SOIL ORGANIC CARBON DYNAMICS IN SOME SELECTED FOREST AREAS OF BANGLADESH

PhD THESIS

MD. MOTIAR RAHMAN
Re-registration No.: 41
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DEPARTMENT OF SOIL, WATER AND ENVIRONMENT
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A DISSERTATION

Submitted to the Department of Soil, Water and Environment, Faculty of Biological Sciences, University of Dhaka, Bangladesh, in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY

DEPARTMENT OF SOIL, WATER AND ENVIRONMENT
FACULTY OF BIOLOGICAL SCIENCES
UNIVERSITY OF DHAKA
DHAKA 1000, BANGLADESH

APRIL 2024

DEDICATED

TO

MY DEPARTED FATHER AND FATHER-IN-LAW

DECLARATION

I do hereby declare that the research study described in this dissertation is my original work except where acknowledged in the usual acceptable manner. This bona fide record of work done by me under the joint guidance and supervision of Dr. Mohammad Enayet Hossain, Associate Professor, Department of Soil, Water and Environment, University of Dhaka, and Dr. Sirajul Hoque, Professor (Retired), Department of Soil, Water and Environment, University of Dhaka, Bangladesh. I further declare that this dissertation or any part of it has not been submitted elsewhere for any academic degree, prize, or scholarship.

(MD. MOTIAR RAHMAN)
Re-registration No.: 41
Session: 2022-2023

CERTIFICATE

This is to certify that the dissertation titled **"Soil Organic Carbon Dynamics in Some Selected Forest Areas of Bangladesh"** submitted by **MD. MOTIAR RAHMAN (Re-registration No. 41, Session: 2022-2023)** for the fulfillment of the requirements for the degree of **Doctor of Philosophy** from the Department of Soil, Water and Environment, Faculty of Biological Sciences, University of Dhaka, Bangladesh is an original research work done by him. Part of this dissertation has not been submitted elsewhere for any academic degree or diploma. It is also certified that the research work presented herein is suitable for submission for the award of a PhD degree.

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LIST OF ABBREVIATIONS AND ACRONYMS

AGB	Above Ground Biomass
ANOVA	Analysis of Variance
BA	Basal Area
BARC	Bangladesh Agricultural Research Council
BD	Bulk Density
BFI	Bangladesh Forest Inventory
BFRI	Bangladesh Forest Research Institute
BGB	Below Ground Biomass
CAGB	Carbon in Above Ground Biomass
CBGB	Carbon in Below Ground Biomass
CLHG	Carbon in Leaf Litter, Herb, and Grass
DBH	Diameter at Breast Height (1.37 meters from the ground)
$dS\ m^{-1}$	Deci Siemens per Meter
EC	Electrical Conductivity
FB	Forest Beat
FD	Forest Department
FR	Forest Range
GoB	Government of Bangladesh
Gt	Gigatonne (1 Gt = 10^{12} Kg = 1 Pg)
ICIMOD	International Centre for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
ln	Natural Log
Mg	Megagram (1 Mg = 1000 Kg = 1 tonne)
MoEFCC	Ministry of Environment, Forests and Climate Change
Pg	Petagram (1 Pg = 1 Gt = 10^{12} Kg = 10^{15} g)
SAGB	Sapling Above Ground Biomass
SBGB	Sapling Below Ground Biomass
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
TAGB	Tree Above Ground Biomass
TBGB	Tree Below Ground Biomass
TBC	Tree Biomass Carbon
TBD	Total Biomass Density
TCD	Total Carbon Density
Tg	Teragram (1 Tg = 10^6 Mg = 10^9 Kg = 10^{12} g)
WD	Wood Density

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ABSTRACT

Forests are important ecosystems because of its association with the global energy balance. In this study, soil samples were collected from different locations of some important forest areas of Bangladesh to estimate the relationship between soil organic carbon (SOC) dynamics and some physical and chemical properties of soils. Quantification of SOC stock and measurement of forest biomass carbon density were also done at the same forest areas. The forest areas under study were the hill forest of Chittagong and Sylhet, the sal forest, the Sundarban mangrove forest, and the coastal afforestation areas in Bangladesh. A total of eighteen locations were selected for this study and each location had three plots. The plots were selected based on a simple random sampling method. Each plot was delineated by an 8.92-meter radius circular area. In this plot, all trees having a diameter at breast height (DBH) from >5 cm were measured. Several subplots were established within each main plot for specific purposes. Inside the 8.92-meter radius plot, a subplot with a 5.64-meter radius was established for measuring saplings and seedlings having a DBH from 1–5 cm. A subplot with a 0.56-meter radius within the main plot was laid out for collecting soil samples from different soil depths, and for collection of leaf litter, herb, and grass.

The texture of the soils was found mostly sandy loam to sandy clay loam and occasionally with loamy sand and clay loam in the hill forest of Chittagong and Sylhet, and in the sal forest areas. Sand was found to be the dominant fraction in the soils of these areas and most of the soils developed predominantly from unconsolidated sandy parent materials. On the other hand, the texture of the soils in Sundarban mangrove forest and the coastal afforestation areas was found to be loam. The concentration of SOC was found to increase significantly ($p<0.05$) with increasing sand fraction in the Chittagong hill forest and coastal afforestation areas and showed a positive correlation whereas Sylhet hill forest showed negative correlation, but the relationship was found highly significant differences ($p<0.001$) between SOC concentration and sand fraction. On the other hand, the relationship between SOC concentration and silt fraction showed positive correlation and highly significant differences ($p<0.001$) in the Sylhet hill forest and Sundarban mangrove forest areas whereas Chittagong hill forest and Coastal afforestation areas showed negative correlation and significant differences ($p<0.01$ and $p<0.05$). No significant

differences were observed between SOC concentration and silt fraction in sal forest areas, but it was found slightly positively correlated with clay fraction.

Soil moisture content (MC) was found to vary among different soil depths and the forested site contained higher MC than the adjacent homestead site across the different locations under study. The relationship between SOC concentration and MC showed a positive correlation in Sylhet hill forest, whereas in other areas negative correlation was seen. A significant ($p<0.05$) relationship was found between SOC concentration and MC in the different forest areas. Soil bulk density (BD) was found relatively higher in homestead sites than in the forested sites and it tended to increase with increasing soil depth in all the studied areas. It could be attributed to the greater compaction in the lower depth of soil related to time. On the other hand, a reverse trend was observed in SOC concentration in the study area. The relationship between SOC concentration and BD showed a negative correlation in all the forest areas except in the Sundarban mangrove forest. Soil pH, total nitrogen (total N) and electrical conductivity (EC) were also observed higher in the forested sites than in the homestead sites and significant differences were found between different soil depths in all the forest areas. The relationship between SOC concentration and total N showed a positive correlation, whereas pH and EC showed a negative correlation with SOC concentration.

The mean value of soil organic carbon (SOC) stocks up to 1 m (0−100 cm) soil depth was found to be higher in the forested site of the Sundarban mangrove forest (103 t ha^{-1}, correspond to 379 t ha^{-1} of soil CO_2 mitigation density) followed by the Chittagong hill forest (99 t ha^{-1}, correspond to 363 t ha^{-1} of soil CO_2-mitigation density) and lower in the Sylhet hill forest and sal forest (60 t ha^{-1}, correspond to 220 t ha^{-1} of soil CO_2 mitigation density). On the other hand, the homestead site of the Sylhet hill forest (84 t ha^{-1}, correspond to 307 t ha^{-1} of soil CO_2 mitigation density) and sal forest areas (62 t ha^{-1}, correspond to 229 t ha^{-1} of soil CO_2 mitigation density) stored higher amount of SOC stocks compared to their forested sites. Among the locations, Goneshpara, Thanchi of Chittagong hill district contained higher SOC stocks in both forested (164 t ha^{-1}) and homestead (143 t ha^{-1}) sites followed by the forested site of Bogi Forest Beat (132 t ha^{-1}) in the Sundarban mangrove forest, Sonarchar, Rangabali (96 t ha^{-1}) in the coastal afforestation areas, Lawachara National

Park (83 t ha^{-1}) in Sylhet hill forest and Dokhola Forest Range (74 t ha^{-1}) of Madhupur sal forest and lower in Tilagarh Eco Park (23 t ha^{-1}) of Sylhet hill forest. On the contrary, the homestead site of the Tilagarh Eco Park (104 t ha^{-1}) and the Kotbari sal forest (73 t ha^{-1}) areas stored higher amount of SOC stocks compared to their corresponding forested site. Highly significant differences (0<0.001) in SOC stocks were observed in both forested and homestead sites among the locations in all the forest areas.

Total biomass density (TBD) was found higher in the Chittagong hill forest (555 t ha^{-1}) followed by the Sylhet hill forest (537 t ha^{-1}), whereas the coastal afforestation areas exhibited lower TBD (284 t ha^{-1}). On the other hand, total carbon density (TCD) and total CO_2 mitigation density was found higher in the Chittagong hill forest (378 t ha^{-1} and 1387 t ha^{-1}) followed by the Sylhet hill forest (338 t ha^{-1} and 1241 t ha^{-1}), while the coastal afforestation areas showed lower TCD (227 t ha^{-1}) and total CO_2 mitigation density and (834 t ha^{-1}). Total carbon density (TCD) in Sundarban mangrove forest areas yielded lower amount compared to Bangladesh Forest Inventory (BFI) report-2020 because the study was conducted sporadically in three locations with each having three plots; BFI report included the whole areas of Sundarban. The study results also revealed that tree biomass carbon (CAGB and CBGB) in all the forest areas contributed almost 61−79% of total carbon density (TCD), whereas SOC stocks contributed about 18−35% and the rest of the carbon in leaf litter, herb, and grass (CLHG) and in saplings biomass. As for the individual tree biomass carbon (both AGB and BGB), tree species of Lohakat (*Xylia xylocarpa*) contained the highest tree biomass carbon (134.12 t ha^{-1}) followed by Pine (*Pinus caribea*) and the value was 58 t ha^{-1}. In case of the individual sapling biomass carbon, Rong (*Morinda angustifolia*) and Goran (*Ceriops decandra*) contained the maximum (0.96 t ha^{-1}) and minimum (0.03 t ha^{-1}) amounts. The overall findings of this research would be useful to policymakers, environmental activists, researchers, and academicians at national and international levels. It is imperative to develop a legacy of sustainable forest and land resources management policy that will protect future generations.

CHAPTER 1
INTRODUCTION

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1.1. Background

The soil is a major compartment of the global carbon cycle. Soil organic carbon (SOC) stocks are the biggest ecosystem carbon repository in the world. Soil organic carbon is required for enhancing quality of soil, sustaining, and improving food production, saving clean water, and reducing the carbon dioxide (CO_2) which has been rising steadily in the atmosphere (Eswaran and Van den, 1992; IPCC, 2000; Pan et al., 2002).

The global soil carbon pool of 2500 gigatons (Gt) includes about 1550 Gt of SOC and 950 Gt of soil inorganic carbon (SIC). The soil carbon pool is 3.3 times the size of the atmospheric pool (760 Gt) and 4.5 times the size of the biotic pool (560 Gt). The SOC pool to 1-meter soil depth ranges from 30 tons ha^{-1} in arid climates to 800 tons ha^{-1} in organic soils in cold regions. However, the pool ranges from 50 to 150 tons ha^{-1} in most of the soils. When natural ecosystems are converted to agricultural ecosystems, it may lead to a depletion of the SOC pool by as much as 60% in soils of temperate regions and 75% or more in cultivated soils of the tropics. The depletion is accentuated when the output of carbon exceeds the input and soil degradation is severe. Some soils may lose as much as 20 to 80 tons C ha^{-1}, most of which increase the loading in the atmosphere. The severity of SOC pool depletion may result in soil quality degradation, biomass productivity reduction, and may adversely impact water quality (Lal, 2004). Soil carbon sequestration is a vital component of the soil-plant ecosystem and influences soil properties and processes, as well as emission and storage of greenhouse gases (Wu and Cai, 2012). Soil organic carbon acts as a source and sink of nutrients for plants thereby playing an important function in the carbon cycle.

In Bangladesh, agriculture comprises the main land use accounting for nearly 65% of the country's land area, followed by forests (17.5%), urban/built-up areas (7.9%), and water. Forests occupy about 2.53 million hectares in Bangladesh (Khan et al., 2007). Of these, 1.52 million hectares (10.3% of the country's total land) are under the jurisdiction of the Forest Department (Alamgir and Turton, 2014). The remaining areas are unclassed state forests (0.73 million hectares) under the control of district administration and homestead forests (0.27 million hectares) owned by smallholder landowners (Khan et al., 2007). Bangladesh lost about 2.8% (~58,000 ha) of its forest coverage between 2000 and 2012 (Hansen et al., 2013), and still has one of the highest rates of deforestation in Asia (Poffenberger, 2000). The state of the state-owned forests is not good either. Most of the country's state-owned forests are degraded in nature (Biswas and Choudhury, 2007).

The forests of Bangladesh are categorized into three major categories, namely evergreen to semi-evergreen Hill forests, littoral Mangrove forests, and deciduous Sal forests based on vegetation and ecology. The highly diverse Hill forests are situated mainly in the Chittagong and Sylhet division (Khan et al., 2007). The Sundarban Mangrove Forest is the world's largest contiguous mangrove forest and is situated in the Bagerhat, Khulna and Satkhira districts. Sundari (*Heritiera fomes*) is the predominant species in this forest. The newly accreted islands of coastal Bangladesh underwent mangrove plantations and are dominated mainly by Keora (*Sonneratia apetala*). The deciduous Sal forests are located on relatively plain lands in the central districts of Bangladesh and are dominated by Sal (*Shorea robusta*). Although managed by smallholders and rural landowners, the homestead forests represent one of the most productive systems in Bangladesh (Kabir and Webb, 2008).

Forests are the principal natural carbon pool and act as carbon source and sink. Forests play a vital role in global carbon flux and act as carbon sink by storing large quantities of carbon for a long period of time. More than 40% of the global primary production in forest ecosystem is achieved by tropical and sub-tropical forests (Beer et al., 2010). Tropical and sub-tropical forests are potentially capable of mitigating climate change and global warming by fixing carbon from the atmosphere. Understanding the global cycle is a difficult and complex task because of changing land use, degradation of existing forests, and other anthropogenic influences. Soils in equilibrium with a natural forest ecosystem possess high carbon density. The ratio of soil:vegetation carbon density increases with latitude (Lal, 2005). As conversion of forest land to agricultural ecosystems depletes the soil carbon stocks, afforestation and management of forest plantations can enhance soil organic carbon stocks through carbon sequestration. On the other hand, fire (natural or managed) is a perturbation that can affect soil carbon stocks for a long period after the event. Increasing production of forest biomass per se may not necessarily increase the soil organic carbon stocks. The rate of soil organic carbon sequestration, and the magnitude and quality of soil carbon stocks depend on the complex interaction between climate, soils, tree species and management, and chemical composition of the litter as determined by the dominant tree species (Lal, 2005). Accurate data on carbon sequestration and stocks are limited especially from sub-tropical forests of Bangladesh where diverse forest communities exist within a small country (Salunkhe et al., 2018).

1.2. Justification of the Study

Soils not only contain carbon but also can represent a significant sink for trophospheric CO_2 and play an important role in the carbon cycle in terrestrial ecosystems and in the global carbon balance (Eswaran et al., 1993; Post et al., 1982). Any kind of perturbation in soil carbon stocks may thus significantly influence the atmospheric CO_2 concentration. The SOC concentration strongly affects soil physical and biological properties and thereby is an indicator of soil fertility (Eswaran et al., 1993; Karlen et al., 1999; Smith et al., 2005). The SOC is more sensitive to land management compared to total SOC and, as a result, it is a better index to predict changes in soil quality (Cambardella and Elliott, 1992; Chan, 2001; Fang et al., 2006). Land management practices can markedly affect soil carbon sequestration in different vegetation types (Li et al., 2013 and 2014; Zhang et al., 2014). For example, the removal of forest cover results in widespread impacts on soils (Don et al., 2011; Ellis and Ramankutty, 2008). Despite being a small country, there is diversity in vegetation/forest types in Bangladesh. All possible forest types ranging from evergreen to very dry forests are present in the country. This phenomenon could be attributed to significant climatic and edaphic variations within the country. However, there is a dearth of comprehensive data on biomass and carbon stocks at local, regional, and national levels. Such data is required to work out strategies and policies for mitigating atmospheric CO_2 through conserving different forest vegetation. A clear understanding of carbon dynamics, more specifically, the quantification of the amount of carbon stored in forest soils and vegetation in Bangladesh is vital for a better understanding of the global carbon cycle and for appreciating the role played by Bangladesh forests in climate change mitigation. Monitoring the SOC and forest carbon stocks over a period of time is likely to help to understand the role of human activities.

1.3. Objectives of the Study

The specific objectives of this study are:

a) to determine some soil physical properties of soils such as soil moisture content, soil bulk density, and particle size analysis in both forested and homestead sites in the Sundarban mangrove forests, Sal forests, Chittagong hill forests, Sylhet hill forests, and coastal afforestation,

b) to determine some soil chemical properties of soils such as soil pH, electrical conductivity, organic carbon (OC), and total nitrogen (N) in the forest areas,

c) to quantify soil organic carbon (SOC) stocks at different soil depths in the forest areas,

d) to determine relationship between soil OC and sand%, silt%, clay%, soil moisture content, bulk density, pH, total N, and C:N ratio,

e) to measure forest biomass carbon density in the selected forest areas, and

f) to assess change in soil organic carbon between two sampling times.

1.4. Organization of the Dissertation

There are six chapters in this dissertation. **Chapter 1** is an overview of the research background, justification, and objectives of this research. **Chapter 2** reviews literature regarding soil organic carbon dynamics, carbon sequestration and carbon stocks, distribution, and composition of forests vis-à-vis Bangladesh and estimation and distribution of global forest biomass carbon density. **Chapter 3** deals with research materials and methods, including study areas and their physiography, procedure and preparation of soil samples and different analytical methods for soil sample analyses, estimation of soil organic carbon stocks and measurement of forest biomass carbon density by using different allometric models and statistical analysis. **Chapter 4** represents the study results with respect to the research objectives and a concomitant discussion in light of the research findings. **Chapter 5** draws the conclusions and recommendations from the research study. **Chapter 6** concludes with references.

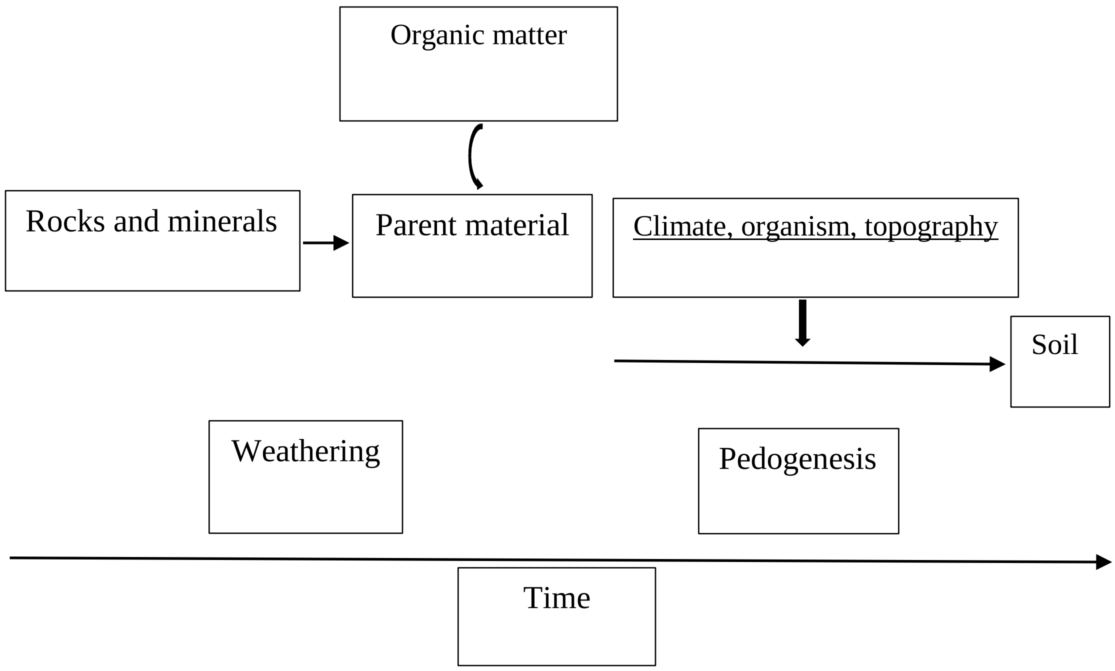
CHAPTER 2

LITERATURE REVIEW

CHAPTER 2
LITERATURE REVIEW

2.1. Soil is a Natural Body

Soil is a natural entity which has evolved through natural processes from natural materials over a long period of time. The materials from which the soils have been formed are called parent materials. Parent materials may be organic and inorganic (Osman, 2013). Mineral parent materials are disintegrated and decomposition products of rocks and minerals. On the other hand, some soils originate from organic parent materials which are residues of past vegetation accumulated under moist or wet conditions. The natural processes associated with disintegration and decomposition of rocks and minerals are collectively known as weathering. When disintegration and decomposition occur during evolution of soil on a bare surface, organisms including plants, animals, and microbes contribute by adding organic matter to the parent materials. Thus, climate and organisms act upon it at a topography and transform it into soil after a long period of time (Jenny, 1941 and 1980). The processes involved in this transformation and soil formation are collectively called pedogenesis.



