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Seasonal Assessment of Soil and Water Conservation in Forest Ecosystems of The Dooars Region of North Bengal

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ABSTRACT

Strategies for soil and water conservation (SWC) are vital for the rehabilitation of damaged forest ecosystems by increasing quality of the soil, promoting moisture retention and lowering land degradation. The present study assessed seasonal variations in soil and vegetation characteristics associated with soil and water conservation across four forest ecosystems of the Dooars region of North Bengal, namely Gorumara, Jaldapara, Buxa, and Chapramari. Field investigations were conducted during the pre-monsoon, monsoon, and post-monsoon seasons of 2025. Soil moisture content, soil pH, soil organic matter, soil organic carbon, and vegetation cover were measured using standard field and laboratory techniques. The data were analyzed using descriptive statistics, Two-Way ANOVA, Tukey's HSD test, and Pearson's correlation coefficient. The results showed significant seasonal and spatial variations in all selected parameters, with the highest soil moisture, organic matter, organic carbon, and vegetation cover recorded during the monsoon season.

Keywords: *Soil Moisture, Organic Matter, Carbon, Vegetation Cover, Seasonal Variation.*

I. INTRODUCTION

For economic growth and development, food production, energy production, and other essentials, the efficient management of soil is crucial. Some serious outcomes of land degradation include environmental risks, ongoing food shortages, economic losses, poverty, and migration. Half of Ethiopia's highlands have already been significantly eroded, leading to a 2.2% decrease in land production every year, as stated in a report. There is no way for the agricultural production system in the highlands of Ethiopia to sustain a year-round vegetative cover given the current social, economic, and ecological circumstances. Soil conservation techniques have been shown to be an essential component of the system in the fight against erosion, especially during key seasons.

People living in poverty are more susceptible to the effects of climate change because tropical soils are steep, erodible, and frequently weak, and these factors are typically poorly managed. It may also contribute to the depletion of soil fertility and vegetation, making climate-induced shocks more

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devastating. Because of this, agroforestry systems, terracing, micro-dam construction, tree planting, and financing have all become very popular and resource-intensive. To combat soil erosion, improve soil moisture, and expand plant cover, the World Bank has spent more than US$10 billion on sustainable land management (SLM) projects in Africa since 2006.

In degraded regions, soil and water conservation is taking measures to limit or avoid soil erosion, compaction, salinity, and water drainage in order to preserve or enhance the land's productive potential, which includes soil, water, and plants.By lowering rates of environmental deterioration and raising agricultural yields, soil and water conservation contributes to the security of people's livelihoods over the long run.

The loss of essential plant nutrients, floods downstream, and sedimentation of reservoirs were all consequences of water-induced soil erosion, which in turn endangered the nation's food supply. First and foremost, we must implement physical soil and water conservation measures. These measures will mainly function as barriers, preventing surface runoff and altering the landscape's interlope gradient through sediment accumulation and moisture storage.

In order to conserve soil and water, physical measures are constructed according to certain principles. These principles include: extending the duration of concentration runoff so that more of it can percolate into the soil; decreasing the quantity and speed of surface runoff by breaking a long slope into multiple shorter ones; decreasing the rate of surface runoff; and safeguarding the environment from harm that excessive runoff can cause. The protective effects of biological measures are enhanced by a higher vegetative cover, which serves to decrease the speed of surface runoff, prevent splash erosion, and aid in the accumulation of soil particles; an increase in surface roughness decreases runoff and increases infiltration; and so on. The presence of organic materials and roots stabilises soil aggregates and enhances infiltration.

II. REVIEW OF LITERATURE

Nyirahabimana, Hyacinthe et al., (2024). Soil overexploitation and subsequent land degradation have resulted from the pressing need to feed a rapidly expanding human population. Crop yields are increased and soil erosion rates are decreased by the implementation of SWCPs. Nevertheless, many nations, particularly in Sub-Saharan Africa, still have poor SWCP implementation rates. Not only that, but not even the farmers that do implement these techniques promptly. Research on the effects of the SWCP adoption lag on agricultural yields is scant. For this study, 506 families from five districts in the Sio-Malaba-Malakisi Basin, which is bordered by Kenya and Uganda, were selected using Generalised Propensity Score Matching to investigate the influence of the adoption lag of SWCPs on agricultural yield. The results show that farmers' agricultural yield decreases as the time it takes to adapt increases, and the problem gets more worse over time. In Kenya, the influence on agricultural output is more pronounced in the short run and less in the long run due to the adoption lag of SWCPs, but in Uganda, the inverse is true. For SWCP assistance programmes to be as effective as possible, they must stress the significance of early adoption and correct maintenance of water and soil conservation buildings.

