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Status of Soil Physical Properties at Various Depths and Slope Positions Under Different Land uses of Sitakunda Hill Forest, Chattrogram

Runa Akter, M. M. Abdullah Al Mamun* and Shyamal Karmakar

Institute of Forestry & Environmental Sciences, University of Chittagong, Chattogram 4331
[*]Corresponding author [mamun@cu.ac.bd]

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Abstract

Soil physical properties act as a determining factor for sustainable land management practices. The study aimed to assess the impacts of slopes and depths on soil physical properties. In three replications, 36 soil samples were collected from three land uses (Natural, Plantation, and Fallow hilly area) from both valley and slope. The investigated variables were moisture content, bulk density, maximum water holding capacity, porosity, particle density, color, structure and texture, and infiltration capacity. Significant differences were found in moisture content, porosity, particle density, and water holding capacity between land use at 15 cm and 30 cm depth on the slope and 15 cm valley. However, no significant differences were found in most of these variables at 30cm depth in the valley. Plantation areas had higher infiltration rates than Natural and Fallow hilly area. The differences are due to topography, human interference, and poor management, which affect the physical properties of soil.

Keywords: *Hill soil, Fallow hilly area, Physical properties, Infiltration capacity, Chattogram.*

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সারমর্ম

মাটির ভৌত বৈশিষ্ট্য টেকসই ভূমি ব্যবস্থাপনা অনুশীলনের জন্য একটি নির্ধারক ফ্যাক্টর হিসাবে কাজ করে। এই গবেষণার লক্ষ্য মাটির ভৌত বৈশিষ্ট্যের উপর ঢাল এবং গভীরতার প্রভাব মূল্যায়ন করা। তিনটি প্রতিলিপিতে, উপত্যকা এবং ঢাল উভয় থেকে তিনটি ভূমি ব্যবহার (প্রাকৃতিক পাহাড়ি এলাকা, বৃক্ষরোপণ পাহাড়ি এলাকা এবং পতিত জমি) থেকে মোট ৩৬টি মাটির নমুনা সংগ্রহ করা হয়েছে। তদন্তকৃত ভেরিয়েবলগুলি হল আর্দ্রতার পরিমাণ, বাল্কঘনত্ব, সর্বাধিক জলধারণ ক্ষমতা, ছিদ্রতা, কণারঘনত্ব, রঙ, গঠন ও টেক্সচার, এবং অনুপ্রবেশ ক্ষমতা। ভূমি ব্যবহারের মধ্যে আর্দ্রতা, ছিদ্রতা, কণার ঘনত্ব এবং জলধারণ ক্ষমতার মধ্যে উল্লেখযোগ্য পার্থক্য ছিল। ঢালে ১৫ সেমি এবং ৩০ সেমি গভীরতায় এবং ১৫ সেমি উপত্যকায়, তবে উপত্যকায় ৩০ সেমি গভীরতায় এই ভেরিয়েবলগুলির বেশির ভাগের মধ্যে কোন উল্লেখযোগ্য পার্থক্য নেই। প্রাকৃতিক ও পতিত জমির তুলনায় আবাদ এলাকায় অনুপ্রবেশের হার বেশি ছিল। পার্থক্যগুলি ভূসংস্থান, মানুষের হস্তক্ষেপ এবং দুর্বল ব্যবস্থাপনার কারণে যা মাটির বৈশিষ্ট্যকে প্রভাবিত করে।