2.2. Soil is a Dynamic System

Soils continually change at different rates and along different pathways. They are never static for more than shorts period (Schaetzl and Anderson, 2005). Daniels and Hammer (1992) termed soils as four-dimensional systems. Time is the fourth dimension because soils change with time. Soils change physically, chemically and biologically. However, most changes are biophysical and biochemical in nature. There is always exchange of gases (oxygen, carbon dioxide and water vapor) between the soil and atmosphere, infiltration and percolation of water, leaching of materials in suspension and solution and aggregation of particles. Soil minerals are continuously being weathered yielding soluble substances into the soil solution. Plants absorb readily available soluble cations and anions thereby altering the composition of soil solution. On the other hand, soil-dwelling organisms are relentlessly consuming and synthesizing substances leading to modification of the environment. There are always decomposition of organic matter and release of carbon dioxide, mineralization of nitrogen, phosphorus, sulfur and bases, formation of humus and organo-metal complexes, fixation of nitrogen, etc. Despite these changes, the state of the soil always tends to remain at equilibrium with the environment it is exposed to. Thus, there are always complex interactions between the soil and the environment.

2.3. Soil is an Ecosystem

An ecosystem is a unit of organisms interacting among themselves at a space and with their abiotic environmental components in a way that flow materials and energy within the system tends to remain a dynamic equilibrium (Osman, 2013). Ecosystems may be broadly classified as terrestrial and aquatic ecosystems. Further divisions as forest ecosystem, grassland ecosystem, marine ecosystem, lake ecosystem, pond ecosystem, etc., may be done. The soil is a component of all terrestrial ecosystems. It harbors many organisms which interact among them and with the physical and chemical soil environment (Figure 2.1).

Among the biotic components of the soil are the producers such as green plants, algae, and autotrophic bacteria. The consumers including soil animals and predators. The decomposers such as fungi and heterotrophic bacteria, and the transformers such as nitrifiers, denitrifiers and sulfur bacteria. A soil acts as a large number of habitats for a diverse group of organisms which have their own niches that overlap with others.

The organisms have both competitive and cooperative relationships among themselves for functional and structural habits.

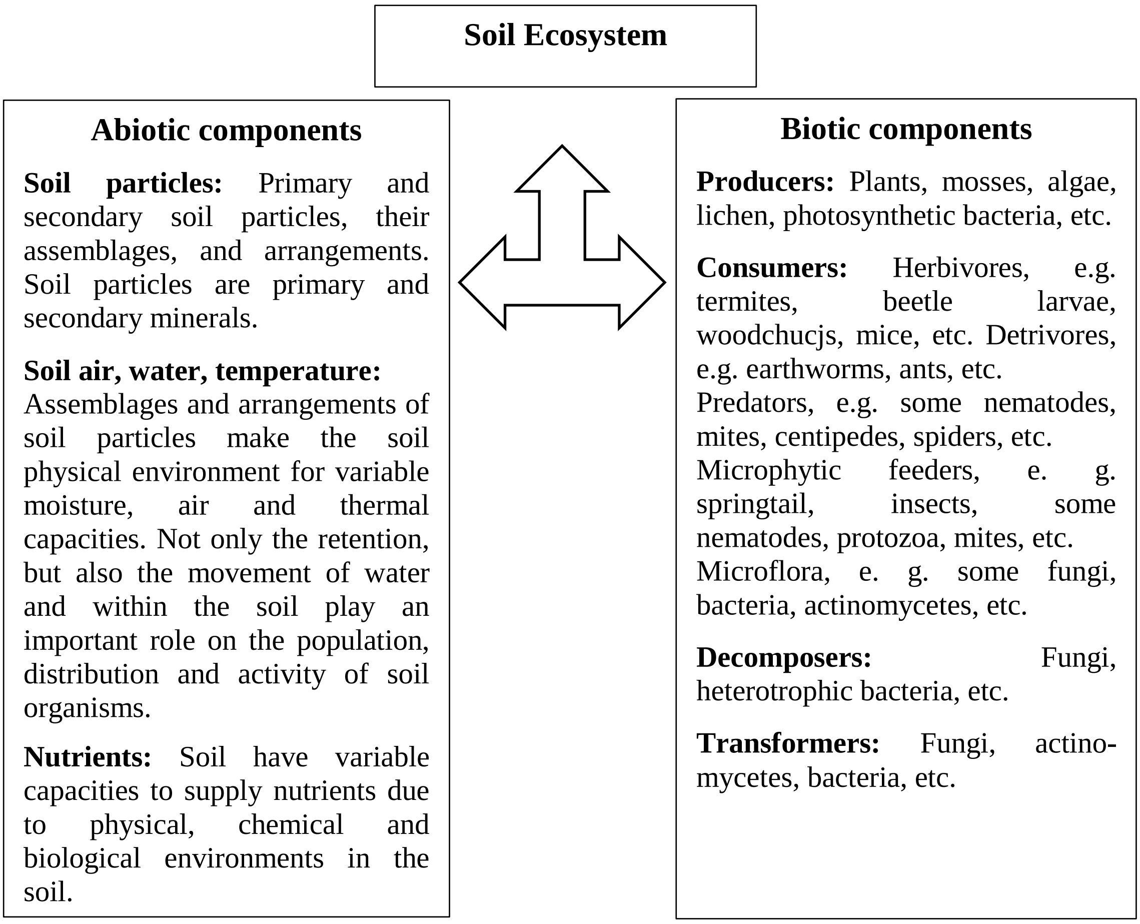


Figure 2.1. Components of soil ecosystem (*Source:* Osman, 2013)

2.4. Soil is a Component of the Environment

Environment may be defined as “that surround an individual or a community at any point in its life cycle” (Lodha, 1996). These include physical and cultural surroundings. Environment consists of the complex of physical, chemical and biotic factors that act upon an organism or an ecological community and ultimately determine its form and survival. An organism or a biotic community interacts with its environment. These interactions between individuals, between populations, and between organisms and their environment form ecological systems or ecosystems.

Environment includes climate (light, temperature, air, humidity, precipitation and wind), lithosphere (rocks and soils) hydrosphere (lakes, streams, groundwater and ocean) and biosphere (organisms–flora and fauna). These environmental components interact to reach equilibrium and form the ecosystems. A permanent change in any of these conditions, such as a change in temperature or intensity of light, is a change in the environment. Change in the environment may be natural, as experienced through the evolution of atmosphere and life, or may be caused by development activities of human. Human-induced environmental changes are abrupt and tax on the health and survival of human itself. Climate affects weathering and determines to a large extent the contents of clay, weatherable minerals, soluble salts, organic matter and nutrients in soil.

On the other hand, soil acts both as a great source and sink of carbon dioxide (CO_2). Further, wet land soils cause emissions of methane (CH_4), hydrogen sulfide (H_2S) and ammonia (NH_3) gases to the atmosphere. Soil properties affect the distribution of natural plants and growth and yield of crop plants. Soil affects qualities of surface and ground water. Better managed watershed areas yield good quality water. Soils may become contaminated with heavy metals. These contaminants may pollute water bodies and affect human health.

2.5. Soil is a Medium of Plant Growth

Soil is one of the factors of plant growth. Terrestrial plants have the anchorage, water, air, nutrients and protection from toxins on soil. Plants need adequate air, water and nutrients in their root zone for optimum growth and yield. For example, plants require some hundred to some thousand grams of water to produce 1.0 g dry matter (Foth, 1990). The capacity of soils to produce air, water and nutrients depends on their physical, chemical and biological properties. It was found that plants suffer from poor air, water and nutrient supply in some soils. There are soil management practices to overcome such soil problems.

Plant species differ in their soil requirements because of their evolution in different environments and due to differences in their genetic makeup. The demands of a particular plant even differ at different growth stages. Lantana (*Lantana camara*) grows well in acid soils and Jhau (*Casuarina equisetifolia*) on saline soils. Soils suitable for rice may not be so for potato. In other words, all soils are not suitable for all plants. So, selection of crop plants according to the characteristics of the soil along with necessary amendments lies behind the success of crop production (Osman, 2013).

2.6. Major Components of Soils

On average, an ideal loam textured surface mineral soil contains 45% mineral matter, 5% organic matter, 25% water and 25% air by volume (Figure 2.2). The volume composition highly varies with soil types. For example, organic matter in soils of warm tropical areas, Ultisols, Oxisols and other soils is very low (<2%) due to rapid decompositions rates. Histosols (organic soils) and holistic horizons in other soils may contain very high (>80%) organic matter. Mollisols (grassland soils) have intermediate organic matter content. Air and water contents in soils are more variable. Some soils are always wet such as hydric soils (soils saturated with water and conducive to the development of hydrophytic vegetation) requiring artificial drainage if they are to be used for agriculture except wetland rice. Some soils such as Aridisols (soils of the dry regions) are continuously dry because of inadequate rainfall or excessive drainage and will grow few plants without irrigation. Most agricultural soils have adequate water to meet vegetation requirement during a considerable part of the year, although plants often suffer during periods of drought (Osman, 2013).

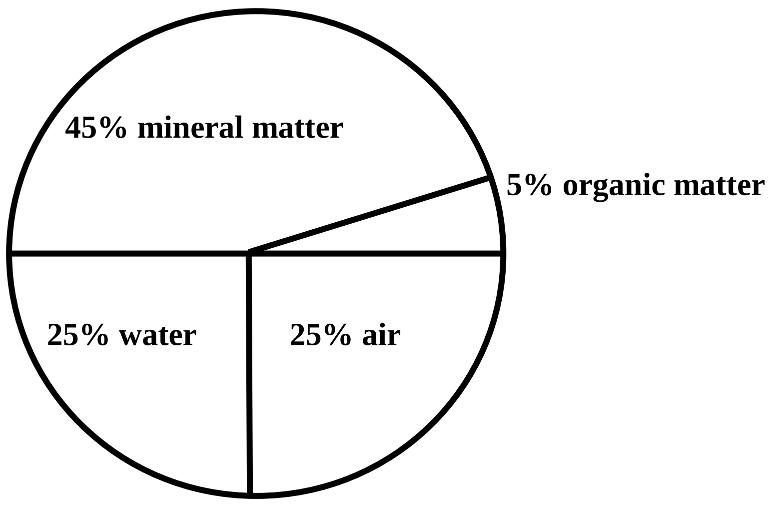


Figure 2.2. Average volume composition of a loam-textured surface soil
(*Source*: Osman, 2013)

2.7. Soil Organic Matter

Soil organic matter (SOM) is an essential component of the soil. It includes plant and animal residues at various stages of decomposition, ranging from fresh undecomposed materials through partially decomposed and short-lived products of decomposition to well-decomposed humus. It affects the state and functioning of other soil components. Loose materials on earth that do not contain organic matter are not soils. Some soils contain high organic matter, even more than 80% by weight (Histosols). Most mineral soils contain <5% by weight SOM (Stanley, 2000). Tropical soils (Oxisols and Ultisols) are known to have low organic matter contents, but Juo and Franzluebbers (2003) reported an average SOM content of about 2 percent. Living organic materials are the plant roots and other soil biota–flora and fauna. Dead materials include plant and animal residues and other intermediate decomposition products. As a component of the soil and as chemical reactants, these dead materials are generally considered as SOM. Surface litter (unless incorporated within the soil) is generally not included as part of the SOM (Juma, 1990).

2.8. Factors Affecting Soil Organic Matter (SOM) Content

Many environmental, edaphic, and management factors affect SOM content. Climate affects SOM content on a global scale. Soil organic matter content increases with increasing rainfall up to a certain level beyond which it decreases. This may be attributed to the higher biomass accretion due to higher moisture supply. After a point, eluviation of organic matter increases. On the other hand, decomposition of organic matter increases as the temperature increases. The rate of decomposition doubles for every 8 or 9ºC increase in mean annual temperature (Anonymous, 2010). So, SOM content decreases from lower to higher temperature regions. Soil texture, structure, water, air, etc. affect the organic matter content. Higher amount of biomass is produced in fine-textured fertile soils. Higher biomass adds larger amounts of organic matter. Decomposition of organic matter is faster in moist arable soils. Under saturated conditions, there is a deficiency of oxygen which reduces organic matter decomposition with a net result of accumulation of SOM.

Soil organic matter content is the highest in the surface soil because organic inputs are generally highest in the surface. It gradually decreases with depth in agricultural and grassland soils and abruptly, with some exceptions in forest soils (Figure 2.3). In some buried soils, subsoil may contain a higher organic matter content. Some soils are Spodosols contain illuvial humus accumulation in the B horizon (Olness and Archer, 2005).

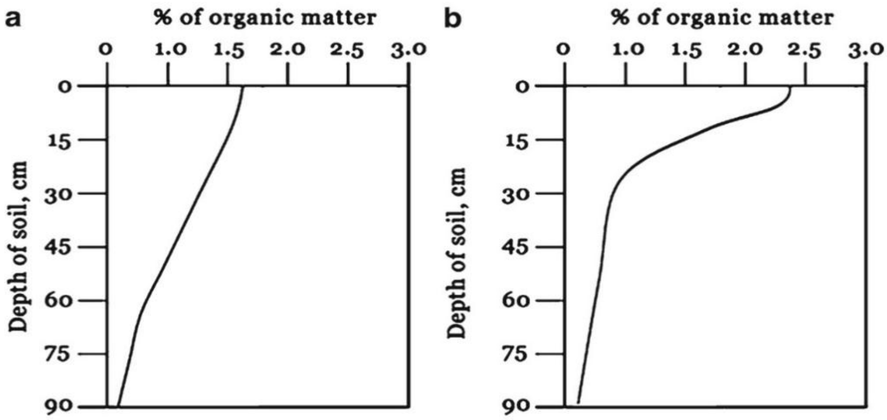


Figure 2.3. Variation in soil organic matter with depth in (a) an agricultural and in (b) a forest soil (*Source:* Osman, 2013)

Vegetation, natural or managed has a profound bearing on the SOM level because different vegetation produces different amount of biomass and of varying decomposability. Cultivation reduces SOM content. Forest and grassland soils are particularly rich in organic matter. When they are brought under agriculture, their organic matter is gradually reduced by enhanced decomposition. Tillage generally favors organic matter breakdown. However, manures, and composts, fallowing, crop rotations, green manure, etc. may improve SOM levels, at least temporarily. Soils at the bottom of slopes generally have higher organic matter because these areas are generally wetter and better in fertility. Some organic matter is lost by runoff from soils of upper slopes (Olness and Archer, 2005).

2.9. Contribution of Soil Organic Matter to Carbon Sequestration

Soil organic matter provides food for microorganisms, stores nutrients, retains water, acts as mulch and performs as a soil conditioner and aggregating agents. It makes the soil friable and fertile. Soil organic matter contributes significantly to the sequestration of carbon. Soil carbon sequestration is the process of transferring carbon dioxide (CO_2) from the atmosphere into the soil through crop residues and other organic solids and in a form that is not immediately reemitted. It represents long-term storage of carbon in soil. This transfer or sequestering of carbon helps offset emissions of fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term agronomic productivity. Soil carbon sequestration can be an effective option of mitigating CO_2 emission that combines with environmental conservation and soil fertility improvement (Smith et al., 2007).

Globally, soil stores approximately 1,500 Pg organic carbon and an additional 900–1,700 Pg inorganic carbon in the surface of 1 m soil. The atmosphere contains □750 Pg carbon as CO_2 (Eswaran et al., 1993). Soil has a carbon stocks three times that of the atmosphere. Thus, soil organic carbon (SOC) can play a significant role in mitigating greenhouse gas emissions. Soil carbon sequestration implies enhancing the concentration/pools of carbon through land-use conversion and adoption of recommended management practices in agricultural, pastoral, and forestry ecosystems and restoration of degraded and drastically disturbed soils. The SOC sequestration involves putting carbon into the surface 0.5–1 m depth through the natural processes of humification (Lal, 2004). A wide range of soil and water management practices can be adopted to sequester atmospheric CO_2 in terrestrial ecosystems. The technical potential of carbon sequestration in terrestrial ecosystems is estimated at 5.7–10.1 Pg carbon per year. This includes carbon sequestration by vegetation and soils. Restoration of degraded and desertified soils is an important mitigation strategy because of its large technical potential for sequestering 1–2 Pg carbon per year (Lal, 2006).

2.10. Soil Carbon Dynamics and Nutrient Cycling

Soil carbon plays a major role in regulating the cycling of plant nutrients, especially nitrogen (N), phosphorus (P) and sulfur (S). This is partly because the organic entities in soil contain these elements combined with carbon and act as a source of nutrients as organic matter undergoes decomposition. Soil carbon is also a source of energy for soil organisms, which are mostly heterotrophs and thus acts as the driver for various biologically mediated processes involved in nutrient transformations. Being a source of nutrients and a controlling factor in nutrient transformations, organic carbon in soil contributes to soil cation exchange capacity (CEC) due to the action of carboxyl groups. Thus, soils with a higher carbon content generally have the ability to retain cations such as calcium (Ca), magnesium (Mg), zinc (Zn), iron (Fe) and many others that are important for plant growth. Organic carbon has an indirect effect on nutrient availability to agricultural crops through its influence on soil physical conditions, especially structural attributes such as the formation and stabilization of aggregates. This in turn has a positive influence on the infiltration and retention of water and the growth of plant roots for agricultural productivity and food security (Powlson et al., 2015).

Soil carbon, the organic moieties that constitute SOM contain substantial quantities of elements such as N, P and S that are highly significant as plant nutrients. The carbon and nitrogen ratio (C : N ratio) of soils surprisingly constant with values almost always in the range between 10 : 1 and 12 : 1. Higher values in the range 15 : 1–20 : 1 occur in peat soils. In a global data set analyzed by Kirkby et al. (2011), the mean C:N ratio was 11 : 1. The measured C:N ratio can vary somewhat according to the amount of fresh plant material in a soil at the time of sampling, which may come from recently added crop residues or in case of soils under grass, be due to dead plant residues. Kirkby et al. (2011) also reported that the C : N ratio of the light fraction organic matter was ranging from 13 : 1 to 21 : 1, more similar to values typical of plants. Further, Kirkby et al. (2011) added in their analyzed data set that the C:S ratio in soil is somewhat more variable than the C : N ratio, but generally fairly constant, and averaged 79 : 1 in a subset of soils where S had been analyzed. Phosphorus content is linked less strongly to carbon, mainly because a substantial fraction of soil P is present in inorganic forms. If only organic forms of P were considered, these authors found a general correlation between carbon and organic P, though much weaker than for N or S. The mean ratio of C:organic P was 133 : 1.

The relatively constant values for the ratio C : N : S : organic P in the stable fraction of soils across a very wide range of soils may be evidence that this material is derived largely from microbial sources, because the ratios in plant material as much more variable. There is evidence from spectroscopic studies that about 85% of the organic N in soil is in the form of amide groups, consistent with being in proteins. However, proteins are among the most labile natural macro molecules, and when added to soil under experimental conditions, normally persist for no more than 2 or 3 days. So, it is surprising to find evidence of their dominant position within SOM. It is thought that this unexpected persistence is a result of stabilization processes that include chemical entrapment by association with humic substances and physical adsorption on clay surfaces (Kirkby et al., 2011).

Crops growing in unfertilized treatments of long-term experiments typically removed at least 20 kg N/ha annually and annual plant uptake in semi-natural ecosystems could also be of this order. Although part of this N uptake will be derived from N deposited in rain or through dry deposition from the atmosphere, in most cases the majority is from the mineralization of SOM. In normal agricultural situations in the temperate regions, it is common for N derived from this source to account for at least 30% of total N uptake by crops (Macdonald et al., 1997). In tropical and subtropical environments, the contribution of SOM is even greater, with an average of 79% of total N uptake by crops being derived from soil organic N in one coordinated set of experiments with 13 sites in nine countries (Dourado-Neto et al., 2010).

2.11. Global Challenge for Soil Carbon

By 2050, the world's population is expected to reach 9.6 billion (UN, 2013). This enormous demographic pressure creates four major global challenges for Earth's soils over the coming four decades. The challenges for global soils are to meet the anticipated demands of humanity (Godfray et al., 2010) to: (i) double the food supply worldwide; (ii) double the fuel supply, including renewable biomass; (iii) increase by more than 50% the supply of clean water, all while acting to (iv) mitigate and adapt to climate change and biodiversity decline regionally and worldwide. The demographic drivers of environmental change and the demand for biomass production are already putting unprecedented pressure on earth's soils (Banwart, 2011). Dramatic intensification of agricultural production is central among proposed measures to potentially double the global food supply by 2050. An urgent priority for action to ensure that soils will cope worldwide with these multiple and increasing demands (Victoria et al., 2012).