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Hu, Yi. (2022). It is well-known that soil erosion from crops is a significant issue with agricultural output. One of the several conservation strategies that have been developed to decrease soil erosion is conservation tillage. At the same time, reports indicate that conservation tillage has other advantages beyond only reducing soil loss. Soil organic matter, water quality, erosion and runoff, and certain physical and physical soil qualities are the focus of this work's concise analysis of the impact of conservation tillage. As a result of variations in soil texture and the pace of crop residue retention, conservation tillage produces varying impacts on surface runoff and soil loss. The literature is replete with accounts of elevated soil organic carbon (SOC), with the majority of these accounts focusing on areas close to the soil's surface. While SOC is more resistant in subsurface, it is more pliable in topsoil when subjected to conservation tillage. Soil physical qualities, including hydraulic conductivity, infiltration, bulk density, and water retention capacity, are enhanced when SOC levels are higher. By decreasing the amount of total silt, nitrate, ammonium, and phosphate in the runoff, conservation tillage has the potential to enhance water quality. Nevertheless, because conservation tillage increases the soil's macropores, it may also make nitrate leaching easier.

Ahuchaogu, Ifechukwude et al., (2022). One of the cornerstones of environmental development is the protection and sustainable use of water and soil resources. Because of its effects on ecosystems, agricultural yields, food safety nets, and human well-being, soil erosion was a major problem all over the world in the twentieth century and is still a major problem now. Soil conservation techniques and methodologies, as well as their applications, are covered extensively in this study. This allows for the identification of the most promising soil conservation solutions, which in turn enhance soil resource management. The overarching goals of this review are to (1) identify key aspects of water and soil loss, (2) investigate the connection between water and soil conservation and sustainable development, and (3) offer practical strategies for reducing water and soil loss. This review's findings demonstrate that efforts aimed to reduce water and soil runoff by tree planting, mulching, multiple cropping, fallowing, and ridging, as well as by building earth bunds and terraces. Technologies such as conservation tillage, crop management, and mulching are well-suited for preserving sandy soils that are very erodible and have a poor ability to retain water. Rainfall is lessened by the use of legume cover crops and the management of residue. In addition to increasing nutrient and organic matter levels, these practices reportedly increased nitrogen levels, which are typically low in tropical soils. For optimal nutrient recycling and weed suppression, try intercropping compatible species. This planting strategy takes use of cultural differences in rooting patterns and growth cycles.

Ahuchaogu, Ifechukwude et al, (2022). Environmental development must adhere to some fundamental principles, one of which is the sustainable use of water and soil resources. Since soil degradation impacts agronomic output, food security, quality of life, and the environment, it was a major worldwide problem in the twentieth century and is still a major concern in the twenty-first. A comprehensive overview of soil conservation techniques, methodologies, and their applications is presented in this paper. This is used to determine which soil conservation methods have the highest potential to enhance soil resource management and conservation. We hope that at the end of this review, you will have a better understanding of what soil and water loss are, how they relate to sustainable development, and what approaches work best to prevent their loss. This research reveals

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that efforts were made to save water and soil by means of ridging, building earth bunds and terraces, mulching, growing numerous crops at once, fallowing, and planting trees. To preserve sandy soils that are very erodible and have a poor ability to retain water, the best strategies to use are conservation tillage, crop management, and mulching. Manage your leftovers and plant legume cover crops to lessen the effect of precipitation. Soil organic matter and nutrient levels were also shown to increase as a result of these practices, particularly nitrogen levels, which are often low in tropical soils. Cultures with diverse rooting patterns and development cycles can encourage nutrient recycling and reduce weeds, making intercropping of compatible species a potential cropping strategy.