1. Introduction

The rate of land use change has increased dramatically in recent decades, particularly in hilly regions, resulting in a loss of productivity due to changes in soil qualities, as well as a loss of biodiversity and ecosystems [1], [2]. Deforestation and degradation is a widespread phenomenon for state-managed Natural forests in Bangladesh, which accelerates the extinction of crucial native floral and faunal species [3] and badly impacts soil properties [4]. In addition, with the increasing demand for firewood, timber, pasture, shelter, and food crops, Natural land covers, particularly tropical forests, are being degraded or converted to cropland at an alarming rate [5]. Like the other soil types, the major factors that regulate the forest soil properties are the relief, elevation, texture, moisture, and temperature regimes of a region [6]. In addition, overgrazing would have a significant influence on soil properties and nutrient conditions [7]. In contrast, some agricultural practices like tillage and harvesting are also associated with the loss of soil biomass, alteration of above and below-ground biodiversity, and finally, lead to a decline in soil quality [8]. Anthropogenic activities such as trampling and illicit felling in forest lands affect litter input, carbon stabilization, and nutrient turnover [9], [10]. Besides, overgrazing, inappropriate agricultural and management practices, and human disturbances leave soil under sparse vegetation or bare conditions, promoting soil erosion [11]–[13]. In the past decades, numerous studies have documented the relevance of slope position and aspect in determining the variability of soil properties. For instance, Zaman et al.; Pierson and Mulla studied the soil properties on different slope positions and terminated that soils formed on foot slope and midslope positions contained higher organic carbon, organic matter, total nitrogen, phosphorus, potassium and aggregate stability compared to summit position [14], [15].But, there is no study so far in Sitakunda hill forest on this context so that we can evaluate agroecosystem sustainability, soil degradation and sustainable land management practices.The overall objective of this study is to assess soil physical characteristics under various land uses in the Sitakunda hill forest. Therefore, it is high time to see the changes in terms of soil's physical properties in diverse land uses and frame rules/regulations to protect arable soils from degradation.

2. Materials and Methods

The soil samples were collected from Sitakunda Upazila in the Chattogram district to analyze important physical parameters. However, this study also used secondary sources for some valuable information.

2.1 The study area

Sitakunda is an Upazila in Chattogram District, Bangladesh. It is flanked by Mirsharai to the north, Pahartali to the south, Fatickchari, Hathazari, and Panchlaish to the east, and the Sandwip Channel to the west. A 32-kilometer-long ridge amid the Upazila, Chandranath, or Sitakunda peak is 352 meters above sea level. On average, the exposed sedimentary rock sequences bearing limestone are 6,500 meters thick [16].

2.1.1 A description of the selected three land uses

Although several land uses were practiced in this area, in the present study, three land uses, i.e., Natural hill forest, Plantation hill forest, and Fallow hilly area, were selected to find out the variation in soil properties and other features. A general observation about these designated land uses is briefly described here.

- **Natural hill forest**

The study site is Sitakunda Upazila, Chattogram district, with an E-W aspect and a 50% slope. The place had a Natural forest patch (regarded as the Village Common Forest) from which the villagers could only extract trees with the permission of the Forest Department. The patch was located at the hilltop, where no large tree was seen and degraded. Leaves were found half-decayed and entirely fresh on the forest floor. Only a few herbs, bushes, and climbers were observed, with an average tree height of 5-8m and a low tree species density. The soil was light brown to dark brown, susceptible to severe erosion risk during the monsoon. The firewood collection was prominent there, which hardened the ground.

- **Plantation hill forest (6 years old)**

Mangifera indica was planted in a 50 percent slope plot with 4m×4m spacing. The Plantation was six years old. The plot is on the E-W aspect, located 3 km from Bashbaria local market and on the eastern side of the Sitakunda rail line. This surface soil was coated with new leaf litter. The soils were granular in shape, brown to yellowish-brown, with a pH of 5.6-5.7. The site has moderate to severe erosion hazards, friable consistency, and severe drought throughout the dry season. However, the pace of soil erosion varied based on the site’s downward sloping features. Several herbs and shrubs were seen in the undergrowth.

- **Fallow hilly land (5 years old)**

The study site was in Barabkunda Union, with a slope percentage of 45 on the N-S slope. A few saplings of neighboring tree species were spotted nearby. The area has been Fallow for five years and was formerly a forest. The pH ranged from 5.7 to 5.9. This surface was well-drained, including a dense undergrowth. Droughtiness and firmness were experienced in the dry season and significant dampness in the rainy season.

2.2 Site selection and sample collection

After a vigorous reconnaissance survey, convenient sampling was used to determine the sample plots (Figure 1). In this composite sampling procedure, a total of three samples were collected, each with a sample plot size measuring 20 m x 20 m. These samples were obtained at a distance of 50 m from one another and subsequently combined to create a single composite sample. Consequently, a total of 36 soil samples were obtained from two distinct locations (Slope and Valley) at varying depths (15 cm and 30 cm) across three distinct land use types (Natural, Plantation, and Fallow) in hilly regions. Samples were collected by soil auger of 45 cm length and stored in tagged, double-layered sample collection bags. Before bagging, straw, root, seed, leaf, or other unwanted materials were handpicked. Samples were air-dried in shades.