Soils have many different essential life-supporting functions, of which growing biomass for food, fuel and fibre is but one (Blum, 1993; European Commission, 2006; Victoria et al., 2012). Soils store carbon from the atmosphere as a way to mediate atmospheric greenhouse gas levels. Soils filter contaminants from infiltrating recharge to deliver clean drinking water to aquifers and provide habitat and maintain a microbial community and gene pool that decomposes and recycles dead organic matter and transforms nutrients into available forms for plants. Soils release mineral nutrients from parent rocks, and store and transmit water in ways that help to prevent floods. These functions underpin many of the goods and services that can lead to social, economic and environmental benefit to humankind. Specific land uses can create trade-offs by focusing on the delivery of one or a few of these functions at the expense of others. Under the pressures of increasingly intensive land use when decisions are made on land and soil management, it is essential to protect and to enhance the full range of the essential life-sustaining benefits that soil provides.

The build-up of organic matter and carbon is one of the key factors in the development of ecosystem functions as soil forms and evolves. Thus, carbon loss is one of the most important contributions to soil degradation. Furthermore, this central role of carbon across the range of soil functions establishes a buffer function for SOM whereby loss of soil carbon results in a decline in the soil functions and maintaining or enhancing soil carbon conifers resilience to these under pressure from environmental changes (Noordwijk et al., 2015). The global soil resource is already showing signs of serious degradation from human use and management. Soil degradation has escalated in the past 200 years with the expansion of cultivated land and urban dwellings, along with an increasing human population. Degradation continues with soil and soil carbon being lost through water and wind erosion, land conversion that is associated with accelerated emissions of greenhouse gases and the burning of organic matter for fuel or other purposes. Significant degradation has taken place since the industrial revolution. Recent and ongoing degradation is substantial. Bulk soil loss from erosion remains severe in many locations with the accompanying loss of soil functions. The release of carbon and nitrogen from soil as the greenhouse gases CO_2, CH_4 and N_2O (nitrous oxide) continues to contribute to global warming (Table 2.1). The capacity of soils to deliver ecosystem goods and services which lead to human benefits and the degree to which these benefits are lost due to soil degradation varies significantly with geographical location. The global results in Table 2.1, provide a first indication of the regional and national pressures on soil and the associated trends in the gain or loss of soil functions.

Table 2.1. Global soil carbon fact sheet

Sl.	**Description**	**Amount** (Approx.)	**References**
1.	Amount of soil carbon in top 1 m of earth's soil (2/3 as organic matter, organic C is around 2 × greater C content than earth's atmosphere)	2200 Gt	Batjes, 1996

2.	Fraction of antecedent soil and vegetation carbon characteristically lost from agricultural land since 19^{th} century	60%	Houghton, 1995
3.	Fraction of global land area degraded in past 25 years due to soil carbon loss	25%	Bai et al., 2008
4.	Rate of soil loss due to conventional agriculture tillage	□1 mm $year^{-1}$	Montegomery, 2007
5.	Rate of soil formation	□ 0.01 mm $year^{-1}$	Montegomery, 2007
6.	Global mean land denudation rate (rate of land lowering due to chemical and physical weathering losses)	□ 0.06 mm $year^{-1}$	Wilkinson & McElroy, 2007
7.	Rate of peat lands loss due to drainage compared to peat accumulation rate	20x faster	Joosten, 2009
8.	Equivalent fraction of anthropogenic greenhouse gas emissions from peat land loss	6% annually	Joosten, 2009
9.	Soil greenhouse gas contributions to anthropogenic emissions in CO_2 equivalents	25%	IPCC, 2007

(*Source*: Banwart et al., 2014)

2.12. Global Distribution of Soil Organic Carbon

The distribution of soil organic carbon (SOC) is basically controlled by climate (moisture regime, temperature), soil properties (parent material, clay content, cation exchange capacity), vegetation and land use. The worldwide distribution of SOC roughly reflects the zonal distribution of rainfall (McLauchlan, 2006), with more carbon occurring in more humid areas. Most SOC is found in the northern hemisphere, simply because it contains more land mass in humid climates than the southern hemisphere. Also, temperature plays an important role in global SOC distribution (Amundson, 2001), with SOC pools decreasing rapidly with increasing temperatures (Lal, 2002). McLauchlan (2006) reported that cool conditions impede decomposition and limit evapotranspiration, so that soils in cool climates are with the same amount of rainfall also wetter than in warm climates. The temperature is not a substantial constraint on SOC formation is illustrated by the occurrence of deep peat deposits in both tropical and polar humid areas. Climate influences both sides of the SOC balance by its effect on both input (primary productivity) and output (decomposition). Within climatic zones, the amount of SOC is determined by soil moisture i.e. in addition to climate, determined by parent material, relief and soil texture. Parent material determines the composition and content of clay minerals, which generally stabilize SOM (McLauchlan, 2006). In vertisols, andosols and podzols, complexation and chelation between organic matter and the inorganic matrix occur, whereas soils dominated by kaolinitic clays and rich in iron and aluminium oxides are less prone to carbon storage.

The carbon content of soils under different land cover types varies substantially (Table 2.2). Within the biomes, natural soil carbon densities may be modified strongly by land use, which may substantially change the carbon fluxes to and from the soil. Forests generally have the largest (all year-around) input of recalcitrant material, grasslands a large input of often less recalcitrant material, whereas croplands have a small input of rather labile material only when a crop is growing (Smith, 2008). Within the land-use types, land-use intensity, drainage conditions and soil type (organic versus mineral soils) play a further important role in controlling soil carbon content, losses or gains.

Table 2.2. Indicative soil organic carbon pool in various biomes and land cover types.

Sl. No.	**Biomes**	**Area** (million ha)	**Soil carbon content** Mg ha^{-1} (mean)	Mg total
1.	Boreal and sub-arctic peatland	340	1,340	455,600
2.	Tundra	880	218	191,840
3.	Boreal forest, wet	690	193	133,170
4.	Tropical woodland and savannah	2,400	54	129,600
5.	Cool temperature steppe	900	133	119,700
6.	Tropical peatland	44	2,000	88,000
7.	Tropical forest, wet	410	191	78,310
8.	Tropical forest. Warm	860	71	61,060
9.	Tropical forest, moist	530	114	60,420
10.	Boreal forest, moist	420	116	48,720
11.	Temperate forest, cool	340	127	43,180

12.	Cool desert	420	99	41,580
13.	Temperate thorn steppe	390	76	29,640
14.	Tropical forest, dry	240	99	23,760
15.	Temperate forest, very dry	360	61	21,960
16.	Boreal desert	200	102	20,400
17.	Warm desert	1,400	14	19,600
18.	Tropical desert bush	120	20	2,400

(*Source*: Amundson, 2001; Lal, 2002; Victoria et al., 2012)

2.13. Variation of Soil Carbon across the Ecosystems

The worldwide distribution of soil organic carbon (SOC) reflects rainfall distribution, with greater accumulations of carbon in more humid areas. Most SOC is found in the northern hemisphere, which contains more land mass in humid climates than the southern hemisphere. Temperature plays a secondary role in global SOC distribution. Within climatic zones, the amount of SOC is determined by soil moisture, which in turn is influenced by relief, soil texture and clay type. The soils of savannas are relatively low in SOC, but the carbon stocks of savanna soils are significant globally due to the large area covered by this biome (Bationo et al., 2014). In contrast, peatlands cover only □2% of the global land area but contain almost one-third of global soil carbon, making them the most space-effective carbon store among all terrestrial ecosystems (Beaulne et al., 2021).

The current rate of change in SOC is attributable mainly to worldwide land-use intensification and the conversion of new land for food and fibre production. The clearing of forests or woodlands and their conversion into farmland in the tropics reduces the soil carbon content, mainly through reduced production of detritus, increased erosion rates and decomposition of SOM by oxidation. Modern industrialized crop production relies on monocultures of highly efficient cash crops, which generally create a negative carbon budget. Alternative uses of crop residues for fodder, fuel or industrial applications exacerbate this trend of decreasing carbon return to the soil. Intensive land uses are also expanding into areas where SOC stocks are less resilient or soil conditions are marginal for agriculture. For example, semi-arid savannas and grasslands, tropical rainforests and peatlands are all being converted to arable land at an increasing rate (Bationo et al., 2014). While temperate humid grasslands lose about 30% of their SOC after 60 years of cultivation (Tiessen et al., 1993), soil carbon stocks in semi-arid environments can decrease by 30% in less than 5 years when native vegetation or pastures are converted to cropland (Zach et al., 2006). Cultivation of tropical forest soils cause losses of more than 60% of original SOC stocks in just a few years (Brown and Lugo, 1990).

Soil erosion is the most widespread form of soil degradation and has a strong impact on the global carbon cycle (Lal, 2003). Lal also reported that being a selective process, erosion preferentially removes the light organic fraction of a low density of <1.8 mg/m^3. A combination of mineralization and carbon export by erosion causes a severe depletion of the SOC pool on eroded compared with un-eroded or slightly eroded soils. In addition, the SOC redistributed over the landscape or deposited in depression sites may be prone to mineralization because of breakdown of aggregates, leading to exposure of hitherto encapsulated carbon to microbial processes among other reasons. Adoption of conservation-effective measures may reduce the risks of carbon loss and promote sequestration of carbon in soil and biota (Lal, 2003).

Several studies in Africa have shown the existence of steep gradients in SOC status between fields located close to homesteads and those located further away (Prudencio, 1993). These gradients reflect the site-specific management practices the land users apply to the respective areas under production. Fields located closer to homesteads benefit more from organic and inorganic nutrient application compared to those located further way (Table 2.3). High SOM status in the home fields is often observed to be related positively with high crop yield (Carsky et al., 1998).

Table 2.3. **Soil fertility of various fields within a farm in Burkina Faso**

Field	**Organic C** ($g\ kg^{-1}$)	**Total N** ($g\ kg^{-1}$)	**Available P** ($mg\ kg^{-1}$)	**Exchangeable K** ($mmol\ kg^{-1}$)
Home garden	11–12	0.9–1.8	20–220	4.0–24
Village field	5–10	0.5–0.9	13–16	4.1–11

Bush field	2–5	0.2–0.5	5–16	0.6–1

(*Source*: Prudencio, 1993)

2.14. Threats to Soil Carbon

The global stocks of soil carbon are under threat, with consequences for the widespread loss of soil functions and an increase in greenhouse gas emissions from land and acceleration of global warming (Lal, 2010a). In many locations, soil functions are already compromised. Some of the consequences include increased erosion, increased pollution of water bodies from the N and P loads that arise from erosion, desertification, declining fertility and loss of habitat and biodiversity (Lal, 2010b). The primary control on the global distribution of soil carbon is rainfall with greater accumulation of SOM in more humid regions. A secondary control is temperature with greater organic matter accumulation in colder regions when otherwise sufficiently humid conditions persist regardless of temperature. Under similar climatic conditions, wetter soils help to accumulate soil carbon by limiting rates of microbial respiration since oxygen (O_2) ingress is restricted by the gas diffusion barrier created by greater water content (Batjes, 2011). Relatively drier conditions favor O_2 ingress and aeration of soil, thus accelerating soil carbon decomposition. Furthermore, physical disturbance such as tillage breaks up larger soil aggregates and exposes occluded carbon within aggregates to O_2 and biodegradation, thus creating conditions that allow greater soil carbon loss.

With enough water, nutrients and O_2 supply–biological processes are relatively faster at higher temperature hence greater rates of productivity and decomposition. Thus, warm-humid conditions favor soil carbon accumulation due to high productivity, while cool-humid conditions favor soil carbon accumulation due to low decomposition rates. Soil carbon varies substantially geographically with land cover. For example, savannah has relatively low soil carbon content but covers a large area globally. On the other hand, peatlands have extremely high carbon content but cover only □2% of the global land surface (Beaulne et al., 2021). Degraded land coincides in large part with earth's drylands, due to low productivity from low water availability and relatively high decomposition due to dry, well-aerated and warm soils.

From these controls on soil carbon content, it is clear that predicted changes to regional as well as global climate in the coming decades will create important impacts on soil carbon (Conant et al., 2011; Schils et al., 2008). Drier and warmer conditions are expected to coincide with greater potential for loss of soil carbon and the associated loss of soil functions. Loss of permafrost will expose accumulated carbon in cold regions to much greater rates of microbial decomposition (Schuur and Abbot, 2011). Furthermore, the demographic drivers of more intensive land use raise the prospect of greater physical disturbance of soils, e.g. tilling of grasslands. More intense tillage and greater areas of mechanical tillage are expected to coincide with higher loss of soil carbon due to greater exposure of soil carbon to O_2 (Powlson et al., 2011).

2.15. Forest Areas of Bangladesh

The total area of forest land in Bangladesh is about 2.60 million ha (FD, 2016). Out of which 1.60 million ha is under the control of the Forest Department (FD). Un-classed State Forests (USF) extending over an area of 0.73 million ha were until recently under the control of the Deputy Commissioner and now have been placed under the control of District Councils. But there is a controversy and the National Forest and Tree Resources Assessment showed that the total area of forest land was 1.44 million ha, which is about 9.8% of the total land (NFA, 2007). However, tree cover in forest land amounts to only 6.70% (FAO, 2009) much less that 17.62% of the land that has been designated as forest lands (FD, 2016). Contrarily, Global Forest Resources Assessment indicates that total forest area of Bangladesh is 1.43 million ha i.e. 11% of the land area of the country (FAO, 2015). The per capita forest area in Bangladesh is less than 0.015 ha (Islam, 2013) against the world average of 0.60 ha (FAO, 2010).

The state-owned forests are eccentrically distributed in the country (Figure 2.4 Forest cover map). Over 90% of state-owned forest land is concentrated mostly in 12 districts in the eastern and south-western regions of the country and out of 64 districts, 32 districts have no state-owned forest at all (BBS, 2016). The two most common types of forest namely hill forest and mangrove forest cover more than 68% of total forest area (Figure 2.5).

Privately owned village forests, also known as homestead forests totaling an area of 0.27 million ha (Hammermaster, 1981) are scattered throughout the country. Almost all the village area (2.86 million ha) is covered by trees of varying density and only a very small area has no tree cover at all (NFA, 2007). Although meager in size, an estimated 70% timber, 90% of firewood, 48% of sawn and veneer logs, and almost 90% of bamboo requirements are met from homestead forests (Douglas, 1982). Almost 50% of the area of Bangladesh has tree cover and more than 30% of the cultivated land has low percentage of tree cover (NFA, 2007). The location, area, major types and main economic resources provided by major forest types in Bangladesh were shown in Table-2.4.

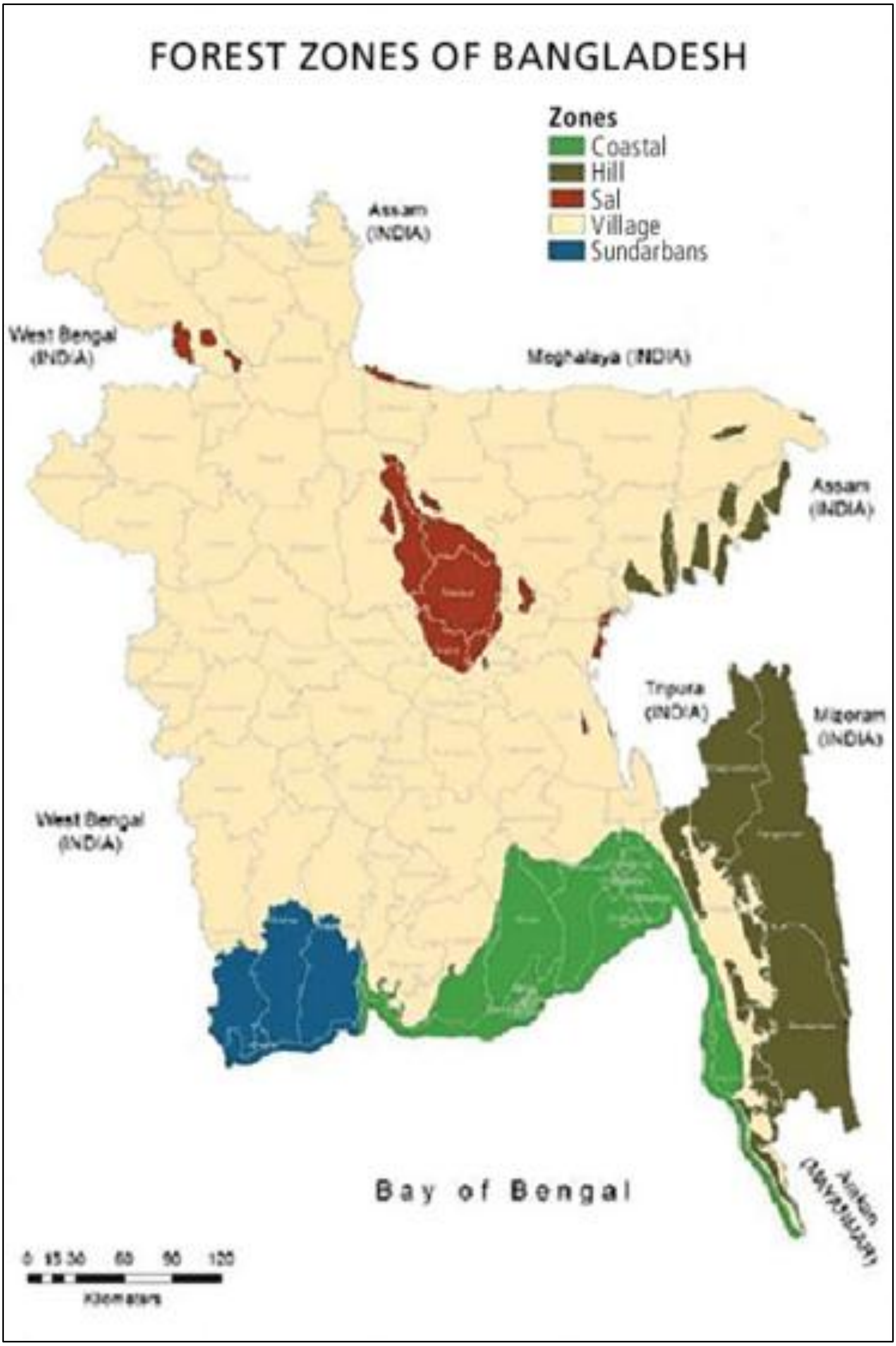


Figure 2.4. Forest Zones of Bangladesh

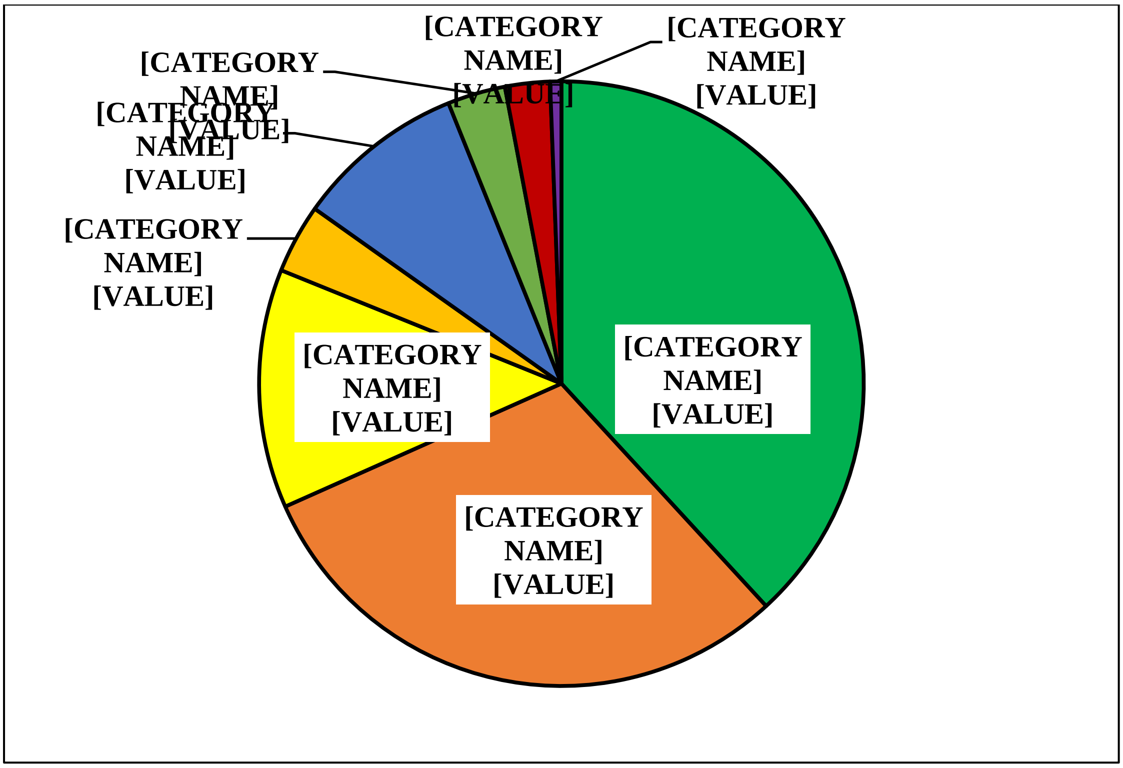


Figure 2.5. Forest area of Bangladesh by forest types

Table 2.4. Distribution of major forest types in Bangladesh

Forest Type	**Location**	**Area** (million ha)	**Remarks**
Hill Forest	Eastern part extending over Sylhet, Habigonj, Moulavibazar, CHTs, Chittagong and Cox'sbazar	0.67	Under the control of FD. Major produce: large saw log, poles, firewood, thatching materials and bamboo
Natural Mangrove (Sundarban)	South-West in Khulna, Bagerhat and Satkhira	0.60	Includes 0.17 million ha water area. Major produce: timber, poles, firewood, pulpwood, thatching materials, etc.
Mangrove Afforestation	Along the coastal zone	0.19	Major produce: firewood, pulpwood, etc.

