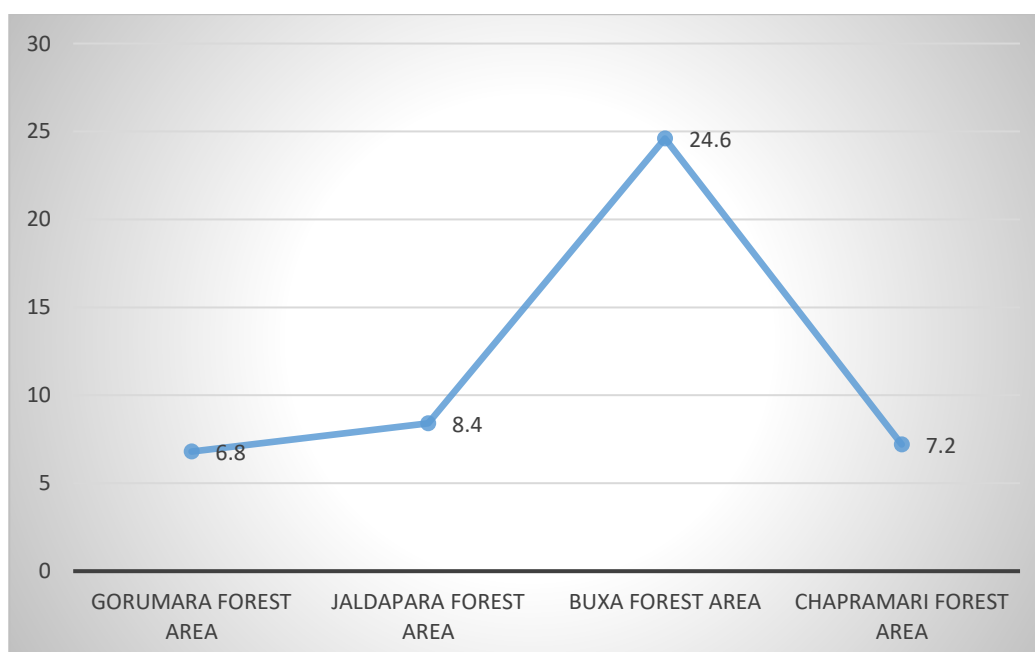


Figure 3: Mean Slope of the Four Forest Sites

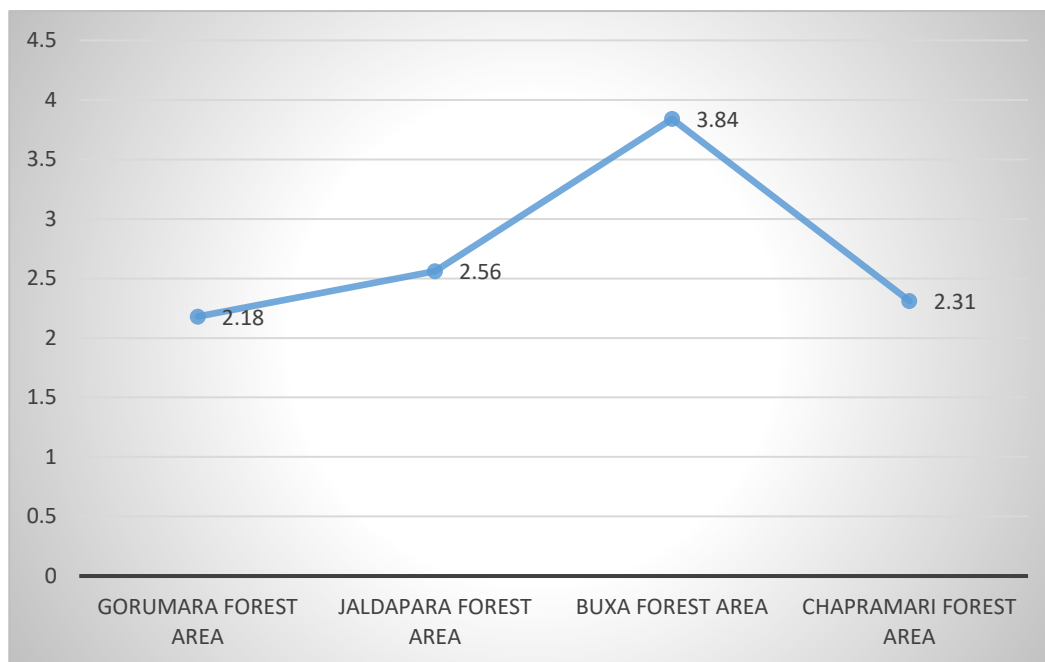


Figure 4: Drainage Density of the Four Forest Sites

The four forest sites' topographies, as shown in Table 2, have a significant impact on runoff production and soil erosion. With an average slope of 24.6 degrees, the highest mean elevation (485 meters), and the highest drainage density (3.84 km/km²), Buxa Forest Area stood out. Seasonal floods and channel erosion were challenges in the Jaldapara Forest Area due to its flood plains and river terraces, which had a moderate average slope (8.4°) and drainage density (2.56 km/km²). The Chapramari Forest Area and the Gorumara Forest Area both have lower drainage densities and relatively mild slopes of 7.2° and 6.8°, respectively.

Table 3. Effectiveness of Soil and Water Conservation Measures in the Forest Sites

Forest Site	Conservation Measure	Soil Loss Before (t/ha/yr)	Soil Loss After (t/ha/yr)	Reduction (%)
Gorumara	Afforestation	42.8	16.2	62.1
Jaldapara	Vegetative Barriers	56.4	23.7	58.0
Buxa	Contour Trenching & Check Dams	82.6	36.8	55.4
Chapramari	Natural Regeneration	48.5	17.1	64.7

Table 3 indicates that all implemented soil and water conservation strategies significantly decreased soil erosion in the four forest locations. The Chapramari Forest Area exhibited the most significant

decline, with natural regeneration decreasing soil erosion from 48.5 to 17.1 t/ha/yr (64.7%). The Gorumara Forest Area subsequently saw afforestation that decreased soil erosion from 42.8 to 16.2 t/ha/yr (62.1%). Soil loss in the Buxa Forest Area decreased from 82.6 to 36.8 t/ha/yr (55.4%), while in the Jaldapara Forest Area it decreased from 56.4 to 23.7 t/ha/yr (58.0%) thanks to vegetative barriers and contour trenching.

V. CONCLUSION

The results indicated that the Buxa Forest Area was the most susceptible to erosion due to its steep Himalayan foothills, elevated altitude, and increased drainage density, while the Chapramari Forest Area exhibited the least soil erosion owing to its mild gradients and thick forest canopy. Gorumara and Jaldapara demonstrated moderate soil erosion, indicative of the interplay between terrain, vegetation, and hydrological factors. The research also validated that both biological and structural techniques for soil and water conservation significantly decreased soil erosion, with natural regeneration and afforestation exhibiting the greatest efficacy, followed by vegetative barriers, contour trenching, and check dams. These conservation methods played a crucial role in enhancing soil stability, minimising surface runoff, and safeguarding forest ecosystems from further deterioration. The research indicates that successful soil preservation in forested areas relies on the amalgamation of scientific land stewardship, ecosystem rehabilitation, and tailored conservation approaches. Preserving thick vegetation, rehabilitating damaged forest regions, and using suitable engineering strategies are crucial for reducing soil erosion and ensuring watershed vitality.

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