Figure 1

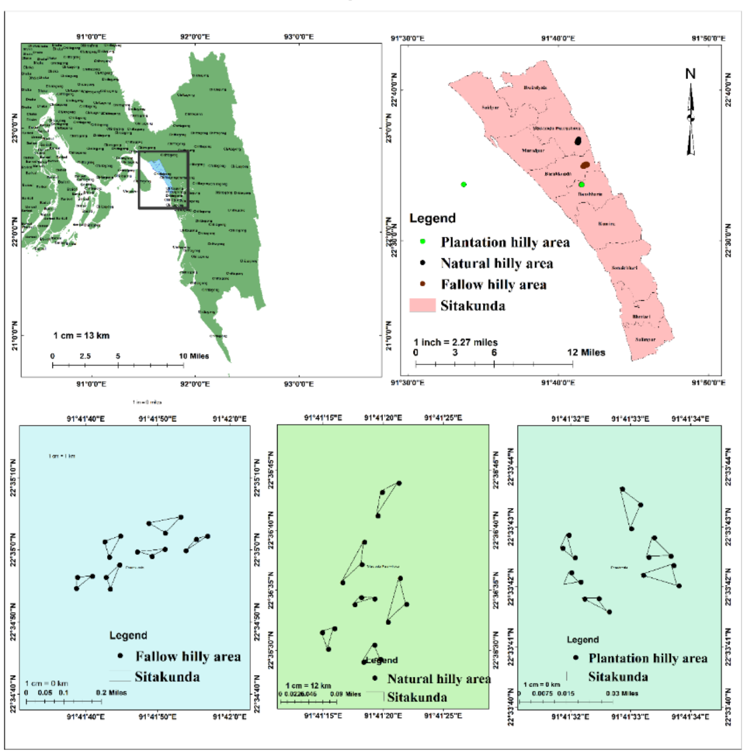

Figure 1. Study area map indicating sampling design and locations.

2.3 Determination of physical properties of soil

Maximum water holding capacity (MWHC), bulk density, and porosity were determined from core samples (a 100 cm^3 soil corer was used for core sample collection) collected for bulk density [13]. At first, field moist soil cores were accurately weighed, and then they were allowed to saturate with water by dividing two-thirds of the cores in a tray. When a thin film of water developed on the upper surface of the cores, they were withdrawn from the water and weighed. The cores were then allowed to drain out of the water on a tray filled with sand for 24 hours and then reweighed. The cores were then dried in an oven at 105°C for 8 hours, cooled in a desiccator, and weighed. From these values, the field moist and oven-dry weight of the soils in the cores were then calculated and divided separately by the core volumes (100 cm^3), and dry bulk density was determined. Finally, MWHC, dry bulk density, moist bulk density, and porosity were calculated using formulae given below.

Maximum water holding capacity (MWHC) (%) = $\frac{W_3 - W_4}{W_4 - W_1} \times 100$

Dry bulk density ($g\ cm^{-3}$) = $\frac{W_4 - W_1}{V} \times 100$

Moist bulk density ($g\ cm^{-3}$) = $\frac{W_2 - W_1}{V} \times 100$

Porosity (%) = $(1 - \frac{Bulk\ density}{Particle\ density}) \times 100$

W_1 = Weight of core
W_2 = Weight of core + Field moist soil
W_3 = Weight of core + Saturated soil
W_4 = Weight of core + Dry soil and
V = Volume of core

Moisture content was determined by the oven-dry method [17]. In this method, soils were taken on the pre-weighted petri-dish. It was kept in an oven at 105ºC for 8 hours, cooled in desiccators, and weighed again. The Munsell Soil Color Chart determined soil color [18]. The texture was determined by jar soil or the shaking method [19], [20]. Soil structure was determined immediately after digging the ground on the field [21] .