Forest Type	**Location**	**Area** (million ha)	**Remarks**
Sal Forest	Chiefly in the central region in Dhaka, Gazipur, Tangail, Sherpur, Cumilla. Small patches also found to occur in Dinajpur, Thakurgaon, Panchagar, Rangpur, and Noagaon in the north-western region	0.12	Indigenous Sal and plantation of short rotation exotics for poles, posts and firewood.
Un-classed State Forest (USF)	Hill Tracts districts	0.73	Under the control of district councils, subject to shifting cultivation. Major produce: bamboo, thatching materials and firewood.
Swamp Forest	Mainly in Sunamgonj and Sylhet districts in the north-eastern part	0.02	Hijal (*Barringtonia acutangula*) and Koroch (*Pongamia pinnata*) are the main species of the forest. The swamp forests support fresh water fisheries and are vital spawning grounds.
Village Forest	Scattered throughout the country mostly on the homestead land	0.27	Almost all the village area is covered by trees of varying density. Major produce: timber, bamboo, poles, posts and firewood.

(*Source*: FD, 2016; NFA, 2007)

2.16. Distribution and Composition of Forests in Bangladesh

2.16.1. Hill forests

The hill forests of Bangladesh are situated dominated in the eastern border and other region of the country in relatively high-altitude hills found in Chittagong Hill Tracts (CHTs), Chittagong, Cox's Bazar and Sylhet. The total area of hill forests is 0.67 million ha, which is 4.7% of the country's surface area and 44% of the total forest land managed by FD. Hill forests are rich in diverse varieties of flora and fauna. Hill forests of Bangladesh are ecologically divided into two classes: (i) tropical wet evergreen forests, and (ii) tropical semi-evergreen forests (Das, 1990).

The tropical wet evergreen forests of this country are an important forest type in terms of biodiversity, forest assets and environmental concerns. These are magnificent dense evergreen forests rich in flora and fauna. The trees in the top canopy reach a height of 45–50 m. A few semi-evergreen or deciduous tree species may occur, but they do not really change the evergreen nature of the forests. The forests floral diversity is rich with epiphytes, orchids, and woody and non-woody climbers, ferns, mosses, aroids and palms, particularly in northern shady moist places. Herbs and grasses are abundant, and the undergrowth is a tangle mass of shrubs, bamboo and cane. These forests occur usually in hills and moist shady areas in CHTs (Bandarban, Khagrachari and Rangamati Hill District), Chittagong, Cox's Bazar, Sylhet, Moulavibazar and Habigonj (Das, 1990). Dominant tree species are Boilam (*Anisoptera scaphula*), Champa (*Michelia champaca*), Chapalish (*Artocarpus chama*), Civit (*Swintonia floribunda*), Garjon (*Dipterocarpus turbinatus*, *D. alatus* and *D. costatus*), Narikeli (*Ptertgota alata*), Segun (*Tectona grandis*), Telsur (*Hopea odorata*), etc (Hossain, 2015).

The tropical semi-evergreen forests occur in more exposed dry locations of Cox's Bazar, Chittagong, CHTs and Sylhet. The top canopy species of the tropical semi-evergreen forests reach a height of 25–50 m. This forest is predominated by the evergreen species, but many deciduous species are also found there. As a result, during winter the forest gives a semi-evergreen (green cover with some distinct brown leafless tree crowns) view to distinguish it from the pure evergreen forests. Many of evergreen forests also occur in this type of forests.

2.16.2. Sal forests

The tropical moist deciduous forests are popularly known as sal forests. These forests occur in Dhaka, Gazipur, Tangail, Mymensingh, Sherpur, Jamalpur, Netrokona, Dinajpur, Panchagar, Rangpur, Noagaon, and a small patch in Cumilla districts (Das, 1990). In these forests, the predominant species is Sal (*Shorea robusta*). The trees are 10–25 m in height, and mostly deciduous. Associate species are Palash (*Butea monosperma*), Haldu (*Haldina cordifolia*), Sidhajarul (*Lagerstroemia parviflora*), Kumbi or Gadila (*Careya arborea*), Hargoza or Ajuli (*Dillenia pentagyna*), Bhela or Beola (*Semecarpus anacardium*), Koroi (*Albizia* spp.) Gandhigazari (*Miliusa velutina*), Menda (*Litsea monopetala*), Kusum (*Schleichera oleosa*), Chapalish (*Artocarpus chama*), Udal (*Sterculia villosa*), Bahera (*Terminalia bellirica*), Kurchi (*Holarrhena antidysenterica*), Horitaki (*Terminalia chebula*), Silbhadi (*Garuga pinnata*), Royna or Pitraj (*Aphanamixis polystachya*), Sheora (*Streblus asper*), Sonalu (*Cassia fistula*), Assar or Datoi (*Grewia nervosa*), Amloki (*Phyllanthus emblica*), etc. (Hossain, 2015).

2.16.3. Mangrove forests

Mangrove forests, both natural and plantations are very important forest resources in Bangladesh. These are also called littoral swamp forests. These are mainly evergreen forests of varying density and height, always associated with wet soils. The mangrove forests are well developed in the Sundarban on the Ganges-Brahmaputra Delta, but very poorly developed in the Chokaria Sundarban (Siddiqi, 2001). The Sundarban mangrove area is now a World Heritage Site. Sundari (*Heritiera fomes*) is the dominant tree species from which it derives its name. The total area of the Bangladesh Sundarban is 6,017 km^2, which is the single largest natural mangrove forest in the world. It is about 4.2% of the total land area of Bangladesh and about 44% of the forest land in the country. Other associate tree species of Sundari are Gewa (*Excoecaria agallocha*), Baen (*Avicennia officinalis*), Goran (*Ceriops decandra*), Kankra (*Bruguiera sexangula*), Golpata (*Nypa fruticans*), Keora (*Sonneratia apetala*) and Garjan or Baragoran (*Rhizophora mucronata*). Many other species also constitute the tidal or mangrove vegetation of Bangladesh (Hossain, 2015).

The Sundarban Reserve Forest has been managed as a protective and productive forest since 1879. The Sundarban are a very vital natural forest providing many products, such as timber, fuelwood, fish, crabs, thatching materials, honey, bee wax and shells (Siddiqi, 2001). In addition, it supports a very rich and diverse flora and fauna (Das and Siddiqi, 1985; Siddiqi, 2001). It is the largest remaining natural habitat for the Royal Bengal Tiger. Some 6,00,000 people are directly dependent on these resources for their livelihood. The mangrove forest acts as a natural barrier to cyclones and tidal bores. It protects the dense population and agricultural crops in the mainland. The Sundarban also act as the world's largest mangrove carbon sink. These are also an important spawning ground for fishes and harboring a very rich aquatic biodiversity. Unfortunately, the other natural mangrove forest known as the Chokaria Sundarban has already degraded for cultivation of salt, shrimp and habitations. However, the coastal plantations of Keora (*Sonneratia apetala*) and Jhau (*Casuarina equisetifolia*) are very promising. These provide shelter, wood and amenity for the coastal people of the country (Hossain, 2015).

2.16.4. Homestead forests

Planting trees near homesteads is a traditional land use system in Bangladesh. Homesteads forests develop as small groves scattered around homesteads through ecological and anthropogenic selections (Alam and Masum, 2005). Multi-layered vertical stratification, species diversity and diversity of economic plants rather than number of individual species are characteristic features of Bangladesh homestead forests. The homestead flora of Bangladesh ranges from seasonal annual herbs to woody perennials including indigenous and exotic species of multiple uses (Khan and Alam, 1996). The homestead vegetation can broadly be stratified into three strata (upper, mid and lower). Trees are the dominant and common feature of the homestead flora of Bangladesh. Common of the upper stratum are Silkoroi (*Albizia procera*), Pitraj (*Aphanamixis polystachya*), Deuwa (*Artocarpus lacucha*), Kanthal (Artocarpus heterophyllus), Debdaru (*Polyalthia longifolia*), Chatian (*Alstonia scholaris*), Neem (*Azadirachta indica*), Chalta (*Dillenia indica*), Am (*Mangifera indica*), Akashmoni (*Acacia auriculiformis*), Jalpai (*Elaeocarpus floribundus*), Shimul (*Bombax ceiba*), Kalojam (*Syzygium cumini*), Raintree (*Samanea saman*), Mahogany (*Swietenia mahagoni*), Tentul (*Tamarindus indica*), Toon (*Toona ciliata*), Babla (*Acacia nilotica*), Jarul (*Lagerstroemia speciosa*), Botgach (*Ficus benghalensis*), Ashwath (Ficus religiosa), Dumur (*Ficus racemosa*), Eucalyptus (*Eucalyptus camaldulensis*), Supari (*Areca catechu*), Kadam (*Neolamarckia cadamba*), Tal (*Borassus flabellifer*), Narikel (*Cocos nucifera*), Gamar (*Gmelina arborea*), Mandar (*Erythrina indica*), Jiol (*Lannea coromandelica*), and Menda (*Litsea monopetala*) (Khan and Alam, 1996).

The mid stratum is dominated by medium-size to small trees, and bamboos. Among them common species are Kurchi (*Holarrhena, pubescence*), Assar or Datoi (*Grewia nervosa*), Jambura (*Citrus grandis*), Punial (*Ehretia serrata*), Sinduri (*Mallotus philippensis*), Sonalu (*Cassia fistula*), Jilapi (*Pithecellobium dulce*) and Khejur (*Phoenix sylvestris*). Besides, Barak (*Bambusa balcooa*), Mirtinga (*Bambusa cacharensis*), Kanakcaich (*Bambusa comillensis*), Makla (*Bambusa nutans*), Korjaba (*Bambusa salarkhanii*), Mitinga (*Bambusa tulda*) and Baizza (*Bambusa vulgaris*) are common bamboo species. Common shrubs include Basak (*Adhatoda zeylanica*), Arhar (*Cajanus cajan*), Daton (*Glycosmis arborea*), Lebu (*Citrus limon*), Dhaincha (*Sesbania grandis*), Mendi (*Lawsonia alba*), Akanda (*Calotrops gigantea*), Camini (*Murraya enotica*), etc. Many of them have medicinal value, and some of them are used as hedge plants. Hijal (*Barringtonia acutangula*), Barun (*Crataeve magna*), Mandar (*Erythrina indica*), Karach (*Pongamia pinnata*), Pitali (*Trewia nudiflora*) are common tree species that grow along water edges in low-lying areas. Jalibet (*Calamus tenuis*) is a common rattan of the village forests (Alam et al., 1991; Hossain, 2015).

2.17. Forests Degradation of Bangladesh

Degradation of forests and their resources have been occurring due to manifold reasons. Among others, major causes of forests degradation and destruction include deforestation, unscrupulous felling, encroachment of forest lands and new settlements for growing population, land grabs by powerful elites, illegal wood cutting, leaf-litter collection, dependency on forests for fuel-wood and grazing, intentional forest burning, jhum or shifting cultivation, etc. Conversion of forest lands into agriculture, infrastructure development, urbanization, industrialization, over-exploitation of economically important species such as medicinal, fodder and dye, indiscriminate use of forests wood in brick fields and in other small industries, and total clearing of undergrowth and excess consumption of forest materials for domestic purposes are another important reason for forest degradation. In addition, natural calamities such as torrential rainfall, occasional landslide, soil erosion and cyclones, increase of salinity, pest and diseases (e.g. top dying of Sundari diseases in the Sundarban) are also major causes of depletion and degradation of forest lands and forest resources (Hasan and Alam, 2006; Hossain, 1998; Hossain et al., 2008; Salam et al. 1999). Between 1990 and 2015, Bangladesh annually lost 2600 ha of primary forest (FAO, 2015). Primary forest land gradually decreased from 1.49 million ha in 1990 to 1.42 million ha in 2015. Thus, annual rate of deforestation in Bangladesh was 0.2% during 1990-2015 (FAO, 2015). Bangladesh Forest Inventory (BFI) report on the tree and forest resources of Bangladesh (GoB, 2020) indicated that the highest decreases in tree cover occurs in plain land sal forest (18%) followed by shifting cultivation (14%) and hill forest (7%).

2.18. Contribution of Forests to Carbon Sequestration and Carbon Stocks

Carbon sequestration is the process of capturing, securing and storing carbon dioxide from the atmosphere. Interest in terrestrial carbon sequestration has increased to explore opportunities for climate change mitigation. Carbon sequestration is the process by which atmospheric carbon dioxide is taken up by trees, grasses, and other plants through photosynthesis and stored as carbon in biomass (trunks, branches, foliage, and roots) and soils. The sink of carbon sequestration in forests and wood products helps to offset sources of carbon dioxide to the atmosphere, such as deforestation, forest fires, and fossil fuel emissions. Sustainable forestry practices can increase the ability of forests to sequester atmospheric carbon while enhancing other ecosystem services, such as improved soil and water quality. Planting new trees and improving forest health through thinning and prescribed burning are some of the ways to increase forest carbon in the long run. Harvesting and regenerating forests can also result in net carbon sequestration in wood products and new forest growth (USDA, 2010).

Forests cover about 31% of the earth's land area, corresponding to about 4 billion ha (FAO, 2011). Lorenz and Lal (2010) reported that the smallest fraction is temperate forests, covering only 5%; boreal forests cover about 11% and tropical forests 15%. They also stated that regarding the carbon stocks of forests, not only the different forests biomes essentially impact the potential carbon storage, but also different management practices; all forest ecosystems sequester carbon by the uptake of atmospheric CO_2 via photosynthesis. FAO (2011) reported that more than half of the total forest areas can be attributed to only five countries: Russia, Brazil, Canada, the United States of America (USA) and China. They also reported that deforestation declined from 16 million ha year^{-1} in the 1990s to 13 million ha year^{-1} from 2000–2010, even though it is still exceeding afforestation efforts. Prime deforestation activities occur in the tropical regions, while afforestation primarily takes place in the temperate and boreal zones. South America and Africa have the largest deforestation and lowest afforestation rate, losing 4 million ha year^{-1} and 3.4 million ha year^{-1} during 2000–2010, respectively. During the same time, forests in Europe and Asia were expanding, especially China carries out large afforestation measures (FAO, 2010). These areas, however, consist mainly of plantation forests. In whole East Asia, these forests account for up to 35% of their total forest areas followed by Europe (excluding Russia) with 27%. In a global perspective, 7% constitute planted forests and 36% primary forests. More and more forests are included in management plans, with a trend towards sustainable forest management (FAO, 2010). By now, two-thirds of the world's forests are under a national forests program (FAO, 2011). Since forests provide multiple environmental services, it is difficult to designate forests for one specific use. About 24% of all forests provide a "multiple use", meaning that their management considers a combination of several environmental services, e.g. protection of soil and water, production of goods, provision of social services and conservation of biodiversity. Yet, forests (30%) are predominately used for production of wood and other forest products, the remaining are mainly subject to conservation of biodiversity (FAO, 2010).

Forests are of paramount importance to the global carbon cycle since they store about half of the total terrestrial carbon. Boreal forests represent the greatest share in terrestrial carbon stocks, containing 26%. Temperate forests account only for 7%, while the carbon stocks in tropical forests amounts to 20% of the terrestrial carbon stocks (Nieder and Benbi, 2008). As stated in the Global Forest Resources Assessment Report conducted by FAO (2010), the carbon stocks in the world's forest ecosystems amount to 162 t C/ha in 2010, of which 45% were stored in forests soils, closely followed by biomass carbon stocks with 44% of the total forest carbon stocks. Dead wood and forest floor carbon constitute 11%. Dixon et al. (1994) reported that up to 80% of all above-ground carbon and 40% of all below-ground carbon is stored in the forests. The ratio of soil and biomass carbon varies between forest biomes. Temperate forests, such as those in Europe, store two-thirds of total forest carbon in soils, while the soil carbon stocks of boreal forests are five times higher than its biomass carbon stocks. Tropical forests depict a one-to-one ratio of soil and biomass carbon pool (Dixon et al., 1994; Lorenz and Lal, 2010).

Bangladesh is a low CO_2 emitting country due mainly to low level of industrialization. Its vulnerability to climate change is very high as a sea rise of 1–2 meters would inundate a substantial area thereby affecting a large coastal population. World Bank (2017) estimated that the per capita CO_2 emission of Bangladesh is to be as 0.4 t $year^{-1}$ which is much lower when compared to 1.4 t $year^{-1}$ in other South Asian countries and 16.4 t $year^{-1}$ in USA. However, the consumption of fossil fuels in the country is growing by more than 5% $year^{-1}$ and motor traffic is increasingly causing environmental pollution. So, effective forest management is one of the ways that can contributes towards emission reductions and to carbon sequestration (Sohel et al., 2009). In that context, carbon forestry is the right way to achieve green economy in Bangladesh involving local communities. Rahman (2012) reported that it is the authentic method to restore organic carbon in biomass from the atmosphere. This involves afforestation and reforestation practices with no cutting of trees where the primary objective is to store atmospheric CO_2. He also mentioned that potential scope of establishing carbon forestry in Bangladesh is immense large. Brown (1996) stated that a hectare of actively growing forest can sequesters 2–5 t carbon $year^{-1}$.

In Bangladesh several forest tree species can sequester almost fifty percent carbon of their biomass (Akter et al., 2011). The carbon credits those are sequestered will be traded with developed industrialized countries that emit CO_2 largely (Rahman, 2012). Bangladesh may think of trading forest biomass organic carbon with developed industrialized countries following rules and procedures of the Kyoto Protocol (Sohel et al., 2009). The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol have introduced a mechanism named CDM (Clean Development Mechanism) allowing for the development of carbon forestry activities in the developing world as means to mitigate climate change and promote sustainable development. With a huge pool of existing plantations and natural forests in Bangladesh, it can be assumed that the country is playing a major role in mitigating global warming. To realize the potential of the forestry sector in Bangladesh for full-scale emission mitigation, understanding carbon sequestration potential of different species in different types of plantations are important (Miah et al., 2011). Thus, the concept of carbon sequestration is required to understand sink and storages by forest trees (Bass et al., 2000).

2.19. Estimation of Global Forests Carbon

In the global carbon cycle, tropical forests play major role as they are storing near about 46% world's terrestrial carbon pool and function as constant sink for atmospheric carbon and act as a major carbon reservoir of earth (Soepadmo, 1993). Brown et al. (1989) developed the allometric regression equations for calculating above-ground biomass of individual trees with the help of DBH, total tree height, wood density and Holdridge life zone (Holdridge, 1967) for tropical forests. Andrade et al. (2010) found that disturbance history of plant communities had highest biomass (313±48 Mg ha^{-1}) in national park followed by from former clear-cut site (297±83 Mg ha^{-1}) and from past selective logging site (204±38 Mg ha^{-1}) of Atlantic Forest of Rio de Janiro, Brazil. Based on national forest inventory data collected in 1994–1998 and 1999–2003, Chen et al. (2012) estimated above-ground biomass carbon and net carbon accumulation rate for trees in major forest types in South China. Plenty of allometric equations are available to estimate above-ground biomass with the help of measurable parameters such as DBH, basal area, tree height, etc. (Pretzsch and Schutze, 2005). Results obtained by Grant et al. (2011) revealed that, in United States, decay and structural loss in standing dead trees significantly results in decreased tree and carbon stock estimation in forests. Chave et al. (2005) proposed a proportional relationship between above-ground biomass and product of wood density, trunk cross section and total height. They also developed a regression model between stem diameter and wood density. This model was tested on many types of forests such as dry, wet, lowland, mountain and mangrove forests. Hernandez-Stefanoni et al. (2011) concluded that landscape structure and spatial variables influence species density more than stand age and can be the main predictor of above-ground biomass.