Tanto, Tesfaye & Laekemariam, Fanuel. (2019). The main problems in Ethiopia that have a harmful effect on soil fertility and agricultural yields are nutrient depletion and soil erosion. The goal of implementing soil and water conservation (SWC) methods is to reduce land degradation concerns. The purpose of this study was to examine the impact of SWC methods on soil quality and agricultural yields in the Bashe micro-watershed in the Wolaita Zone in southern Ethiopia. The five practices that were analysed were non-conserved land, physical SWC (2 and 5 years old), physical SWC combined with biological practices (2 and 5 years old), and physical SWC without any conservation efforts at all. Over the course of five years, the soil's bulk density was lowered by integrated SWC. In comparison to non-conserved land, the soil's pH rose from 5.87 to 6.60, organic carbon from 1.34 to 1.74 percent, and accessible phosphorous from 8.06 to 25.23 mg kg^{-1} by 12%, 30%, and 203%, respectively. Also, according to agronomic data, SWC procedures greatly improved wheat plant height, tiller formation, spike length, thousand seed weight, biomass, and grain production ($p < 0.05$). Grain yield was 72.8% higher in the five-year SWC-integrated group compared to the control group. It has been determined that SWC techniques can improve soil and crop production on farmed land. The impact is much greater when physical and biological SWC measures are combined and when the procedures are established over a longer period of time.

Salifu, Eliasu et al., (2019). The majority of Ghana's farmers in the country's northern region are subsistence farmers. Poor agronomic methods cause soil degradation and unpredictable rains, which they constantly have to deal with. In places where there is a lack of moisture and the topsoil is important, interventions can be put in place to reduce soil loss and retain soil moisture using Soil and Water Conservation (SWC) approaches. An on-farm experiment was carried out in the Region during the 2014 cropping season to evaluate the impact of four SWC techniques on root zone soil moisture content, growth components, and maize yield: Contour Farming (CF), Half Moon (HM), Contour Ridges (CR), and Flat Land (FL). With a p-value of 0.00181, the SWC approaches significantly affected soil moisture in the maize root zone. With an average volumetric soil moisture of 18.4%, the CF retained the most amount of soil moisture at the root zone. The CR came in at 18.1%, the HM at 17.8%, and the FL at 16.8%, in that order. Grain yield ($P = 0.00578$), root biomass ($P = 0.035$), maize stem ($P = 0.0174$), and maize height ($P = 0.0112$) were all significantly impacted by the SWC approaches. Among the approaches evaluated for SWC in the Northern Region of Ghana, CF is indicated as the best choice due to its better soil moisture retention and yield.

Ademe, Yonas et al., (2017). The most significant obstacle that is negatively impacting Ethiopia's agricultural output is the acceleration of soil erosion. In the 1970s and 1980s, people began working towards the aim of soil and water conservation (SWC) in an effort to reduce soil erosion and increase agricultural yield. Nevertheless, there has been a dearth of research on how SWC methods might really improve soil qualities. Soil organic carbon (SOC), cation exchange capacity (CEC), total nitrogen (TN), exchangeable potassium (K+), accessible phosphorus (P), pH, and percentages of sand, silt, and clay were all measured. The study examined 36 soil samples collected from three different landscape positions (upper slope, middle slope, and bottom) in two different sub watersheds (SWs) that had or did not have SWC practices: Elmo without, Elmo with, Hobene without, and Hobene with. There was no significant relationship ($p < 0.05$) between the sand and silt percentages and SWC techniques. The landscape position had a substantial impact on P, SOC, %silt, and CEC. According to the research, SWC methods can significantly enhance soil qualities. In order to maximise the development of soil qualities, it is crucial to consistently raise awareness about the need of technically efficient implementation and effective maintenance of SWC activities.