2.4 Statistical analyses

IBM SPSS version 26.0 for Windows was used to analyze all relevant data [22]. Then, a one-way analysis of variance (ANOVA) was applied to compare the differences between the land uses [23]. In addition, the Duncan Multiple Range Test (DMRT) was exercised to see if the treatment means were substantially different at p 0.05 [24].

3. Results and Discussion

3.1 Moisture content

Water collected in the soil that is not all available for plant roots is soil moisture. Figure 2 shows the MC of soil at various depths and slopes for diverse land uses. At 15cm slope and 15 cm valley, the mean MC differed significantly ($p \leq 0.05$).

The timeline of MC in 30 cm and MC in 15 cm is intriguing. MC is maximum at 30 cm slope of Plantation hilly area (19.28%), but the lowest at 15 cm slope (4.01%) of similar land use. At 15 cm valley position, Natural and Fallow hilly area and at 30 cm valley position of both Natural and Plantation hilly area MC was found as the same range. The mean MC of Fallow and Natural hilly areas was 33.33% greater than Plantation hilly areas. The hierarchy can be shown as follows-

Fallow hilly area>Natural hilly area>Plantation hilly area

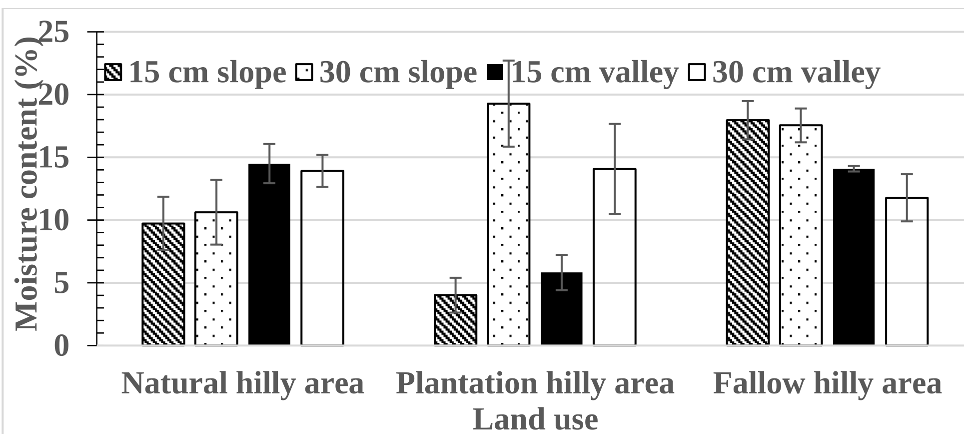

Figure 2. Moisture contents of soils collected from the various depth and slope position under different land uses in Sitakunda.

Changes in bulk density and organic matter content are anticipated to soil moisture content [25], [26]. MC levels in Fallow regions may be boosted by the presence of certain bushy ground plants. A decrease in the bulk density of Fallow hilly area may also be a contributing factor [27]. As a result of greater human access and the lack of forest floor plants, Natural steep slopes have a lower MC (%). The Plantation hills have more deteriorated surfaces than the rest of the area because of firewood gathering. Because of the abundance of parent material, the Plantation showed low MC [14].

3.2 Particle density

Table 1 shows soil particle density at various depths and slopes for different land uses. However, only a 30 cm slope position showed significant ($p \leq 0.05$) differences in mean particle density. Particle density was 8.51 percent higher in Fallow hilly areas and 5.34 percent lower in Plantation hilly areas compared to Natural hilly regions. Particle density was highest at 30 cm depth of slope in

Plantation hilly area and most lacking in Natural hilly area. The hierarchy of mean particle density under different land uses can be shown below-

Fallow hilly area>Plantation hilly area>Natural hilly area.

This condition was owing to thick ground plants and coarse soil texture. The finer particles in aged soil may be the key factor [28]. Low particle density in the Natural hilly area may be due to erosion or locals collecting firewood. Human intervention was also hardening soil.

3.3 Porosity

Table 1 depicts soil porosity for various land uses at varying depths and slopes. Only at a 30 cm slope soil porosity differed significantly ($p \leq 0.05$) between land uses. The highest mean soil porosity was found on Plantation hilly area, whereas the lowest was found in Fallow hilly area. The most considerable soil porosity was found at the 30 cm slope of the Fallow field and the lowest at the 15 cm slope of the Fallow hilly area (Table 1). Plantation hilly area had a 10.46 percent higher porosity than Natural hilly regions and a 19.15 percent higher porosity than Fallow hilly area. The porosity hierarchy for different land uses is shown below.