In South Asia, Patra et al. (2013) estimated net biospheric CO_2 flux based on atmospheric CO_2 inversion as sink as 104±150 Tg C $year^{-1}$ during 2007–2008, while with the help of bottom-up approach, it was estimated to be 191±193 Tg C $year^{-1}$. Wittmann et al. (2008) estimated the above-ground wood biomass of riparian forest of lower Miranda River, Southern Pantanal of Brazil. The non-destructive method based on DBH, height, specific gravity and basal area showed that the estimated above-ground wood biomass was 259.4±102 Mg ha^{-1}. Berenguer et al. (2014) concluded that live vegetation was extremely sensitive to disturbance. The understory fire and selective logging depleting less above-ground carbon by 40% than undisturbed forests in Eastern Amazon. Huang and Asner (2010) observed long term carbon loss and recovery in selective logging of Amazon forests with the help of remote sensing data from 1999 to 2002 and estimated carbon emission ranging from 0.04–0.05 Pg C $year^{-1}$. They have also estimated biomass damage due to logging activities during last two to three decades from 1999 to 2002 as 89.1 Tg C $year^{-1}$ over the study region.

In India, Devi and Yadava (2009) carried out study for estimation of above-ground biomass and net primary productivity of semi-evergreen tropical forests of Manipur, North-Eastern India with the help of harvest method. They analyzed total biomass in two different stands as 22.50 t ha^{-1} and 18.27 t ha^{-1} in forest stand I and II respectively. A positive correlation between tree species, DBH and above-ground biomass of trees was also reported. Kale et al. (2009) estimated carbon sequestration and conclude that natural plantations had the highest (20.27 t ha^{-1}) of carbon sequestration than natural forests (mixed moist deciduous forest 8%) in Western Ghats. Using carbon density, remote sensing and growing stock data, Kaul et al. (2011) estimated carbon pool size from 41 to 48 Mg C ha^{-1} and 39 to 47 Mg C ha^{-1} for 1992 and 2002 respectively. Sheikh et al. (2011) estimated India's forest biomass and reported variations from 3,325 to 3,161 Mt (metric ton) during the year 2003 to 2007 respectively. Net fluxes of CO_2 were 372 Mt in I assessment and for II assessment period it was 288 Mt with annual emission of 186 and 114 Mt of CO_2, respectively.

Since 2003, the carbon stock in Indian forests biomass decreased continuously. In scared forest of Terai region of Garhwal Himalaya, Uttarkhand of India biomass and total carbon density of different species based on non-destructive method were 1549.704 Mg ha^{-1} and 774.77 Mg C ha^{-1} respectively (Pala et al., 2013). Phytomass of moist deciduous forest of Gujrat, India, estimated with the help of spectral modeling showed a range from 6.13 to 389.166 t ha^{-1}, while it was 5.534 to 134.082 t ha^{-1} using area weights for 250 × 250 m sites. The mean biomass of the study area was 40.50 t ha^{-1} with mean carbon density of 19.44 t ha^{-1} respectively (Patil et al., 2012). In Garhwal Himalaya of Uttarkhand in India, the total live tree biomass density ranged from 215.50 to 486.20 Mg ha^{-1} and live carbon density varied from 107.80 to 234.10 Mg C ha^{-1} (Gairola et al., 2011). Mani and Parthasarathy (2007) estimated above-ground biomass in inland and coastal tropical dry evergreen forests of peninsular India, the above-ground biomass ranged from 39.69 to 170.02 Mg ha^{-1} using basal area method, while based on height and basal area method, it ranged from 73.06 to 173.10 Mg ha^{-1}. In both the forests type basal area and above-ground biomass showed positive relationship. Kumar et al. (2011) estimated mean above-ground biomass of Northern Hariyana which varied from 30.46 Mg ha^{-1} to 310.10 Mg ha^{-1} across in all forest types, while the total above-ground biomass and carbon stock accounted for 26.99 Tg ha^{-1} and 12.96 Tg C ha^{-1}, respectively.

In Pakistan, Ahmad et al. (2014) carried out study for assessment of biomass and carbon stocks in coniferous forests of Dir Kohistan. They estimated the mean carbon stocks in Deodar and Deodar Kail forests was 140.37 and 134.60 Mg C ha^{-1}, respectively. The average carbon stocks in mixed coniferous forest was calculated as 142.40 Mg C ha^{-1}.

2.20. Assessment of Forest Carbon in Bangladesh

There is no complete inventory for forest carbon estimation in Bangladesh. The Food and Agriculture Organization of the United Nations (FAO) conducted an inventory on "Global Forest Resources Assessment-2015" and measured that in Bangladesh forest carbon was 127.28 million Mg ha^{-1}. In their report, the above-ground, below-ground, dead wood, litter, and soil carbon were measured to be 83, 16.45, 2.75, 1.19 and 23.89 million Mg C ha^{-1}, respectively (FAO, 2015). Alamgir and Turton (2014) reported carbon density between 49–121 Mg ha^{-1} in the country's forests depending on the condition of the vegetation (e.g., open canopy versus closed canopy). Mukul et al. (2014) estimated 179.10 million Mg carbon in biomass and 72.70 million Mg carbon in soil (up to 30 cm soil depth) in Bangladesh forest ecosystems that are currently under the FD managed forests. A few researchers (Brown, 1997) observed a large variability exists also in the national level estimates of forests carbon density, which is mainly attributable to differences in methods and sampling strategies. They reported in the literature, the carbon stocks in FD managed forests are estimated to be between 98.80 and 240.20 million Mg. The estimated carbon storage in soil (up to 30 cm soil depth) in the country's forests is about 92.90 million Mg (FAO, 2007). The highest soil carbon density is in the mangrove forests due to the greatest concentration of organic carbon in soil and is the lowest in the mangrove plantations. The plain land sal forests, due to their degraded nature, also have relatively lower levels of soil carbon density and stock. Mahmood et al. (2008) mentioned that on an average, 92 t ha^{-1} carbon is stored by the existing tree tissues in the forests of Bangladesh.

Environmentally and Socially Sustainable Development (ESSD) of World Bank (1998) reported that forests soils in Bangladesh store carbon at a rate of 115 Mg ha^{-1}, 100 Mg ha^{-1} and 60 Mg ha^{-1} in moist, seasonal, and dry soils, respectively. Rahman et al. (2015) calculated from the roadside plantations an average biomass carbon of 192 Mg ha^{-1} (range: 56.75–380.11), among them 86% was above-ground and 14% was below-ground. Miah et al. (2011) found that the average highest biomass carbon (145 Mg ha^{-1}) was in the Pitraj (*Aphanamixis polystachya*) stands and the lowest (43 Mg ha^{-1}) in the Mahogany (*Swietenia mahagoni*) stands in the Chittagong hilly regions of Bangladesh. They also found that 8-years old Akashmoni (*Acacia auriculiformis*) stand had the highest (173 Mg ha^{-1}) biomass carbon content followed by 12-years old Pitraj (*A. polystachya*) stand (166 Mg ha^{-1}) and lowest (55.20 Mg ha^{-1}) carbon content was found in the 6-years old Teliagarjan (*Dipterocarpus turbinatus*) stand. Average biomass content was found 183 Mg ha^{-1}. The potential organic carbon in forest stands is almost 92 Mg ha^{-1}, especially in the natural hill forests of Bangladesh (Miah et al., 2011).

Akter et al. (2013) found an average 107.48 Mg ha^{-1} organic carbon has been stored in the Chittagong University campus for managed plantation forests. In another study, Akter et al. (2011) found that mean biomass carbon was 185.03 kg $tree^{-1}$ for Sal (*Shorea robusta*), 167.51 kg $tree^{-1}$ for Telsur (*Hopea odorata*) and 142.64 kg $tree^{-1}$ for Telia garjan (*D. turbinatus*) in Dipterocarpaceae plantations of Chittagong University campus. Ullah and Al-Amin (2012) found tree biomass carbon to be 110.94 t ha^{-1} in a purely natural forest. Ullah et al. (2013) observed that the total (above- and below-ground) carbon stocks were found 211.09 t ha^{-1} for Akashmoni (*A. auriculiformis*), 171.61 t ha^{-1} for Segun (*Tectona grandis*) and 148.96 t ha^{-1} for Chakuakoroi (*Albizia chinensis*) on 18-years old plantations in Bangladesh. Mahmood et al. (2015, 2016a and 2016b) studied to estimate total above-ground biomass, nutrients (N, P and K) and carbon content for three different mangrove species [Khalsi (*Aegiceras* *corniculatum*), Gewa (*Excoecaria agallocha*) and Guria (*Kandelia candel*)] in Sundarban, Bangladesh. They derived carbon concentrations by developed allometric models. They found concentration of carbon 43.10–48.59% for Khalsi (*A. corniculatum*), 45.95–48.60% for Gewa (*E. agallocha*) and 41.72–45.53% for Gora (*K. candel*) in different proportion of plant (leaf, branch, bark, and stem without bark) and highest carbon concentration was attained in stem.

CHAPTER 3

MATERIALS AND METHODS

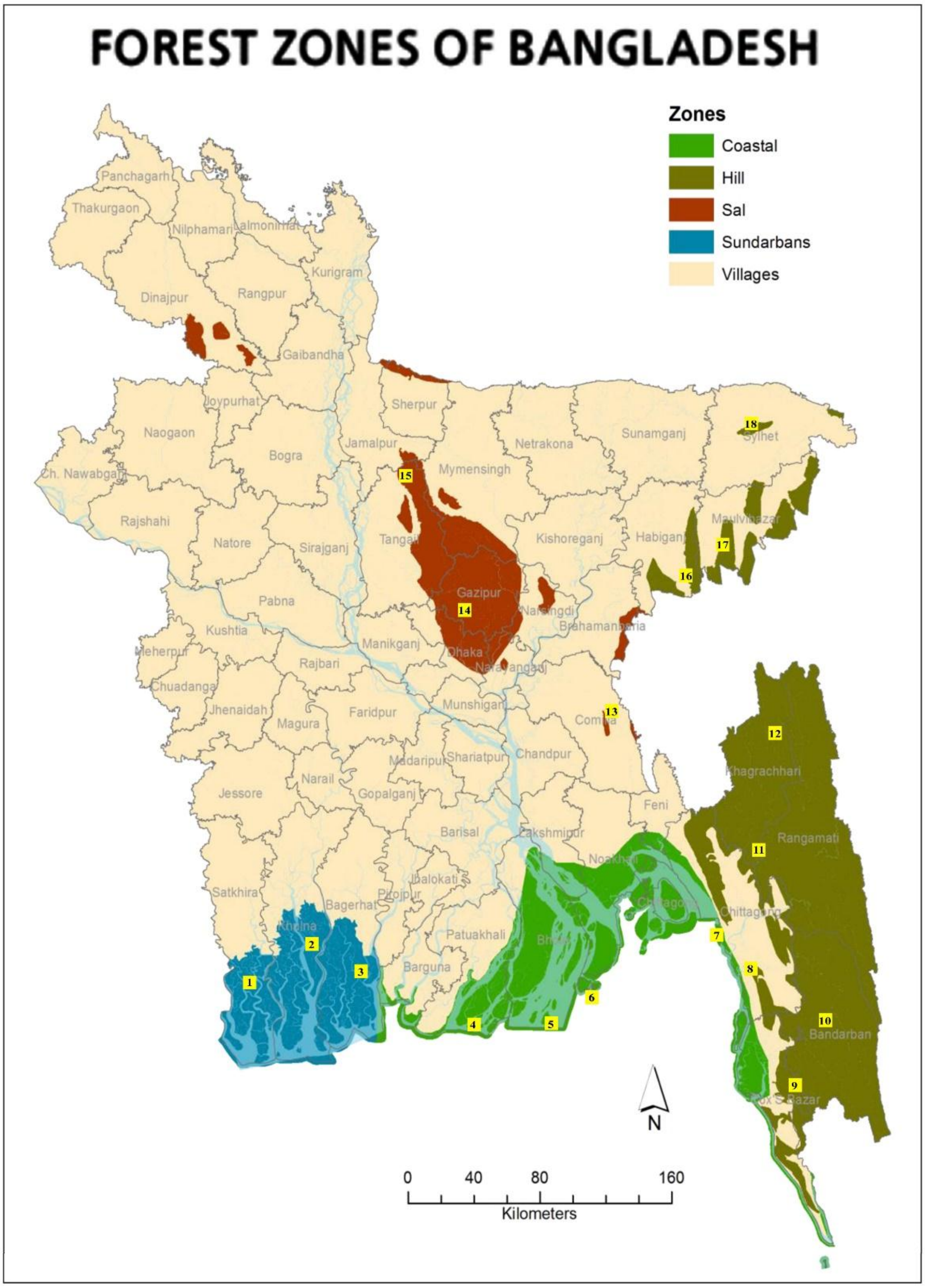
CHAPTER 3

MATERIALS AND METHODS

3.1. Site Selection

The present research work was carried out collecting soil samples and data from five major forest areas of Bangladesh. The areas were Sundarban mangrove forests, Sal forests, coastal afforestation, and Hill forests of Chittagong Forest Division and Hill forests of Sylhet Forest Division. In each forest area, three representative locations were selected except Hill forests of Chittagong and coastal plantations. In the Hill forests of Chittagong, five representative locations and in the coastal afforestation area, four representative locations were selected. In the Hill forest of Chittagong, the locations were (1) Baraiyadhala National Park of Sitakunda, Chittagong; (2) Dulahazra Forest Beat of Fanshiakhali Forest Range, Chakoria, Cox's Bazar; (3) Goneshpara of Thanchi, Bandaban hill district; (4) Kaptai National Park of Rangamati hill district; and (5) Washu of Matiranga, Khagrachari hill district. In Sylhet Hill Forest, the locations were (1) Satchari National Park of Chunarughat, Habigonj district; (2) Lawachara National Park, Sreemongal, Moulavibazar district; and (3) Tilagarh Eco Park of Sylhet. In the Sundarban Mangrove forests, the locations were (1) Munshigonj Forest Beat, Burigoalini Forest Range, Shamnagar, Satkhira district; (2) Dhangmari Forest Beat, Chandpai Forest Range, Dakop, Khulna district; and (3) Bogi Forest Beat, Sharankhola Forest Range, Sharankhola, Bagerhat district. The selected locations of coastal afforestation areas were (1) Sonarchar, Rangabali, Patuakhali district; (2) Kukri-Mukri, Charfashion, Bhola district; (3) Nijhumdwip National Park, Hatiya, Noakhali district; and (4) Dumkhali of Mirersarai, Chittagong district. In the Sal forests, the locations were (1) Kotbari of Cumilla Sadar, Cumilla district; (2) Dokhola Forest Range of Madhupur, Tangail district; and (3) Bhawal National Park, Salna of Gazipur district (Figure 3.1).

Three representative sub-plots were selected from each location for collecting soil samples and growth parameters such as diameter at breast height (DBH) and height of the different forest tree species. The exact locations of sampling points were recorded by using a Global Positioning System (GPS, GARMIN *etrex-30x*) and the collected latitudinal and longitudinal data are given in Appendix A-1.



Locations

1	Munshigonj Forest Beat	7	Dumkhali, Mirersarai	13	Kotbari, Cumilla
2	Dhangmari Forest Beat	8	Baraiyadhala National Park	14	Bhawal National Park
3	Bogi Forest Beat	9	Dulahazra Forest Beat	15	Dokhola Forest Range
4	Sonarchar, Rangabali	10	Goneshpara, Thanchi	16	Satchari National Park
5	Kukri-Mukri, Charfashion	11	Kaptai National Park	17	Lawachara National Park
6	Nijhumdwip, Hatiya	12	Wasu, Matitanga	18	Tilagarh Eco Park

Figure 3.1. Location map showing the sampling plots of the study areas

3.2. Physiography of the Study Areas

Bangladesh can be divided into three main physiographic divisions: Tertiary hills, Pleistocene terraces, and recent plains. The different physiographic divisions are characterized by different types of soil. The tertiary hills are situated in Rangamati, Bandarban, Khagrachari, Cox's Bazar, Chittagong, Sylhet, Moulavibazar, and Habiganj districts. These hills are comprised mainly of sandstone, shale and clay. The average altitude of these hills is 450 meters. The tertiary hill areas are characterized by 'hill soils' that are mainly composed of tertiary rocks and unconsolidated tertiary and Pleistocene sediments. The soil is usually acidic with pH varying from 4.0 to 4.5. The soil texture allows comparatively lower infiltration. High porosity allows high moisture content. The Pleistocene terraces comprise mainly the Madhupur and the Barind Tracts, Bhawal's Garh and the Lalmai hill area. The average height of the tract from the adjacent flood plains is 6 to 12 meters. Madhupur and Bhawal stretch over 4,103 sq. km where the average height from the adjacent floodplain is 30 meters. The Lalmai Hill area of Cumilla district comprises 34 sq. km and is on an average 15 meters higher than the adjacent floodplain. The Pleistocene terraces are composed of 'old alluvial soils' which were formed from the alluvium of the Pleistocene period. They stand on high land above the flood level. They are clayey in texture and reddish to yellowish in colour due to the presence of iron and aluminium. They are highly aggregated and have a high phosphate fixing capacity. The soil is acidic with a pH ranging from 6.0 to 6.5.

The recent plains comprise 124,266 sq. km of the country (86 percent). Recent plains can be further classified into five types: piedmont plain, floodplain, deltaic plains, tidal plains and coastal plains. The five types of plains are generally expressed by the common term 'floodplain'. The flood plains of Bangladesh are mainly composed of deltaic silt plains, built up from both alluvial and marine deposits. Because of the low altitude and relief of the land, water travels very slowly on the plain and the rivers tend to meander. The recent plains have been developed and are being re-worked continuously through the processes of erosion and deposition, and by recurring flooding or inundation. The recent plains are composed of 'recent alluvial soils'. Since soil composition in the upstream area is an important factor in determining the properties of the down-stream soils, variations are common in the properties of soils in different river basins. Gangetic alluvium is rich in calcium, magnesium and potassium. It also contains free calcium carbonate. The soil is characterized by nitrogen and phosphate deficiency as well as by alkalinity. The pH range is 7.0 to 8.5 (Banglapedia, 2003).

3.3. Different Forest Zones in the Country

The hill zone represents hilly geographical areas in the eastern part of the country. The average elevation is 125 m, and water and terrestrial land area occupy 3% and 97% of the land, respectively (GoB, 2019). The mean annual precipitation is 2720 mm (2061–4370 mm) (Hijmans et al., 2005). The soils of hill zone have been classified as acid sulphate, brown hill, and non-calcareous grey floodplain (non-saline) (FAO-UNDP, 1988). Evergreen and semi-evergreen forest types dominate, and the most common tree species are Garjan (*Dipterocarpus* spp.), Jam (*Syzygium* spp.), Gamar (*Gmelina arborea*), Dumur/Anjur (*Ficus carica*), Achergola (*Grewia* spp.), Korai (*Albizia* spp.), Akashmoni (*Acacia auriculiformis*), Kanthal (*Artocarpus heterophyllus*), Mahogany (*Swietenia mahagoni*), Segun (*Tectona grandis*), and homestead tree species as Aam (*Mangifera indica*) (GoB, 2020).

The Sundarban zone represents the mangroves of the Sundarban reserve forest found in the south-western part of the country. The elevation ranges from 2 to 9 m with an average of 6 m. Water and terrestrial land area occupy 37% and 63%, respectively. The mean annual precipitation is 2,004 mm (1,783–2,343 mm). The soils have been classified as acid sulphate and non-calcareous grey floodplain (non-saline). This zone consists of natural mangrove forest and the most common tree species are Sundari (*Heritiera fomes*), Gewa (*Excoecaria agallocha*), and Goran (*Ceriops decandra*) (GoB, 2020).

The coastal zone represents geographical areas with accreted land in the southern part of the country. The average elevation of coastal zone is 3 m, and water and terrestrial land area occupy 55% and 45%, respectively. The mean annual precipitation is 2,870 mm (2,267–3,698 mm). The soils of coastal zones have been classified as brown hill, acid sulphate, calcareous alluvium (non-saline), calcareous grey flood plain, non-calcareous alluvium, and non-calcareous grey floodplain. The most common tree species are Keora (*Sonneratia apetala*), Baen (*Avicennia officinalis*), Gewa (*Excoecaria agallocha*), Narikel (*Cocos nucifera*), Supari (*Areca catechu*), and homestead tree species such as Kanthal (*Artocarpus heterophyllus*), Rain tree/Sirish

(*Samanea saman*), Neem (*Azadirachta indica*), and Aam (*Mangifera indica*) (GoB, 2020).