Zougmoré, R. et al., (2004). Sub-Saharan soil degradation, nitrogen imbalance, and insufficient water make for typically unproductive soil. Soil water balance, sorghum performance, and water usage efficiency were the subjects of an experiment carried out in Burkina's northern sudanian climatic zone to investigate the impact of integrated local water and nutrient management strategies. In the experiment, which took place on Ferric Lixisol with a 1.5% slope, there were two sets of nine treatments. One set included soil and water conservation (SWC) measures like stone rows and grass strips, while the other set included organic or mineral N-inputs like compost, manure, and urea-N. A control group did not receive either N-input or SWC measure. In the sorghum-rooting zone (0-80 cm), composting with stone rows or grass strips and in years with evenly distributed rainfall enhanced soil water storage the greatest. Soil water storage was lower in the organic treatments compared to the mineral treatments during a wet season that was unpredictable. More so than nutrient additions, composting improved soil drainage and evapotranspiration. In addition, compared to grass strips, stone rows improved evapotranspiration and drainage. When compared to treatments without barriers, the two permeable barriers significantly affected soil water storage. We observed that in the rain-fed cropping system that was investigated, stone rows or grass strips mixed with compost decreased runoff, improved soil water storage, and sorghum biomass production, even during a wet season that was unpredictable and had numerous episodes of water stress. By working together, these methods improved the soil's water quality, which in turn met the growing needs of the sorghum. Based on our findings, water usage efficiency was enhanced by combining water-harvesting technologies with the provision of organic or mineral resources. Sahelian rain-fed agriculture might benefit from a more efficient use of water (less runoff and drainage losses) and higher yields from the right mix of organic resources and fertilizers.

III. RESEARCH METHODOLOGY

Research Design

The present study adopted a quantitative field-based observational research design.

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Study Area

The study's four primary forest habitats were situated in India's North Bengal's Dooars area. Four of these forest areas were located in the Jalpaiguri District and Alipurduar District: Gorumara, Chapramari, Jaldapara and Buxa,

Measurement Periods

Different climatic conditions in the Dooars region were represented by three separate seasonal periods of field observations and laboratory investigations.

- **Measurement Period 1 (M1): Pre-Monsoon (March–May 2025)** symbolised very arid climate conditions marked by poor soil moisture, stunted plant development, and little water supply.
- **Measurement Period 2 (M2): Monsoon (June–September 2025)** During the wet season marked by heavy downpours, saturated soil, quick greening, more litter, and better recharging of underground water sources.
- **Measurement Period 3 (M3): Post-Monsoon (October–December 2025)** depicted the scene after the rains had subsided, when the soil had stayed somewhat moist and the plants and soil had taken on the characteristics of the monsoon season.

Soil Sampling Procedure

Soil specimens were extracted from the upper 15 cm of the soil profile, the biologically active stratum where nutrient cycling and organic matter development are most pronounced. Following the careful removal of any superficial detritus that may jeopardise the soil's stability, samples were extracted via a hand auger. Soil specimens were gathered from every plot and stored in designated plastic bags prior to being sent to the laboratory for further analysis.

Soil samples were methodically prepared for laboratory investigation by allowing them to air-dry at ambient temperature, gently crushing them, and then passing them through a 2 mm screen to collect any leftover stones, roots, or other organic material. Once the samples were generated, the selected soil quality metrics were assessed using them.

Measurement of Soil and Vegetation Parameters

Five indicators of soil and water conservation were evaluated at each study site during every measurement period.

- **Soil Moisture Content (%)** was determined using the oven-drying method by drying fresh soil samples at 105°C for 24 hours and calculating moisture loss.
- **Soil pH** was measured using a calibrated digital pH meter in a 1:2.5 soil-to-water suspension.
- **Soil Organic Carbon (%)** was estimated using the Walkley and Black wet oxidation method.
- **Soil Organic Matter (%)** was calculated from soil organic carbon values using the standard conversion factor of 1.724.
- **Vegetation Cover (%)** used the quadrat visual estimate method to determine the proportion of ground covered by vegetation within each sampling plot.

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Statistical Analysis

The collected data were examined with the help of IBM SPSS Statistics Version 29.0. Descriptive statistics were used to summarise the chosen soil and vegetation characteristics, including the mean ± SD. We used a two-way analysis of variance (ANOVA) to look at the correlations between the forest ecosystems, measurement time, and soil organic matter, pH, moisture content, and plant cover. Pairwise comparisons that revealed statistically significant differences were followed up with Tukey's HSD post hoc test. To find relationships between the evaluated variables, we used Pearson's correlation coefficient (r). If the p-value was less than 0.05, we considered it statistically significant; if it was less than 0.01 or considerably different, we considered it very significant.