Plantation hilly area>Natural hilly area>Fallow hilly area.

Table 1. Particle density (g cm^{-3}) and porosity (%) of soils collected from different depths at different slope positions under various land use in Sitakunda.

Land use	Position	Depth	Particle density (g/cm3)	Porosity (%)
Natural hilly area	Slope	15 cm	2.0833 a	37.1267 a
			(.13667)	(7.33214)
		30 cm	1.7200 a	27.3433 a
			(.09000)	(1.83830)
	valley	15cm	2.3600 a	50.0600 a
			(.25794)	(2.47674)
		30 cm	2.6833 a	51.1500 a
			(.33328)	(6.85712)
Plantation hilly area	Slope	15 cm	2.2200 a	47.2933 a
			(.00000)	(2.93121)
		30 cm	2.8000 b	46.3800 b
			(.32140)	(9.97266)

	valley	15 cm	2.1467 a	44.8467 a
			(.07333)	(4.41235)
		30 cm	2.1800 a	46.5200 a
			(.32000)	(3.80575)
Fallow hilly area	Slope	15 cm	2.3333 a	10.91436 a
			(.16667)	(6.30141)
		30 cm	2.6467 b	52.7633 b
			(.21333)	(1.95197)
	Valley	15 cm	2.5233 a	45.2400 a
			(.18224)	(3.10902)
		30 cm	2.1667 a	40.7000 a
			(.16667)	(4.47102)

Note: *Each value is the mean of three replications. Values in the same column by different letters (a & b) indicate a significant ($p \leq 0.05$) difference. The numbers in the parentheses are standard errors of the mean.*

This condition was owing to thick cover crops and coarse soil texture [29]. Temperature variations can also impact soil porosity and the interface between liquid and solid, especially in heavy clay loams [30]. The finding of the study mirrored another study [31] where authors claimed that Plantations can reestablish soil porosity faster than Natural forests. Another reason of lower soil porosity in Natural hill forest is due to erosion and extraction of firewood by the local people. Additionally, it should be noted that excessive human interference on Fallow hilly area hardened the soil, which ultimately resulted in lower porosity in this land use.

3.4 Soil color and structure

Table 2 shows the structure and color of soil obtained from different depths and slopes in Sitakunda. Most soils were brown to dark brown. The color difference was visible between land uses. The color of the Plantation hills may be due to hardened dry dirt. The dark brown color of Natural forest soil is caused by partially degraded leafy and non-leafy litter and microorganisms. Only the soil at 15 cm slope of Fallow hilly area is sub-angular blocky. Soil structure reflects soil health. High organic matter soils agglomerate, while low organic matter soils are loose. The soil structure also reveals the degree of weathering. These findings coincide with other research outcomes [28] and [31].

Table 2. Soil structure and color collected from different depths at various slope positions under different land uses in Sitakunda.

Land use	**Position**	**Depth**	**Soil Structure**	**Soil Color**		**Soil condition**
				Value	**Description**	
Natural Hilly area	Slope	15cm	Granular	7.5 YR 5/2	Brown	Moist
		30 cm	Granular	7.5 YR 4/6	Strong brown	Moist
	Valley	15 cm	Granular	7.5 YR 6/4	Light brown	Moist
		30 cm	Granular	7.5 YR 4/6	Strong brown	Moist
Plantation Hilly area	Slope	15cm	Granular	10 YR 6/6	Brownish yellow	Moist
		30cm	Granular	10 YR 5/4	Yellowish brown	Moist
	Valley	15cm	Granular	7.5 YR 5/3	Brown	Moist
		30cm	Granular	10 YR 6/6	Yellowish brown	Moist
Fallow Hilly Area	Slope	15cm	Sub angular blocky	7.5 YR 4/3	Brown	Moist
		30cm	Granular	7.5 YR 4/4	Brown	Moist
	Valley	15cm	Granular	7.5 YR 4/6	Strong brown	Moist
		30cm	Granular	7.5 YR 4/1	Dark grey	Moist

3.5 Soil texture

Within each of the three land covers, soil texture varied from sandy loam to loamy sand (Table 3). The soil was all coarse to moderately coarse-grained. Therefore, the texture of the compared lands was nearly the same.