The Sal zone represents the geographical areas in Madhupur and Barind Tract with small hillocks and plain land. The average elevation is 17 m and water and terrestrial land area occupy 3% and 97%, respectively. The mean annual precipitation is 2,040 (1,804–2,462 mm). The soils of the Sal zone have been classified as acid basin clays, brown hill, brown mottled terrace, deep red-brown terrace, shallow grey, and shallow red-brown terrace. This zone consists of deciduous Sal Forest, and the most common tree species are Sal (*Shorea robusta*), Korai (*Albizia* spp.), Kanthal (*Artocarpus heterophyllus*), Mahogany (*Swietenia mahagoni*), Akashmoni (*Acacia auriculiformis)*, etc. and homestead tree species such as Aam (*Mangifera indica*) (GoB, 2020).

3.4. Plot Layout

GP-guided circular plots were selected for soil sample collection and forest carbon measurement using the simple random sampling method. Circular plots were chosen for this study because they are relatively easy to establish. The radius of each plot is usually dependent on the density of the forest. As the selected sites contained moderately dense vegetation, an 8.92-m radius was employed, which is a recommended default value (ICIMOD, 2010) (Figure 3.2). Within each circle, several subplots were created for specific purposes. A subplot with a 5.64-m radius was established for saplings inside the 8.92-m radius plot. Further, a subplot with a 1-m radius was created for counting regeneration. And, finally, a subplot with a 0.56-m radius was established for collecting samples of leaf litter, herbs, grass, and soil (ICIMOD, 2010).

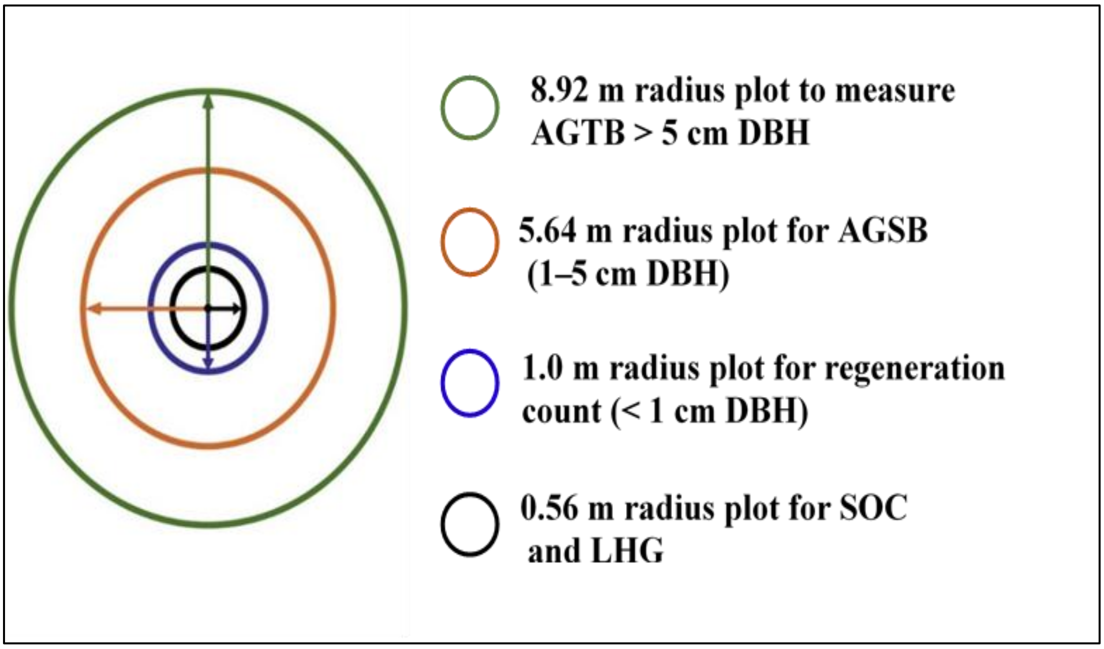


Figure 3.2. Sampling design of circular plot for soil sample and plant data collection

3.5. Soil Sample Collection

Soil samples were collected in two phases: in 2019 and 2022. In 2019, the soil samples were collected from a 0.56-m radius of circular subplots selected by a simple random sampling method (ICIMOD, 2010). A total of 162 (18 locations × 3 plots × 3 replications) soil profiles up to 0−100 cm soil depth were excavated from different forest areas. In this way, a total of 648 (18 locations × 3 plots × 3 replications × 4 soil depths) soil samples from four soil depths (0−15, 15−30, 30−50, and 50−100 cm) were collected by a core sampler for analysis of soil moisture content, bulk density, and particle size analysis (soil texture). Separately, a total of 256 composite soil samples (18 locations × 3 plots × 4 soil depths) were collected using a soil auger for analysis of soil pH, electrical conductivity, organic carbon, and total nitrogen. In 2022, the same number of composite soil samples were collected from the same sampling spots to observe the trend of change in soil organic carbon in the selected areas. In the hill forests of Chittagong and Sylhet Forest divisions, the top hill, medium hill, and foothill were considered for soil sample collection. After the collection of soil samples, each sample was taken in a polyethylene plastic bag. The bags were properly labeled with the name of the sampling site, depth, and date. The bags were tied securely with proper tags. The collected soil samples were carefully brought and preserved in the laboratory of the Soil Science Division, Bangladesh Forest Research Institute (BFRI), Chittagong for detailed analysis.

3.6. Preparation of Soil Samples

In the laboratory, the collected composite soil samples were air-dried by spreading in a thin layer on a clean piece of paper. Visible litter, roots, stones, and debris were removed from the samples and discarded. After air-drying, a portion of the sample containing the larger aggregates was ground by gentle crushing with a wooden hammer. Ground samples were passed through a 2-mm sieve. The sieved samples were then thoroughly mixed and stored in labeled plastic containers until required for various physical and chemical analyses. Another portion of the soil sample (2 mm sieved) was further ground and passed through a 0.5-mm sieve. The sieved samples were then thoroughly mixed and stored as above until required for chemical analyses.

3.7. Determination of Soil Physical Properties

3.7.1. Soil moisture content

The moisture content (MC) of soil samples was determined by the gravimetric method (Blake, 1965). The gravimetric method of determining soil moisture consists of measuring the moist and dry soil. The weight of moist soil was taken by weighing the samples as it was at the time of sampling. The dry weight was obtained after drying the samples to a constant weight in an oven at 105 ℃ for 48 h. The moisture content of the samples on a dry mass basis was given by:

$$\%\mathrm{MC} = \frac{\mathrm{W_1} - \mathrm{W_2}}{\mathrm{W_2} - \mathrm{W_3}} \times 100$$

where,

W_1 = weight of wet soil + tare;

W_2 = weight of oven-dry soil + tare; and

W_3 = weight of tare (weight of empty soil moisture can with lid).

3.7.2. Soil bulk density

The bulk density (BD) of the soil sample was measured by the core method as described by Blake and Hartge (1986). In this method, a cylindrical metal sampler was driven into the soil to a desired depth and was carefully removed to preserve a known volume of a soil sample as it existed *in situ*. The samples were dried at 105 ℃ for 48 h and weighed.

BD (g cm^{-3}) of soil = Oven-dry weight of soil sample (g) / ______

Volume of the sample (cm^3)

3.7.3. Particle size analysis

The particle size analysis (PSA) of the soil sample was carried out by the hydrometer method as described by Day (1965). The textural classes were determined using Marshall's Triangular Coordinate as described by the United States Department of Agriculture (USDA, 1951).

3.8. Determination of Soil Chemical Properties

3.8.1. Soil pH

The soil pH was measured electrochemically with the help of a glass electrode pH meter (TOA-DK, Japan) maintaining the ratio of soil to water was 1:2.5, and the time of shaking was approximately 30 min as suggested by Jackson (1958).

3.8.2. Electrical conductivity of soil

The electrical conductivity (EC) of soil was measured at a soil: water ratio of 1:5 with the help of an EC meter (WTW, USA) (Rhoades et al., 1989).

3.8.3. Soil organic carbon

The soil organic carbon (SOC) was determined by Walkley and Black's (1934) wet-oxidation method. Organic matter (OM) of soil was calculated by multiplying the percent value of organic carbon by the conventional Van Bemmelen's factor of 1.724, on the assumption that organic matter of an average soil contains 58% of organic carbon (Piper, 1950).

3.8.4. Soil total nitrogen

For the determination of soil total nitrogen, the samples were digested by Kjeldahl's method as described by Jackson (1958). The distillation of digested samples was done with 40% sodium hydroxide (NaOH) and the distillates were collected on a 4% boric acid (H_3BO_3) and mixed indicator solution. The distillates were titrated against a standard sulfuric acid (H_2SO_4) solution.

3.9. Estimation of Soil Organic Carbon Stocks

The total soil organic carbon (SOC) stocks (t ha^{-1}) were calculated by multiplying the SOC concentration (%) with the calculated bulk density (g cm^{-3}) and depth of soil layer (cm) by using the following formula described by Pearson et al. (2007):

$$\text{SOC stocks (t ha}^{-1}\text{)} = \text{SOC conc. (\%)} \times \text{BD (g cm}^{-3}\text{)} \times \text{Soil Depth (cm)} \times 100$$

3.10. Estimation of Forest Biomass

Forest biomass was estimated following the definition of above-ground biomass (AGB) and below-ground biomass (BGB) proposed by FAO (2018b) for the global forest resource assessment 2020 (FAO, 2018a). All live trees and saplings were used for estimating above- and below-ground biomass.

3.10.1. Above-ground biomass

The above-ground biomass (AGB) is the function of tree diameter, height, and wood density. Above-ground biomass contains the biomass of trees, saplings, bamboo, and live stumps. The estimation procedure of above-ground biomass for trees and saplings, bamboo, and stumps are different (Hossain et al., 2019). In this regard, different allometric models or equations were used for estimating forest above-ground biomass. An allometric equation is a statistical relationship between key characteristic dimension(s) of trees and saplings that are easy to measure, such as diameter at breast height (DBH) or height, and other properties that are more difficult to assess such as above-ground biomass. The selection of the appropriate allometric equation is a crucial step in estimating above-ground tree and sapling biomass.

Allometric equations for biomass usually include information on trunk diameter at breast height DBH (in cm), total tree height H (in m), and wood specific gravity ρ (g cm^{-3} or kg m^{-3}). Baker et al. (2004) reported that ignoring variations in wood density results in poor overall prediction of the AGB. The DBH (at 1.37 m tree or sapling height above the ground) and height of individual trees greater than or equal to 5 cm DBH were measured in each 8.92 m radius circular (250 m^2) plot using diameter tape and clinometer, respectively. Similarly, the nested sub-plots having a 5.64 m radius (100 m^2) inside larger plots were established for sapling measurement. Specific wood density value for the respective tree species was obtained from Sattar et al. (1999) and the global wood density database developed by Zanne et al. (2009). In cases where the wood density for a species was not listed, an average value of 0.5 was used, as recommended by Chave et al. (2005) for trees from tropical areas. The biomass values of trees and saplings include foliage, branch, and stem compartments.

Many allometric equations were developed under the Bangladesh Forest Inventory (BFI) for five (5) zones (coastal, Hill, Sal, Sundarban, and village zones) and eighteen (18) common tree species (Akashmoni, Dhakijam, Eucalyptus, Gamar, Garjan, Gewa, Jarul, Keora, Mahogany, Mangium, Minjiri, Raintree, Rajkoroi, Sal, Segun, Silkoroi, Sissoo, and Sundari) of Bangladesh. It is to be mentioned that the equation of coastal zones and Keora tree species are identical. In addition to these, there are existing allometric equations verified under the BFI process which were also considered for use to compute tree or sapling biomass. The following allometric equations were used for estimating the AGB of trees and saplings (GoB, 2020; Hossain et al., 2019; Hossain et al., 2020).

$\ln Y_{TSagb} = -1.7608 + 2.0077 \times \ln(D) + 0.2981 \times \ln(H)$ for coastal zones ---------- (1)

$\ln Y_{TSagb} = -6.6937 + 0.809 \times \ln(D^2 \times H \times \rho)$ for hill zones ---------------------------- (2)

$\ln Y_{TSagb} = -2.46 + 2.17 \times \ln(D) + 0.367 \times \ln(H) + 0.161 \times \ln(\rho)$ for sal zones ---- (3)

$\ln Y_{TSagb} = -6.7189 + 2.1634 \times \ln(D) + 0.3752 \times \ln(H) + 0.6895 \times \ln(\rho)$ for Sundarban zones --- (4)

$\ln Y_{TSagb} = -6.0325 + 1.9715 \times \ln(D) + 0.8193 \times \ln(\rho)$ for village zone ------------ (5)

$\ln Y_{TSagb} = -2.459 + 1.869 \times \ln(D) + 0.800 \times \ln(H)$ for Akashmoni tree species -- (6)

$\ln Y_{TSagb} = -2.713 + 1.529 \times \ln(D) + 1.324 \times \ln(H)$ for Dhakijam tree species ---- (7)

$\ln Y_{TSagb} = -2.663 + 1.915 \times \ln(D) + 0.832 \times \ln(H)$ for Eucalyptus tree species --- (8)

$\ln Y_{TSagb} = -2.421 + 1.585 \times \ln(D) + 1.011 \times \ln(H)$ for Gamar tree species --------- (9)

$\ln Y_{TSagb} = -2.525 + 0.897 \times \ln(D^2 \times H)$ for Garjan tree species ------------------------ 10)

$\log Y_{TSagb} = -0.8572 + 1.0996 \times \log (D^2)$ for Gewa tree species ---------------------- (11)

$\ln Y_{TSagb} = -2.909 + 1.976 \times \ln (D) + 0.829 \times \ln (H)$ for Jarul tree species --------- (12)

$\ln Y_{TSagb} = -1.7608 + 2.0077 \times \ln (D) + 0.2981 \times \ln (H)$ for Keora tree species----- (13)

$\ln Y_{TSagb} = -2.302 + 0.894 \times \ln (D^2 \times H)$ for Mahogany tree species ------------------ (14)

$\ln Y_{TSagb} = -3.005 + 0.923 \times \ln (D^2 \times H)$ for Mangium tree species -------------------- (15)

$\ln Y_{TSagb} = -2.597 + 1.835 \times \ln (D) + 0.951 \times \ln (H)$ for Minjiri tree species ------- (16)

$\ln Y_{TSagb} = -2.461 + 1.933 \times \ln (D) + 0.660 \times \ln (H)$ for Raintree tree species ---- (17)

$\ln Y_{TSagb} = -2.111 + 1.832 \times \ln (D) + 0.648 \times \ln (H)$ for Rajkoroi tree species ---- (18)

$\ln Y_{TSagb} = -3.3592 + 2.1830 \times \ln (D) + 0.6787 \times \ln (H)$ for Sal tree species ------ (19)

$\ln Y_{TSagb} = -2.180 + 0.875 \times \ln (D^2 \times H)$ for Segun tree species ----------------------- (20)

$\ln Y_{TSagb} = -1.984 + 1.911 \times \ln (D) + 0.572 \times \ln (H)$ for Silkoroi tree species ------ (21)

$\ln Y_{TSagb} = -2.608 + 0.905 \times \ln (D^2 \times H)$ for Sissoo tree species ---------------------- (22)

$\ln Y_{TSagb} = -2.1324 + 2.3895 \times \ln (D) + 0.1367 \times \ln (H)$ for Sundari tree species -- (23)

where,

Y_{TSagb} = Tree or sapling above ground biomass (kg);

D = Diameter at breast height of tree or sapling (cm);

H = Height of tree or sapling (m);

P = Wood density (kg m^{-3}); and

ln = Natural log.

3.10.2. Below-ground biomass

Like above-ground biomass, below-ground biomass (BGB) consists of trees and saplings. The estimation procedure for all trees and saplings of the four zones is the same. The following allometric equation (24) was used for estimating below-ground biomass for the coastal, Hill, Sal, Sundarban, and village zones (Pearson et al., 2007).

$$Y_{TSbgb} = \exp\left[-1.0587 + 0.8836 \times \ln\left(Y_{TSagb}\right)\right] \text{ --------------------------------- } (24)$$

where,

Y_{TSbgb} = Tree or sapling below-ground biomass (kg); and

Y_{TSagb} = Tree or sapling above-ground biomass (kg).

3.10.3. Leaf litter, herb, and grass biomass

To determine the biomass of leaf litter, herb, and grass (LHG), samples were taken destructively in the field within a small area of 1.0 m^2 (0.56 m radius circular plot). Fresh samples were weighed in the field and the sub-sample was used to determine an oven-dry-to-wet mass ratio, which was used to convert the total wet mass to oven-dry mass. A sub-sample was taken to the laboratory and oven dried until constant weight to determine water content. For the forest floor (herbs, grass, and litter), the amount of biomass per unit area was given by:

$$LHG = \frac{W_{field}}{A} \times \frac{W_{subsample,\ dry}}{W_{subsample,\ wet}} \times 10{,}000 \text{ -------------------------------------- } (25)$$

where,

LHG = biomass of leaf litter, herbs, and grass (t ha^{-1});

W_{field} = weight of the fresh field sample of leaf litter, herbs, and grass destructively sampled within an area of size A (g);

A = size of the area in which leaf litter, herbs, and grass were collected (ha);

$W_{subsample,\ dry}$ = weight of the oven dry sub-sample of litter, herbs, and grass (g); and

$W_{subsample,\ wet}$ = weight of the fresh sub-sample of litter, herbs, and grass (g) (ICIMOD, 2010).

3.11. Estimation of Forest Biomass Carbon

Carbon stocks were estimated for different pools – carbon in tree and sapling aboveground biomass (CAGB), carbon in tree and sapling belowground biomass (CBGB), carbon in leaf litter, herb and grass (CLHG) and soil organic carbon (SOC).

The methods of estimating carbon density and stocks in different pools are described below.

3.11.1. Carbon in trees and saplings above-ground biomass

Carbon in above-ground biomass (CAGB) is the sum of carbon from above-ground biomass of trees and saplings. The proportion of carbon in the above-ground biomass of trees and saplings is different. Thus, the computation methods are also different. Carbon in above-ground biomass of trees and saplings was estimated using the allometric equations mentioned below which were developed under the BFI program and selected based on the different zones and tree species (GoB, 2020; Hossain et al., 2019).

$\ln(CAGB_{TS}) = -2.5035 + 2.0042 \times \ln(D) + 0.3188 \times \ln(H)$ for coastal zones ----- (26)

$\ln(CAGB_{TS}) = -7.7129 + 0.8268 \times \ln(D^2 \times H \times \rho)$ for hill zones -------------------- (27)

$\ln(CAGB_{TS}) = -3.014 + 2.206 \times \ln(D) + 0.302 \times \ln(H) + 0.262 \times \ln(\rho)$ for sal zones-- (28)

$\ln(CAGB_{TS}) = -7.5236 + 2.1628 \times \ln(D) + 0.3834 \times \ln(H) + 0.7004 \times \ln(\rho)$ for Sundarban zones -- (29)

$\log_{10}(\sqrt{CAGB_{TS}}) = -0.630 + 0.614 \times \log_{10}(D^2)$ for Akashmoni tree species ------- (30)

$\ln(CAGB_{TS}) = -2.5035 + 2.0042 \times \ln(D) + 0.3188 \times \ln(H)$ for Keora tree species -- (31)

$\log_{10}(\sqrt{CAGB_{TS}}) = -0.652 + 0.607 \times \log_{10}(D^2)$ for Mangium tree species ---------- (32)

$\ln(CAGB_{TS}) = -3.9802 + 2.1660 \times \ln(D) + 0.6984 \times \ln(H)$ for Sal tree species -- (33)

$\ln(CAGB_{TS}) = -2.7488 + 2.4723 \times \ln(D)$ for Sundari tree species ------------------- (34)

where,

$CAGB_{TS}$ = Carbon in above-ground biomass of tree or sapling (kg).

3.11.2. Carbon in trees and saplings below-ground biomass

Carbon in below-ground biomass (CBGB) is the sum of carbon in the below-ground biomass of trees and saplings. Carbon in below-ground biomass of trees and saplings was estimated as 50% of the below-ground biomass (Hairiah et al., 2001 and Matthews, 1997).

$CBGB_{TS} = BGB_{TS} \times 0.50$ -- (35)

where,

$CBGB_{TS}$ = Carbon in below ground biomass of tree or sapling (kg); and

BGB_{TS} = Below ground biomass of tree or sapling (kg).

3.11.3. Carbon in leaf litter, herb and grass

The carbon content of leaf litter, herb, and grass (CLHG) was calculated by multiplying the biomass of leaf litter, herb and grass with the IPCC (2006) default carbon fraction of 0.47.

$CLHG = BLHG \times 0.47$ -- (36)

where,

CLHG = Carbon in leaf litter, herb and grass (kg); and

BLHG = Biomass of leaf litter, herb and grass (kg).

Finally, the total carbon stocks density was calculated by summing the carbon stock densities of the individual carbon pools of that forest type using the following formula (ICIMOD, 2010).