IV. RESULTS AND DISCUSSION

Table 1: Mean (±SD) Values of Selected Soil and Vegetation Parameters During Different Measurement Periods

Measurement Period	Soil Moisture (%)	Soil pH	Soil Organic Matter (%)	Soil Organic Carbon (%)	Vegetation Cover (%)
M1 (Pre-Monsoon)	18.72 ± 2.14	6.42 ± 0.18	3.21 ± 0.41	1.86 ± 0.24	74.63 ± 4.82
M2 (Monsoon)	31.84 ± 2.87	6.21 ± 0.15	4.38 ± 0.46	2.54 ± 0.28	89.47 ± 3.76
M3 (Post-Monsoon)	27.43 ± 2.52	6.29 ± 0.17	4.02 ± 0.44	2.31 ± 0.26	84.58 ± 4.11
F-value	86.52	9.84	37.68	34.55	72.91
P-value	<0.001**	0.002**	<0.001**	<0.001**	<0.001**

**** Significant at p < 0.01**

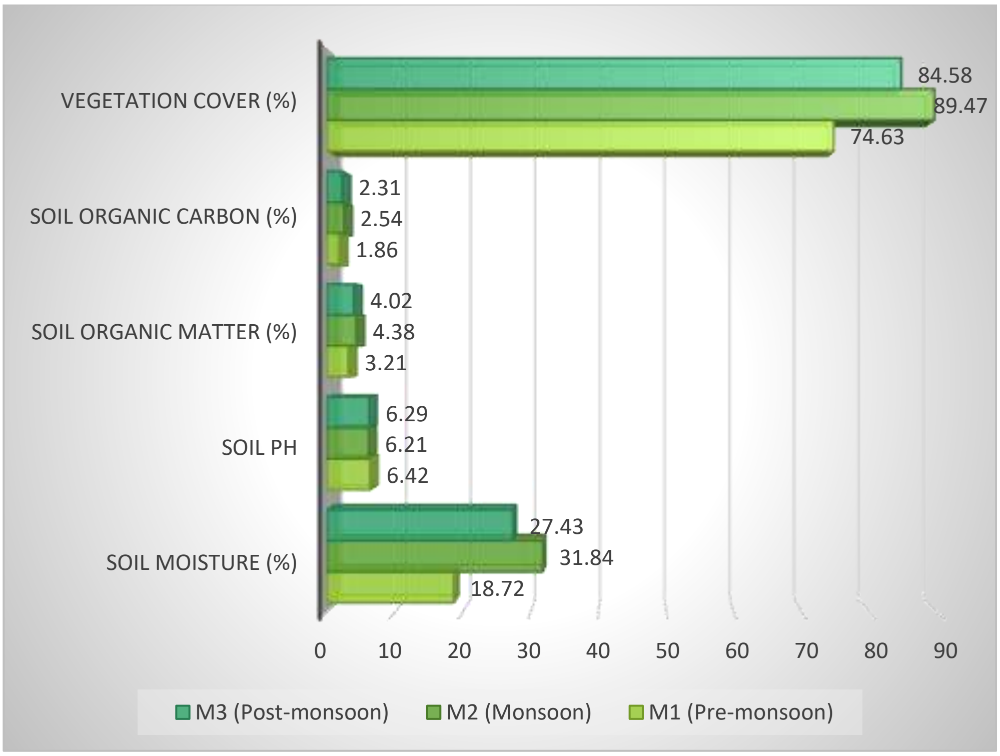

Figure 1: Seasonal Variation of Selected Soil and Vegetation Parameters

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Table 1 shows that all soil and vegetation variables tested across the four forest ecosystems show considerable seasonal change. Heavy rainfall and improved infiltration caused a dramatic rise in soil moisture content from 18.72% before the monsoons to 31.84% during the monsoons. The moisture content stayed reasonably high at 27.43% after the rain ended. According to statistical analysis, there was a substantial seasonal fluctuation ($p < 0.001$). The pH of the soil varied slightly from season to season, from 6.21 to 6.42. During the monsoon season, the pH dropped to its lowest point, perhaps as a result of the accelerated breakdown of organic materials and the leaching of basic cations caused by the heavy rainfall. Statistical significance was maintained despite the slight fluctuation ($p = 0.002$).