Table 3. Texture of soils collected from two depths at different slope positions under diverse land uses in Sitakunda.

Land use	Position	Depth	Soil particles			Textural class
			Sand (%)	Silt (%)	Clay (%)	
Natural Hilly area	Slope	15cm	68.41	18.44	13.15	Sandy loam
		30 cm	53.79	26.71	19.5	Sandy loam
	Valley	15 cm	78.89	15.83	5.28	Loamy sand
		30 cm	63.49	20	5.64	Sandy loam
Plantation Hilly area	Slope	15cm	62.62	31.31	6.07	Sandy loam
		30cm	77.46	16.72	5.84	Loamy sand
	Valley	15cm	60.85	24.87	16.67	Sandy loam
		30cm	66.13	25.71	8.65	Sandy loam
Fallow Hilly Area	Slope	15cm	53.6	30.39	10.59	Sandy loam
		30cm	54.44	28.79	16.77	Sandy loam
	Valley	15cm	73.44	21.87	4.70	Sandy loam
		30cm	69.54	22.41	8.05	Sandy loam

3.6 Maximum water holding capacity of soil

The water holding capacity of soil reveals the soil's pore space and water channeling capacity. Various land uses at different depths and slope aspects have no significant ($p \leq 0.05$) differences for maximum water holding capacity (Figure 3). Water holding capacity was best in the 15 cm valley of the Fallow hilly area and the lowest in the 30 cm slope of the Natural hilly area. Below is the MWHC hierarchy for various land uses found as-

Fallow hilly area>Plantation hilly area>Natural hilly area.

Fallow areas have excellent water holding capacity due to bushy ground vegetation, soil porosity, and particle density [27]. Hardened soil, severe erosion, and human meddling may cause low MWHC (%) in Natural hilly soil.

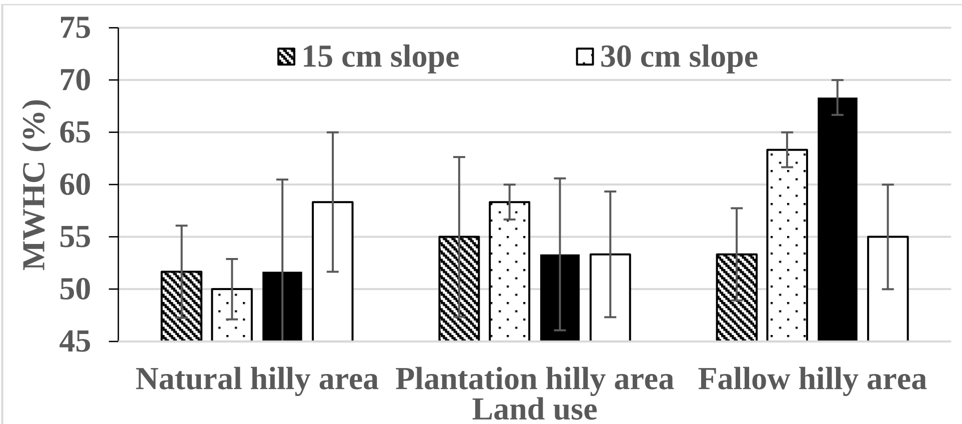

Figure 3. MWHC (%) of soils collected from the different depth and slope positions under three land uses in Sitakunda.

3.7 Moist and dry bulk density

There was no significant ($p \leq 0.05$) difference in soil's moist and dry bulk density at different depths and slope positions. The mean moist bulk density of soil collected in Fallow and Natural hilly areas was roughly similar (Table 4). It is obvious that Plantation hilly areas had the lowest bulk density and Fallow hilly areas had the highest in both moist and dry condition. More specifically, the moist bulk density is highest at a 15 cm valley in a Fallow hilly area and lowest at a 15 cm slope in a Plantation hilly area. Fallow hilly areas had a mean bulk density that was 10.59% higher than Plantation hilly areas. On the other hand, specifically at different depths and slope positions dry bulk density is highest at 15 cm valley of Fallow hilly area and lowest at 15 cm slope of Plantation hilly areas. So it is clear that bulk density of Planation and Natural hilly areas followed the Fallow hilly area in both moist and dry conditions. It is as follows-

Fallow hilly area>Natural hilly area>Plantation hilly area

Table 4: Moist & dry bulk density of soils collected from different depths at different slope positions under different land uses in Sitakunda.