Carbon stock density of a forest type:

$C_{FT} = CAGB_T + CAGB_S + CBGB_T + CBGB_S + CLHG + SOC$ -------------- (37)

where,

C_{FT} = carbon stock density for a forest type (t ha^{-1});

$CAGB_T$ = carbon in above-ground biomass of tree (t ha^{-1});

$CAGB_S$ = carbon in above-ground biomass of sapling (t ha^{-1});

$CBGB_T$ = carbon in below-ground biomass of tree (t ha^{-1});

$CBGB_S$ = carbon in below-ground biomass of sapling (t ha^{-1});

CLHG = carbon in leaf litter, herb and grass (t ha^{-1}); and

SOC = soil organic carbon stocks (t ha^{-1}).

3.12. Statistical Analysis

The collected and analytical data from the field and laboratory were arranged first according to locations and soil depths. Descriptive statistics such as means, standard deviation, standard error, minimum and maximum values were calculated to summarize the data. One-way analysis of variance (ANOVA) was performed to identify whether there were any significant differences in the mean values of the soil properties among the different locations and soil depths. When the F-test was significant at 5% level of significance, Tukey’s post-hoc test was employed to test differences among means. The significant differences are indicated by using different uppercase and lowercase letters alongside the means. In order to compare the forested and homestead sites vis-à-vis various soil properties, a paired-t test was performed. The relationship between SOC stocks and forest carbon density and other soil properties was tested with a Karl-Pearson correlation matrix followed by linear regression analysis. The statistical analysis was performed using MINITAB software (version 17) and SPSS-22 software. Microsoft Excel 19 was used to create charts and graphs.

CHAPTER 4

RESULTS AND DISCUSSION

CHAPTER 4
RESULTS AND DISCUSSION

This chapter includes the results from sampling and analysis of soils from some selected forest areas of Bangladesh. In this study, there were eighteen locations which are mentioned in Chapter 3 (Materials and Methods). Some soil properties, including soil texture, moisture content, bulk density, soil pH and EC, and total nitrogen were determined which were deemed to be important for the present study. Estimation of forest biomass and forest carbon density as well as CO_2 mitigation density are also presented in this chapter. A comparison was made between forested and homestead sites.

4.1. Soil Physical Properties

The mechanical composition (percentage of sand, silt, and clay) and the textural classes of the soil at different locations of different forest areas are presented in Table 4.1 (compiled from Appendix A-2).

4.1.1. Soil texture

Texture is an important property of soil. Soil texture depends on the types of parent materials. The soils of Bangladesh have developed on pre-weathered alluvial materials that were deposited at different geological periods. The content and distribution of soil particles in these soils are largely dependent on the lithology of the sediments deposited by the major river systems over different geological periods. The analytical data of soil particle size revealed that sand is the major fraction in the Hill forest areas of Chittagong and Sylhet and Sal Forest areas (Table 4.1). In the Chittagong hill forest areas, sand fraction in soil ranged from 43% to 89% at different locations at different soil depths. The highest value was found at Goneshpara, Thanchi Bandarban Hill Forest at 50 – 100 cm soil depth and the lowest value was obtained at Kaptai National Park, Rangamati Hill District at 50 – 100 cm soil depth. As for silt fraction, the highest value (28%) was observed at Kaptai National Park, Rangamati Hill District at 0 – 15 cm soil depth, and the lowest value (2%) was obtained at Goneshpara, Thanchi Bandarban Hill Forest at 50 – 100 cm soil depth. The clay fraction ranged from 9 –33%. The highest clay content was found at Kaptai National Park, Rangamati Hill District at 50 – 100 cm soil depth, and the lowest at Goneshpara, Thanchi Bandarban Hill Forest at 50 – 100 cm soil depth. The textural class of

Chittagong hill forest areas was mainly found to be sandy clay loam with some being sandy loam, clay loam, and loamy sand.

In the hill forest of Sylhet, sand fraction at different soil depths ranged from 72–88% which was much higher than silt (ranging from (1–14%) and clay fraction (11–18%). The textural class of Sylhet Hill Forest soils was found to be sandy loam with few exceptions. In the sub-surface layer (30–50 and 50–100 cm) of Tilagarh Eco Park, the loamy sand textural class was observed.

In the Sundarban Mangrove Forest, the textural class of soils was found to be loam. On the other hand, the soil samples collected from different depths in the coastal afforestation area were also loamy in texture. Brady and Weil (2002) defined an ideal loam texture as a mixture of sand, silt, and clay particles that exhibits the properties of those separates in about equal proportions. Sandy loam texture was found to be the dominant class in the Sal Forest area. Huq and Shoaib (2013) reported that the floodplains of both Gangetic and non-Gangetic alluvium contain 40–45% clay that remains unchanged with depth. Tidal and estuarine floodplains contain a much higher content of clay and silt and a remarkably low content of fine sand (<5%) compared to meander floodplains. They also mentioned that the soils of Bangladesh are mainly loam in texture. Central and southwest parts of Bangladesh are heavy loam, whereas the north and southeastern parts are light loam in texture. The coastal areas of the south, southeast, and central parts are clayey in texture. Sandy soils occupy a small portion of the northern part of Bangladesh. The findings of the present study substantiate the above statements (Table 4.1). Generally, soil textural class did not show any definite trend of variation with the depth of soil, although it was finer in the subsoil in some ecological areas (Akhtaruzzaman, 2016).

In the sub-surface layer of Kaptai and Bhawal National Park, the textural class was found to be clay loam. In these sites, clay migration might have occurred from the surface to the sub-surface layer. Here, clay content was seen to increase gradually with depth. The evidence indicates the presence of an Argillic horizon. Bole and Hole (1961) stated that an argillic horizon must contain a minimum clay increase relative to the eluvial horizon or an underlying horizon and show evidence of clay movement. Gafur et al. (2004) reported the occurrence of clay accumulation in the sub-horizons of some profiles in hill soils in the Bandarban district. They observed an increase in clay content from topsoil layers to the B horizon and attributed this phenomenon to the selective removal of clay, silt, and fine-sand particles from the surface. These soils are classified in the order Ultisols of Soil Taxonomy (Soil Survey Staff, 2014). Brammer (1971) reported that sand is the dominant particle in brown hill soils (soils of Chittagong, Sylhet Hill Forest, and Sal Forest areas) because these soils developed from unconsolidated sandstones or sandy sediment parent materials. The sub-soils were to some extent finer in composition. The soils were reported to be underlain by tertiary sediments of unconsolidated and partially unconsolidated beds of sandstones and shales of mid-Miocene to Pliocene age, into a folded succession of pitching anticlines and synclines (Huizing, 1971; SRDI, 1976).

Table 4.1. Analysis of soil particle size at different locations of different forest areas under different soil depth

Sl. No.	Location	Depth (cm)	Sand	Silt	Clay	Textural Class
			%			
Chittagong hill forest						
01.	Baraiyadhala National Park Sitakunda, Chittagong	0–15	54	26	20	SCL
		15–30	58	18	24	SCL
		30–50	59	20	21	SCL
		50–100	58	22	20	SCL
02.	Dulahazra Forest Beat Fanshiakhali Forest Range Chakoria, Cox's Bazar	0–15	69	15	16	SL
		15–30	60	17	23	SCL
		30–50	58	17	25	SCL
		50–100	56	18	26	SCL
03.	Goneshpara, Thanchi Bandarban Hill Forest	0–15	69	18	13	SL
		15–30	65	20	15	SL
		30–50	81	7	12	LS
		50–100	89	2	9	Sand
04.	Kaptai National Park Kaptai, Rangamati Hill District	0–15	47	28	25	SCL
		15–30	44	26	30	SCL
		30–50	44	24	32	CL
		50–100	43	24	33	CL
05.	Wasu, Matiramga Khagrachari Hill District	0–15	82	7	11	LS
		15–30	78	9	13	SL
		30–50	75	9	16	SL
		50–100	75	8	17	SL

Table 4.1 Continued

Sl. No.	Location	Depth (cm)	Sand	Silt	Clay	Textural Class
			%			
Sylhet Hill Forest						
06.	Satchari National Park Chunarughat, Habigonj	0–15	80	5	15	SL
		15–30	81	3	16	SL
		30–50	82	2	16	SL
		50–100	85	1	14	SL
07.	Lawachara National Park Sreemongal, Moulavibazar	0–15	72	14	14	SL
		15–30	73	12	15	SL
		30–50	73	11	16	SL
		50–100	72	10	18	SL
08.	Tilagarh Eco Park, Sylhet	0–15	82	3	15	SL
		15–30	84	2	14	SL
		30–50	85	4	11	LS
		50–100	88	1	11	LS
Sundarban Mangrove Forest						
09.	Munshigonj Forest Beat Burigoalini Forest Range Shamnagar, Satkhira	0–15	35	40	25	Loam
		15–30	38	35	27	Loam
		30–50	38	34	28	Loam
		50–100	39	31	30	Loam
10.	Dhangmari Forest Beat Chandpai Forest Range Dakop, Khulna	0–15	40	42	18	Loam
		15–30	41	41	18	Loam
		30–50	38	43	19	Loam
		50–100	40	41	19	Loam
11.	Bogi Forest Beat Sharankhola Forest Range Sharankhola, Bagerhat	0–15	39	49	12	Loam
		15–30	38	46	16	Loam
		30–50	37	48	15	Loam
		50–100	38	44	18	Loam
Coastal Afforestation						
12.	Sonarchar, Rangabali Patuakhali	0–15	44	45	11	Loam
		15–30	44	43	13	Loam
		30–50	43	42	15	Loam
		50–100	45	40	15	Loam
13.	Kukri-Mukri, Charfashion Bhola	0–15	42	42	16	Loam
		15–30	40	41	19	Loam
		30–50	37	45	18	Loam
		50–100	39	46	15	Loam
14.	Nijhumdwip National Park Hatiya, Noakhali	0–15	38	47	15	Loam
		15–30	36	47	17	Loam

		30–50	37	47	16	Loam
		50–100	36	47	17	Loam

Table 4.1 Continued

Sl. No.	Location	Depth (cm)	Sand	Silt	Clay	Textural Class
			%			
15.	Dumkhali, Mirersarai Chittagong	0–15	39	37	24	Loam
		15–30	39	34	27	Loam
		30–50	37	34	29	Loam
		50–100	37	34	29	Loam
Sal Forest						
16.	Kotbari, Cumilla Sadar Cumilla	0–15	54	28	18	SL
		15–30	59	22	19	SL
		30–50	67	10	23	SL
		50–100	55	29	16	SL
17.	Dokhola Forest Range Madhupur, Tangail	0–15	54	28	18	SL
		15–30	52	26	17	SCL
		30–50	53	24	23	SCL
		50–100	77	5	18	SL
18.	Bhawal National Park Salna, Gazipur	0–15	51	30	19	SL
		15–30	40	27	33	CL
		30–50	45	17	38	CL
		50–100	46	15	39	CL

Values are the mean of triplicate measurement
SCL = Sandy Clay Loam, SL = Sandy Loam, LS = Loamy Sand, and CL = Clay Loam

4.1.2. Soil moisture content

Soil moisture content was found to vary at different soil depths in different locations. In general, soil moisture content was found higher in all locations of Sundarban mangrove forest and coastal afforestation areas compared to the Hill Forest of Chittagong and Sylhet and Sal Forest areas. This phenomenon could be ascribed to the continuous wetting conditions (i.e. inundation) resulting from flood and ebb tides in the Sundarban mangrove forest and coastal afforestation areas. The forest areas were found to contain higher moisture content than the adjacent homestead areas in different locations of different forest areas. The analytical data (Table 4.2 compiled from Appendix A-3) of moisture content revealed that in the Hill Forest of Chittagong, the highest amount of moisture content was found in Dulahazra Forest Beat (25%) at 50–100 cm soil depth and the lowest in Goneshpara, Thanchi (13%) at the topsoil (0–15 cm). In the homestead area of Chittagong hill forest, the maximum amount of moisture content was found in Kaptai National Park (24%) at 50–100 cm soil depth and the minimum in Baraiyadhala National Park (7%) at 0–15 cm soil depth. In this forest area, the one-way ANOVA test showed that there were significant differences ($p<0.01$) in moisture content at the same depth among the locations both in forested and homestead sites. No significant differences ($p>0.05$) were found between different soil depths in the forest area of Ganeshpara, Thanchi; Kaptai National Park; and Wasu, Matiranga.

In the hill forest of Sylhet, the highest amount of moisture content was found in the forest area of Lawachara National Park (~20%) followed by Satchari National Park (~13%) and the lowest in Tilagarh Eco Park (~4–8%) at different soil depths. A similar trend was found in the homestead area of Sylhet hill forest. The one-way ANOVA test revealed that there were significant differences ($p<0.05$) in moisture content at the same depth among the locations in both forested and homestead sites. However, no significant difference ($p>0.05$) was observed among the different depths in the forest area of Satchari National Park (Table 4.2).

Significant differences were found in moisture content among the locations of Sundarban mangrove forest and coastal afforestation areas at different soil depths except in the forested site of Dhangmari Forest Beat and the homestead site of Sonarchar, Rangabali. The soil moisture content was found higher in the forested site of the Sundarban mangrove forest (~38–45%) compared to the forested site of the coastal area (~27–34%). However, in the homestead site, the moisture content was higher in the coastal area (~37–33%). Munshigonj and Dhangmari Forest Beat contained ~40% moisture content at all soil depths. Bogi Forest Beat contained relatively lower (~22–26%) moisture content in the forested site (Table 4.2). In the Sal Forest area, moisture content was at par in both forested and homestead sites, and it was found to vary from ~16–25% (Table 4.2). Akhtaruzzaman (2016) reported that the moisture content generally increases with depth although there was no specific trend in the present study. Soil moisture content depends on the clay and humus content, rate of evapotranspiration, and percolation. Evaporation from a location is also related to vegetation cover, solar radiation, and soil physical properties. Downward loss of water depends on soil texture, structure, porosity, and on land level.

Table 4.2. Soil moisture content (%) at different soil depths in forested and homestead sites in different forest areas

Location	Forested Site					Homestead Site				
	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test
Chittagong hill forest										
Baraiyadhala National Park Sitakunda, Chittagong	17.43^{Ba} (0.94)	18.04^{BCa} (0.35)	17.80^{Ba} (2.27)	12.41^{Cb} (1.66)	**	6.87^{Db} (0.44)	10.37^{Ba} (1.93)	5.72^{Db} (0.22)	4.04^{Db} (1.17)	**
Dulahazra Forest Beat Chakoria, Cox's Bazar	16.32^{Bc} (0.83)	20.93^{ABb} (1.25)	23.71^{Aa} (0.53)	24.90^{Aa} (0.20)	**	9.58^{CDb} (1.45)	11.91^{Bb} (1.83)	15.52^{Ba} (0.84)	18.72^{Ba} (0.04)	**
Goneshpara, Thanchi Bandarban Hill District	13.13^{Ca} (0.25)	13.29^{Da} (0.33)	14.23^{Ca} (0.25)	14.20^{Ca} (0.92)	ns	10.99^{Ca} (0.13)	11.46^{Ba} (1.62)	11.79^{Ca} (1.28)	13.06^{Ca} (0.76)	ns
Kaptai National Park Rangamati Hill District	21.06^{Aa} (1.51)	23.23^{Aa} (0.67)	22.58^{Aa} (0.41)	22.67^{Aa} (0.30)	ns	19.88^{Ab} (0.74)	20.90^{Ab} (1.12)	19.78^{Ab} (0.65)	24.06^{Aa} (0.01)	**
Wasu, Matiranga Chagrachari Hill District	16.34^{Ba} (0.98)	17.69^{Ca} (2.05)	18.04^{Ba} (1.66)	18.29^{Ba} (0.45)	ns	16.52^{Bb} (1.49)	18.73^{Aab} (0.75)	19.34^{Aa} (0.35)	19.65^{Ba} (1.20)	*
F-test	**	**	**	**		**	**	**	**	
Sylhet Hill Forest										
Satchari National Park Chunarughat, Habigonj	13.05^{Ba} (1.12)	13.28^{Ba} (1.57)	13.34^{Ba} (0.76)	13.20^{Ba} (0.18)	ns	12.63^{Bb} (0.46)	13.20^{Bb} (0.18)	15.44^{Aa} (0.35)	11.82^{Ac} (0.08)	**
Lawachara National Park Sreemongal, Moulavibazar	19.56^{Aab} (1.02)	19.11^{Aab} (0.95)	18.63^{Ab} (0.51)	20.86^{Aa} (0.56)	*	17.38^{Aa} (0.19)	16.22^{Ab} (0.09)	15.67^{Ab} (0.30)	12.32^{Ac} (0.34)	**
Tilagarh Eco Park, Sylhet	7.73^{Ca} (0.33)	6.71^{Ca} (0.22)	5.41^{Cb} (0.75)	3.88^{Cc} (0.11)	**	5.74^{Ca} (0.28)	5.48^{Ca} (0.16)	4.60^{Bb} (0.23)	3.53^{Bc} (0.28)	**
F-test	**	**	**	**		**	**	**	**	
Sundarban Mangrove Forest										
Munshigonj Forest Beat Shamnagar, Satkhira	37.74^{Bb} (1.20)	40.32^{Aab} (1.24)	40.65^{Aab} (0.88)	42.05^{Aa} (1.62)	*	15.41^{Bd} (0.35)	17.22^{Ac} (0.23)	18.56^{Cb} (0.13)	20.24^{Ca} 0.30)	**
Dhangmari Forest Beat	40.96^{Aa}	41.59^{Aa}	42.09^{Aa}	45.02^{Aa}	ns	21.73^{Ad}	23.41^{Ac}	24.57^{Ab}	26.89^{Aa}	**

Table 4.2. Continued

Location	Forested Site					Homestead Site				
	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test
Dakop, Khulna	(1.54)	(1.41)	(3.68)	(2.09)		(0.15)	(0.24)	(0.30)	(0.38)	
Bogi Forest Beat Sharankhola, Bagerhat	22.28^{Cbc} (0.63)	19.55^{Bc} (0.89)	25.03^{Bab} (0.45)	26.38^{Ba} (1.86)	**	13.69^{Cd} (0.35)	18.52^{Bc} (0.15)	20.77^{Bb} (0.25)	23.29^{Ba} (0.22)	**
F-test	**	**	**	**		**	**	**	**	
Coastal Afforestation										
Sonarchar, Rangabali Patuakhali	27.08^{Cc} (1.34)	28.32^{Cbc} (0.98)	30.61^{Bab} (0.99)	31.42^{Ca} (0.57)	**	26.18^{ABa} (0.14)	25.13^{Ba} (0.88)	25.85^{Ba} (0.92)	27.23^{Ba} (1.39)	ns
Kukri-Mukri, Charfashion Bhola	31.44^{Bb} (0.20)	31.18^{Bb} (0.92)	33.20^{Aab} (1.25)	34.42^{Aa} (0.48)	**	26.05^{Bc} (0.20)	29.36^{Ab} (0.54)	29.63^{Ab} (0.83)	32.62^{Aa} (0.89)	**
Nijhumdwip, Hatiya Noakhali	31.46^{Bb} (0.44)	34.02^{Aa} (0.11)	33.16^{Aab} (0.74)	33.95^{ABa} (1.44)	*	16.79^{Cd} (1.05)	22.53^{Cc} (0.48)	25.94^{Bb} (0.41)	28.63^{Ba} (0.29)	**
Dumkhali, Mirersarai Chittagong	34.24^{Aa} (0.27)	29.77^{BCc} (0.46)	31.17^{ABb} (0.67)	31.84^{BCb} (0.40)	**	27.59^{Ad} (0.22)	29.78^{Ac} (0.40)	30.84^{Ab} (0.33)	32.84^{Aa} (0.32)	**
F-test	**	**	*	**		**	**	**	**	
Sal Forest										
Kotbari, Cumilla Sadar Cumilla	22.18^{Ab} (0.73)	21.72^{Bb} (0.44)	24.85^{Ba} (0.52)	24.91^{Aa} (0.73)	**	23.28^{Aa} (0.48)	23.83^{Aa} (0.63)	23.26^{Aa} (1.55)	18.09^{Bb} (1.32)	**
Dokhola Forest Range Madhupur, Tangail	21.31^{Ac} (0.31)	24.77^{Ab} (0.77)	27.64^{Aa} (0.31)	24.54^{Ab} (0.35)	**	16.16^{Bb} (0.24)	17.33^{Bb} (1.01)	17.67^{Bb} (0.83)	19.69^{ABa} (0.10)	**
Bhawal National Park Salna, Gazipur	19.37^{Bc} (0.48)	21.99^{Bb} (0.90)	23.66^{Ca} (0.55)	24.91^{Aa} (0.06)	**	16.30^{Bd} (0.85)	17.88^{Bc} (0.50)	19.24^{Bb} (0.22)	21.20^{Aa} (0.16)	**
F-test	**	**	**	ns		**	**	**	**	

Values are the mean of triplicate measurement and values in parentheses are standard deviation. Different capital (A, B, C, D) and small letters (a, b, c, d) in superscript indicate significant differences among locations at the same depth and within a location at different soil depths, respectively.