As a result of higher rates of litter deposition, microbial activity, and moisture availability, soil organic matter increased by 4.38% during the monsoon season. The value stayed quite high at 4.02% after the rainy season. Soil organic carbon also increased with the seasons, rising from 1.86% before the monsoon to 2.54% during the monsoon and then slightly falling to 2.31% after the monsoon. The increased carbon storage during the rainier months was a result of better nitrogen cycling and higher biomass output. The monsoon saw the greatest percentage of vegetation cover (89.47%), which corresponds to the peak of plant development under conditions of optimal rainfall. Compared to the level before the monsoon (74.63%), vegetation cover is still significantly greater, despite a small decrease after the rains (84.58%). The overall impact of seasonal climate variation on the dynamics of vegetation was statistically significant ($p < 0.001$).

Table 2: Mean (±SD) Values of Selected Soil and Vegetation Parameters Across the Four Forest Ecosystems

Forest Site	Soil Moisture (%)	Soil pH	Soil Organic Matter (%)	Soil Organic Carbon (%)	Vegetation Cover (%)
Gorumara	27.84 ±2.91	6.18 ±0.16	4.28 ±0.39	2.47 ±0.25	88.12 ±3.74
Jaldapara	26.63 ±2.72	6.27 ±0.19	4.02 ±0.42	2.31 ±0.24	85.76 ±4.05
Buxa	28.95 ±2.88	6.14 ±0.15	4.51 ±0.43	2.61 ±0.27	90.34 ±3.51
Chapramari	25.87 ±2.61	6.36 ±0.18	3.81 ±0.37	2.18 ±0.23	82.94 ±4.26
P-value	0.003**	0.015*	0.002**	0.001**	<0.001**

*** Significant at $p < 0.05$; ** Significant at $p < 0.01$**

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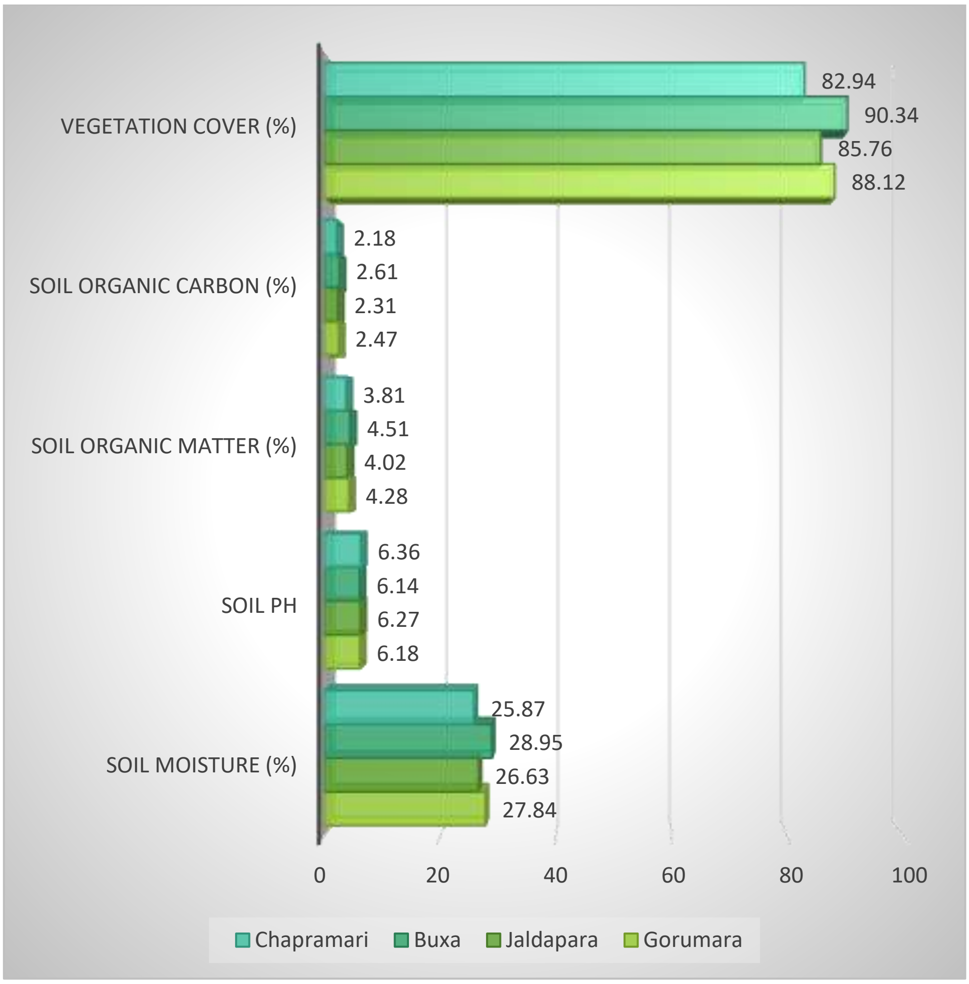