Land use	Position	Depth	Moist bulk density (g/cc)	Dry bulk density (g/cc)
Natural hilly area	Slope	15 cm	1.4167 a	1.2900 a
			(.08253)	(.06083)

		30 cm	1.3867 a	1.2467 a
			(.06489)	(.04096)
	valley	15cm	1.3533 a	1.1800 a
			(.17072)	(.14224)
		30 cm	1.4433 a	1.1800 a
			(.08353)	(.14224)
Plantation hilly area	Slope	15 cm	1.2167 a	1.1700 a
			(.07881)	(.06506)
		30 cm	1.4867 a	1.2400 a
			(.18224)	(.11504)
	valley	15 cm	1.2467 a	1.1800 a
			(.06984)	(.07937)
		30 cm	1.3133 a	1.1800 a
			(.18095)	(.07937)
Fallow hilly area	Slope	15 cm	1.4367 a	1.2167 a
			(.09939)	(.07333)
		30 cm	1.4633 a	1.2433 a
			(.09821)	(.06936)
	Valley	15 cm	1.5667 a	1.3733 a
			(.07535)	(.06692)
		30 cm	1.4200 a	1.3733 a
			(.03512)	(.06692)

Note: *Each value is the mean of three replications. Values in the same column by different letters (a & b) indicate a significant ($p \leq 0.05$) difference. The numbers in the parentheses are standard errors of the mean.*

Extreme erosion increased bulk density, surface soil compaction, and decreased water holding capacity and porosity. Compared to other land uses, Fallow hilly areas have less pore space and bulk density than other land use due to severe erosion and mechanical movement [32]. Other researchers found the same outcome [31].

3.8 Soil infiltration

Initially, Plantation hills had maximum infiltration depth of the three land uses. Suddenly, the depth was lower than both Natural and Fallow hilly areas (Figure 5). The initial infiltration depth of the Natural hilly area was 4.5 cm that is 35.72 percent lower than Plantation hilly area (Figure 5). Infiltration depth and the rate did not differ between land uses ($p > 0.05$). (Figures 4 & 5). Plantation hilly area's infiltration rate (cm/hr.) was 14.17 percent higher than Natural hilly areas.

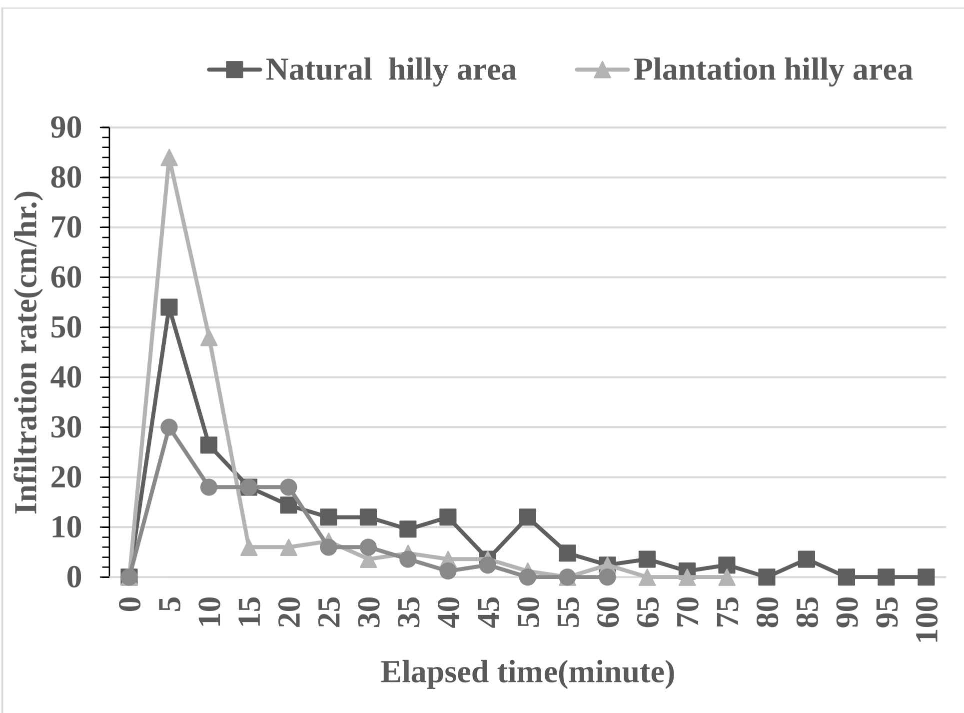

Figure 4. Infiltration rate (cm/hr.) of soil under different land uses in Sitakunda hill forest.

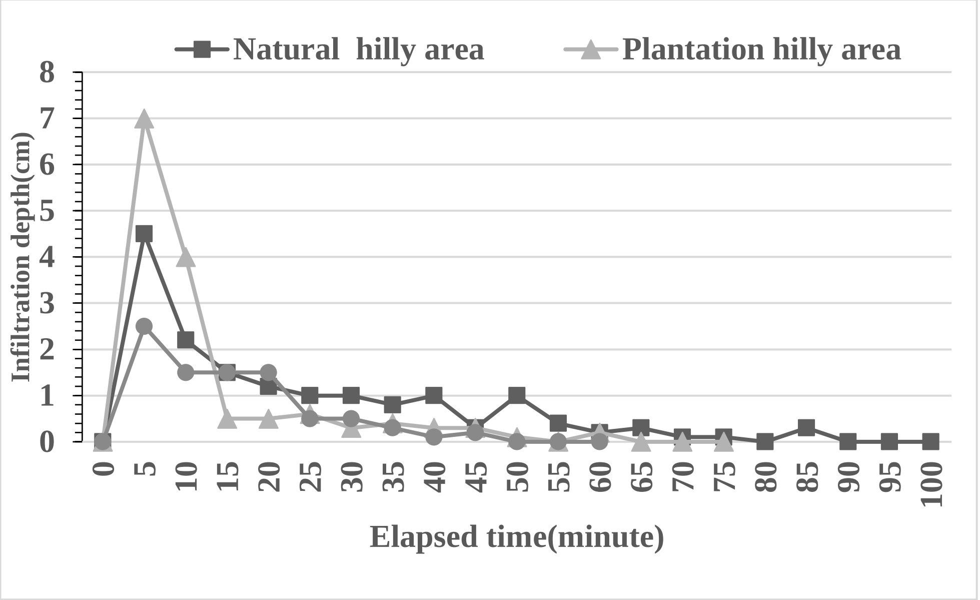

Figure 5. Infiltration depth (cm) of soil under different land uses in Sitakunda hill forest.

The higher infiltration depth in forested sites was typical in most locations [33]. According to them, infiltration depths in deforested regions were consistently lower than nearby forested lands in Cox's Bazar forest areas. Soil physicochemical features such as porosity, particle density, better weathering of parent material, and partially degraded litter composition may contribute to higher infiltration rates in Sitakunda Plantation hilly areas. The lower infiltration rate in Fallow areas may be due to grazing and soil compaction. The result coincides with other studies [34].

4. Conclusion

This study shows that slope position substantially affects soil physical qualities, with the highest and lowest content in valleys and slopes. Forest cover is declining in Natural hilly areas due to human disturbance and grazing. The findings in this paper reveal that the Plantation hill forest outperforms the other forest types in practically every soil health metric. In contrast, disturbed soils in Natural hill forests have less capacity to support healthy plants. Due to excessive human interference, the Naturall hilly area loses its leading position in soil health and vegetation. Another puzzle is the capacity of Fallow hilly area's having better positions of few soil physical properties. Generally, the land is reclaimed in five years in the Fallow hilly regions. However, a Plantation or Natural hilly area may have more attributes. In a nutshell, this is an initial attempt to understand the physical condition of Sitakunda's hilly regions, which will help the practitioners to choose an appropriate land-use system.

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