Figure 2: Comparison of Selected Soil and Vegetation Parameters Among the Four Forest Ecosystems

The mean (±SD) values of the chosen soil and vegetation characteristics in the four forest ecosystems of the Dooars region—Gorumara, Jaldapara, Buxa, and Chapramari—are displayed in Table 2. Each of the forest locations had significantly different soil quality and plant characteristics, as seen by the wide range of assessed values. Soil organic matter (4.51%), soil organic carbon (2.61%), and vegetation cover (90.34%) were all greatest in Buxa Forest Area, indicating that the soil there is more fertile, that it retains more water, and that the plant structure is healthier. Soil moisture content is 28.95%. Similar to other areas with suitable ecological circumstances, Gorumara Forest Area has quite high values for these characteristics.

Soil organic carbon (2.18%), soil moisture (25.87%), and plant cover (82.94%) were all lowest in the Chapramari Forest Area, suggesting a lower density of vegetation and less availability of nutrients. Each of the research locations had somewhat acidic soil pH, with Buxa having the lowest at 6.14 and Chapramari the highest at 6.36; still, these circumstances are often conducive to the proper functioning of forest ecosystems. We found statistically significant variations across the four forest ecosystems in soil organic matter, soil pH, soil organic carbon, soil moisture content, and plant cover.

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Table 3: Pearson Correlation Matrix of Selected Soil and Vegetation Parameters

Parameter	SMC	pH	SOM	SOC	VC
Soil Moisture Content (SMC)	1				
Soil pH	-0.514**	1			
Soil Organic Matter (SOM)	0.781**	-0.463*	1		
Soil Organic Carbon (SOC)	0.758**	-0.437*	0.981**	1	
Vegetation Cover (VC)	0.835**	-0.521**	0.746**	0.729**	1

**** Correlation significant at p < 0.01, * Correlation significant at p < 0.05**

Strong positive correlations among the chosen soil quality indicators were shown by the correlation analysis. An extremely strong positive correlation was found between soil organic matter ($r = 0.781$, $p < 0.01$), soil organic carbon ($r = 0.758$, $p < 0.01$), and vegetation cover ($r = 0.835$, $p < 0.01$), suggesting that more moisture is needed to encourage more organic matter accumulation and increased vegetation development. There was a very significant positive correlation between soil organic carbon and soil organic matter ($r = 0.981$, $p < 0.01$), which supports the idea that organic carbon is mainly linked to the organic leftovers contained in forest soils.

It may be inferred that dense vegetation improves litter deposition, nutrient cycling, and soil fertility since vegetation cover showed high positive associations with soil organic matter ($r = 0.746$, $p < 0.01$) and soil organic carbon ($r = 0.729$, $p < 0.01$). Soil organic matter ($r = -0.463$), soil organic carbon ($r = -0.437$), soil moisture ($r = -0.514$), and vegetation cover ($r = -0.521$) all demonstrated strong negative correlations with soil pH, indicating that, on the flip side, soil organic carbon and organic matter decomposition both contribute to slightly acidic soil conditions.

V. CONCLUSION

The results showed that during the monsoon season, soil organic matter, soil organic carbon, and plant cover all increased, suggesting that soil and water conservation were better under such circumstances. Moreover, there were notable distinctions between the four forest habitats, which may be attributed to disparities in ecological traits and preservation possibilities. The significance of preserving robust forest ecosystems for enhancing soil quality and ecosystem sustainability is shown by the positive connections among the chosen soil and vegetation characteristics.

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