* indicates significant at 5% level of significance ($p<0.05$), ** indicates significant at 1% level of significance ($p<0.01$), and ns indicates not significant.

4.1.3. Soil bulk density

The soil bulk density is an important physical property of soil. The analytical data in Table 4.3 (compiled from Appendix A-4) revealed that in the Chittagong hill forest, the bulk density was found to vary from 1.33 to 1.55 g cm^{-3} in the forested site. In surface soils (0–15 cm), the bulk density was found to vary from 1.33 to 1.45 g cm^{-3} and increase with increasing depth. A similar trend was observed in the homestead area of the hill forest. The soil bulk density in the homestead area was found to vary from 1.39 to 1.58 g cm^{-3}. The maximum soil bulk density was found in the homestead area of Dulahazra Forest Beat (1.55 to 1.63 g cm^{-3}) and the minimum in the forested site of Baraiyadhala National Park at different soil depths (1.33 to 1.38 g cm^{-3}). The one-way ANOVA test revealed that in the forested site, there were significant differences ($p<0.05$) in bulk density among the locations and different soil depths. No significant differences were found between different soil depths in Baraiyadhala National Park. Soil bulk density was found higher in the Sylhet hill forest compared to other forest areas. On the other hand, the Sundarban mangrove forest showed the lowest soil bulk density. In the Sylhet hill forest, soil bulk density was found higher at Satchari National Park in both forested (1.60 to 1.67 g cm^{-3}) and homestead (1.68 to 1.74 g cm^{-3}) sites at different soil depths compared to other locations. In the forested site of Sylhet Hill Forest, no significant differences ($p>0.05$) were observed among the locations and soil depths except in Lawachara National Parks where significant differences were found between different soil depths ($p<0.05$). In the homestead site, significant differences were observed among the locations and soil depth ($p<0.05$) except at 50–100 cm soil depth among the locations.

Comparing natural (Sundarban) and afforested (coastal) mangrove forest areas, it was observed that the natural mangrove exhibited lower bulk densities compared to the afforested mangrove areas across different locations and soil depths. The soil bulk density of the Sundarban mangrove forest was found to range from 1.16 to 1.43 g cm^{-3}, whereas, in coastal afforestation areas, it was found to range from 1.22 to 1.45 g cm^{-3}. A similar trend was observed in the homestead site of that area. Significant differences were found in the homestead site of the Sundarban mangrove forest, but the differences were statistically nonsignificant ($p>0.05$) in the coastal afforestation area. In the Sal Forest area, soil bulk density was found higher at Kotbari Sal forest of Cumilla district (1.46 to 1.57 g cm^{-3}) at different soil depths followed by Bhawal

National Park of Gazipur (1.43 to 1.55 g cm^{-3}) and Dokhola Forest Range, Madhupur, Tangail (1.39 to 1.49 g cm^{-3}). The ANOVA result showed that in the forested site, there were significant differences ($p<0.05$) between different soil depths but statistically nonsignificant differences among the locations at the same soil depth except 30 – 50 cm soil depth (Table 4.3).

The results in Table 4.3 revealed that the bulk density of soils increased with depth in all locations of different forest areas. It could be attributed to the greater compaction occurring over time at the lower depths in the soils. The results of the present study are in agreement with the findings of other investigators (Akhtaruzzaman, 2016; Gupta et al., 2010; Lee et al., 2009). Han et al. (2010) reported an increase in soil bulk density with soil depth in different soils of Loess Plateau, China. Loose soils have lower bulk density and compact soils have higher bulk density. Coarse textured or sandy soils tend to have a higher bulk density. Forest soils are more porous in nature and possess lower bulk density than cultivated soils (Osman, 2013). Batjes and Dijkshoorn (1999), Brown and Lugo (1990), Davidson and Ackerman (1993), Feller et al. (2001) and Rosell and Galantini (1997) reported higher soil bulk densities in natural forests compared to cultivated areas. Mongia and Bandopadhyay (1994) reported that the replacement of a virgin forest with highly valued plantation species viz. Padauk/Redwood (*Pterocarpus dalbergioides*), Sal (*Shorea robusta*), Segun (*Tectona grandis*), and Oil palm (*Elaeis guinensis*) in Andaman resulted in a rapid deterioration in soil physical properties. They observed an increase in bulk density from 1.05 g cm^{-3} in the virgin forest of the surface soil to 1.30 g cm^{-3}, 1.49 g cm^{-3}, 1.35 g cm^{-3}, and 1.28 g cm^{-3} with Padauk/Redwood, Sal, Segun, and Oil palm plantations, respectively. Singh et al. (2001) found higher bulk density values in both degraded and slightly degraded lands compared to the undisturbed site.

The variation in bulk density could be ascribed to variation in organic matter, texture, etc. (Evrendilek et al., 2004; and Sharma and Kumar, 2003), and soil aggregate stability and porosity (Yan et al., 2009). The higher bulk density values could be associated with their coarse texture and low organic matter content (Swarnam et al., 2004). Bulk density is closely related to soil organic matter (Curtis and Post, 1964; and Perie and Ouimet, 2008) as well as soil compaction (Tamminen and Starr, 1994). The fact that the natural mangrove area possesses lower bulk density values results in more gas exchange processes and higher permeability compared to planted mangrove stand. On the other hand, higher bulk density reduces the volume of macropores accounting for a reduction in gaseous exchanges (Gnanamoorthy et al., 2019).

Table 4.3. Soil bulk density (g cm^{-3}) at different soil depths in forested and homestead sites in different forest areas

Location	Forested Site					Homestead Site				
	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test
Chittagong hill forest										
Baraiyadhala National Park Sitakunda, Chittagong	1.33^{Ba} (0.05)	1.35^{Ba} (0.02)	1.37^{Ba} (0.06)	1.38^{Ba} (0.00)	ns	1.39^{Bb} (0.02)	1.52^{Aa} (0.03)	1.56^{Aa} (0.02)	1.56^{Aa} (0.05)	**
Dulahazra Forest Beat Chakoria, Cox's Bazar	1.41^{ABc} (0.03)	1.46^{Abc} (0.03)	1.55^{Aab} (0.04)	1.59^{Aa} (0.06)	**	1.55^{Aa} (0.04)	1.58^{Aa} (0.04)	1.62^{Aa} (0.09)	1.63^{Aa} (0.04)	ns
Goneshpara, Thanchi Bandarban Hill District	1.34^{ABa} (0.06)	1.42^{ABa} (0.06)	1.46^{ABa} (0.02)	1.47^{Ba} (0.02)	*	1.55^{Aa} (0.03)	1.56^{Aa} (0.02)	1.58^{Aa} (0.03)	1.58^{Aa} (0.03)	ns
Kaptai National Park Rangamati Hill District	1.45^{Ab} (0.01)	1.48^{Ab} (0.02)	1.52^{Aa} (0.01)	1.55^{Aa} (0.01)	*	1.50^{Ab} (0.03)	1.51^{Aab} (0.02)	1.58^{Aa} (0.04)	1.54^{Aab} (0.01)	*
Wasu, Matiranga Chagrachari Hill District	1.45^{Ab} (0.01)	1.48^{Ab} (0.02)	1.52^{Aa} (0.01)	1.55^{Aa} (0.01)	**	1.50^{Ab} (0.03)	1.51^{Aab} (0.02)	1.54^{Aab} (0.01)	1.58^{Aa} (0.04)	*
F-test	**	**	**	**		**	ns	ns	ns	
Sylhet Hill Forest										
Satchari National Park Chunarughat, Habigonj	1.60^{Aa} (0.07)	1.64^{Aa} (0.08)	1.65^{Aa} (0.06)	1.67^{Aa} (0.03)	ns	1.68^{Ab} (0.01)	1.71^{Aab} (0.01)	1.72^{Aab} (0.01)	1.74^{Aa} (0.03)	*
Lawachara National Park Sreemongal, Moulavibazar	1.50^{Ab} (0.04)	1.59^{Aab} (0.03)	1.65^{Aab} (0.07)	1.66^{Aa} (0.07)	*	1.47^{Cc} (0.02)	1.50^{Cc} (0.02)	1.60^{Cb} (0.02)	1.70^{Aa} (0.02)	**
Tilagarh Eco Park, Sylhet	1.54^{Aa} (0.00)	1.61^{Aa} (0.06)	1.62^{Aa} (0.05)	1.65^{Aa} (0.04)	ns	1.56^{Bc} (0.03)	1.65^{Bb} (0.02)	1.66^{Bab} (0.01)	1.73^{Aa} (0.03)	**
F-test	ns	ns	ns	ns		**	**	**	ns	
Sundarban Mangrove Forest										
Munshigonj Forest Beat Shamnagar, Satkhira	1.21^{Bb} (0.01)	1.26^{Aab} (0.06)	1.26^{Bab} (0.01)	1.31^{Ba} (0.04)	ns	1.21^{Bc} (0.01)	1.28^{Bb} (0.02)	1.28^{Bb} (0.01)	1.34^{Ba} (0.02)	**

Table 4.3 Continued

Location	Forested Site					Homestead Site				
	0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**F-test**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**	**F-test**
Dhangmari Forest Beat Dakop, Khulna	1.16^{Bb} (0.03)	1.27^{Aa} (0.03)	1.27^{Ba} (0.03)	1.29^{Ba} (0.02)	**	1.21^{Bb} (0.03)	1.26^{Bab} (0.02)	1.29^{Bab} (0.04)	1.35^{Ba} (0.03)	**
Bogi Forest Beat Sharankhola, Bagerhat	1.37^{Aa} (0.08)	1.40^{Aa} (0.08)	1.41^{Aa} (0.01)	1.43^{Aa} (0.05)	ns	1.34^{Ab} (0.02)	1.38^{Ab} (0.02)	1.39^{Ab} (0.01)	1.45^{Aa} (0.02)	**
F-test	**	ns	**	**		**	**	**	**	
Coastal Afforestation										
Sonarchar, Rangabali Patuakhali	1.37^{Aa} (0.03)	1.37^{Aa} (0.02)	1.39^{Aa} (0.02)	1.40^{ABa} (0.03)	ns	1.38^{Aa} (0.02)	1.40^{Aa} (0.02)	1.40^{Aa} (0.04)	1.44^{Aa} (0.04)	ns
Kukri-Mukri, Charfashion Bhola	1.22^{Bb} (0.04)	1.32^{Aab} (0.06)	1.35^{Aa} (0.01)	1.36^{Ba} (0.04)	*	1.39^{Aa} (0.04)	1.40^{Aa} (0.02)	1.42^{Aa} (0.01)	1.43^{Aa} (0.01)	ns
Nijhumdwip National Park Hatiya, Noakhali	1.34^{Ab} (0.00)	1.35^{Ab} (0.01)	1.36^{Ab} (0.02)	1.44^{Aa} (0.01)	**	1.39^{Ab} (0.04)	1.39^{Ab} (0.04)	1.44^{Aab} (0.01)	1.48^{Aa} (0.01)	*
Dumkhali, Mirersarai Chittagong	1.36^{Ab} (0.03)	1.38^{Aab} (0.03)	1.42^{Aab} (0.03)	1.45^{Aa} (0.02)	*	1.40^{Aa} (0.00)	1.44^{Aa} (0.02)	1.44^{Aa} (0.09)	1.51^{Aa} (0.07)	ns
F-test	**	ns	*	*		ns	ns	ns	ns	
Sal Forest										
Kotbari, Cumilla Sadar Cumilla	1.46^{Aa} (0.07)	1.47^{Aa} (0.03)	1.53^{Aa} (0.03)	1.57^{Aa} (0.03)	*	1.51^{Aa} (0.03)	1.54^{Aa} (0.03)	1.59^{Aa} (0.07)	1.60^{Aa} (0.10)	ns
Dokhola Forest Range Madhupur, Tangail	1.39^{Ab} (0.02)	1.43^{Ab} (0.01)	1.44^{Bab} (0.01)	1.49^{Aa} (0.02)	**	1.41^{Ba} (0.03)	1.44^{Ba} (0.01)	1.47^{Ba} (0.01)	1.50^{Aa} (0.07)	ns
Bhawal National Park Salna, Gazipur	1.43^{Ab} (0.00)	1.46^{Ab} (0.03)	1.49^{ABab} (0.01)	1.55^{Aa} (0.05)	**	1.42^{Bb} (0.02)	1.46^{Ab} (0.03)	1.48^{ABb} (0.03)	1.57^{Aa} (0.02)	**
F-test	ns	ns	**	ns		**	*	*	ns	

Values are the mean of triplicate measurement and values in parentheses are standard deviation. Different capital (A, B, C, D) and small letters (a, b, c, d) in superscript indicate significant differences among locations at the same depth and within a location at different soil depths, respectively.
* indicates significant at 5% level of significance (p<0.05), ** indicates significant at 1% level of significance (p<0.01), and ns indicates not significant.

4.2. Soil Chemical Properties

Among the different chemical properties of soils, only soil pH, electrical conductivity (EC), soil organic carbon (SOC), and total nitrogen were determined or estimated in the study. The data are described and discussed below.

4.2.1. Soil pH

Soil pH is one of the important soil quality parameters used to assess the potential accessibility of beneficial nutrients and toxic elements to plants. The data presented in Table 4.4 (compiled from Appendix A-5) shows that the pH was found to be higher in the soils of Sundarban mangrove forest and coastal afforestation areas than that of the Hill Forest of Chittagong and Sylhet and the sal forest areas. The data also reveals that the soil pH values in the forested site of Sundarban mangrove forest and coastal afforestation areas were generally higher than that of the homestead site of that forest areas. The hill forest of Chittagong exhibited pH values classified as very strongly acid (4.5 – 5.0), strongly acid (5.1 – 5.5), moderately acid (5.6 – 6.0), and slightly acid (6.1 – 6.5) (Soil Survey Division Staff, 1993). In the forested site, pH values range from 5.48 to 6.26 in Kaptai National Park, from 5.50 to 5.75 in Baraiyadhala National Park, from 5.16 to 5.35 in Goneshpara, Thanchi, from 4.98 to 5.25 in Dulahazra Forest Beat, and from 4.81 to 4.84 in Wasu, Matiranga. Generally, the pH of the soils was found to increase with increasing soil depth. The one-way ANOVA test shows that there were significant differences in soil pH among the locations at different soil depths ($p<0.05$) in both forested and homestead sites. No significant difference was found between different soil depths in the homestead site of Kaptai National Pak. With few exceptions, significant differences were obtained in pH values among different locations at the same depth and among different depths within the same site in Sylhet Hill Forest ($p<0.05$). In the Sal Forest area, significant differences were found in pH values among locations and depths ($p<0.05$).

In the soils of Sundarban mangrove forest and coastal afforestation areas, the soil pH was found to range from 7.74 to 9.98 and 7.75 to 8.24 in the forested site, respectively; in the homestead site, the values varied from 6.65 to 7.99 and 7.51 to 8.14, respectively. The maximum soil pH (9.98 at 50 – 100 cm depth) was found in the forested site of Munshigonj Forest Beat and the minimum at Bogi Forest Beat (7.74 at 0 – 15 cm depth). These two sites under study belong to a strong saline zone (polyhaline) and a less saline zone (oligohaline), respectively. On the other hand, Dhangmari Forest Beat belongs to a moderate saline zone (mesohaline). In the coastal afforestation areas, the highest soil pH was found in the forested site of Sonarchar, Rangabali (8.30 at 15 – 30 cm depth) and the lowest in Dumkhali, Mirersarai (7.75 at 0 – 15 cm depth). In the homestead site, the highest pH was found in Nijhumdwip National Park (8.14 at 50 – 100 cm depth) and the lowest in Kukri-Mukri, Charfashion (7.51 at 0 – 15 cm depth).

The soils in the hill forest of Chittagong and Sylhet were very strongly acidic to slightly acidic (4.5–6.5) in nature probably because of higher topography, erosion, weathering, and leaching due to heavy rainfall in the monsoon (Karim and Khan, 1955). The acidic nature of the brown hill soils in the southeastern region of Bangladesh was reported by other investigators (CERDI, 1983; Islam and Haque, 1995; and SRDI, 1976). Osman (2013) opined that coarse-textured soils, highly weathered soils, and intensely leached soils are usually acidic. The soils may be subjected to acidification via the decomposition of organic matter and subsequent production of acids. The magnitude of acidification due to soil organic matter (SOM) or humus will vary with the type of vegetation such as coniferous forest soils generally having a lower pH than deciduous forest soils. Larcher (1980) reported that large quantities of aluminum (Al^{3+}), iron (Fe^{2+}), and manganese (Mn^{2+}) ions are liberated at low pH values which are toxic to most plant species. Soil characteristics such as weathering processes, soil structure, humification, mineral transformation, microbial population and activity, mobilization of nutrients, and ion exchange influence the pH of the soil (Larcher, 1980). Soil pH changes seasonally with the distribution of precipitation. Thus, an accurate characterization of root zone pH must be done by covering all the seasons. Precipitation has a bearing on soil pH because rainwater leaves elements in the soil that produce acid and carries and solubilizes nutrients in soil. Soil pH affects the number of available nutrients and elements deemed toxic for plants in soil solution (Rahman and Bahauddin, 2018).

Zaman et al. (2010) found that soil pH decreased with depth and pH values were significantly higher in forested sites in comparison to the deforested sites. Changes in land use and deforestation might have a significant effect on soil acidity. Haque and Karmakar (2009) opined that soil organic matter through litter decomposition decreased the soil pH (or increased soil acidity) in the hill forests of Bangladesh; the effects are more prominent in the natural forests than in plantation forests. Mature mixed plantation forests were found to exhibit lower pH than younger plantation forests. In another study, Haque et al. (2014) revealed that soil pH is significantly higher in deforested land than in adjacent forest soil in an upland watershed of Bangladesh.

Table 4.4. Soil pH at different soil depths in forested and homestead sites in different forest areas

Location	Forested Site					Homestead Site				
	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test
Chittagong hill forest										
Baraiyadhala National Park Sitakunda, Chittagong	5.50^{Ab} (0.05)	5.59^{Aab} (0.06)	5.61^{Bab} (0.06)	5.75^{Ba} (0.09)	*	5.29^{Bc} (0.02)	5.45^{Bb} (0.01)	5.53^{Bb} (0.05)	5.71^{Ba} (0.05)	**
Dulahazra Forest Beat Chakoria, Cox's Bazar	4.98^{Cc} (0.02)	4.77^{Cd} (0.01)	5.16^{Db} (0.03)	5.25^{Ca} (0.02)	**	5.03^{Cc} (0.04)	5.11^{Cbc} (0.02)	5.13^{Bb} (0.01)	5.35^{Ca} (0.03)	**
Goneshpara, Thanchi Bandarban Hill District	5.16^{Bb} (0.03)	5.14^{Bb} (0.02)	5.32^{Ca} (0.01)	5.35^{Ca} (0.04)	**	5.02^{Cb} (0.02)	5.10^{Ca} (0.01)	5.06^{Ba} (0.00)	5.08^{Da} (0.01)	**
Kaptai National Park Rangamati Hill District	5.48^{Ad} (0.02)	5.62^{Ac} (0.03)	5.83^{Ab} (0.02)	6.26^{Aa} (0.01)	**	6.25^{Aa} (0.02)	6.35^{Aa} (0.03)	5.51^{Aa} (0.58)	6.18^{Aa} (0.05)	ns
Wasu, Matiranga Chagrachari Hill District	4.81^{Db} (0.02)	4.86^{Cb} (0.09)	5.24^{CDa} (0.04)	4.84^{Db} (0.05)	**	4.92^{Da} (0.06)	4.70^{Db} (0.00)	4.98^{Ba} (0.01)	4.72^{Eb} (0.04)	**
F-test	**	**	**	**		**	**	**	**	
Sylhet Hill Forest										
Satchari National Park Chunarughat, Habigonj	4.63^{Ba} (0.04)	4.88^{Aa} (0.60)	4.74^{Ba} (0.04)	4.83^{Ca} (0.04)	ns	5.12^{Ba} (0.04)	5.08^{Ba} (0.03)	4.84^{Bb} (0.03)	4.76^{Bb} (0.04)	**
Lawachara National Park Sreemongal, Moulavibazar	4.77^{Ab} (0.02)	4.62^{Ac} (0.01)	4.76^{Bb} (0.02)	5.02^{Ba} (0.00)	**	5.40^{Aab} (0.03)	5.44^{Aa} (0.04)	5.27^{Ac} (0.01)	5.35^{Abc} (0.03)	**
Tilagarh Eco Park, Sylhet	4.68^{Bd} (0.01)	4.73^{Ac} (0.02)	4.95^{Ab} (0.01)	5.24^{Aa} (0.00)	**	4.65^{Ca} (0.04)	4.64^{Cab} (0.02)	4.46^{Cc} (0.00)	4.58^{Cb} (0.01)	**
F-test	**	ns	**	**		**	**	**	**	
Sundarban Mangrove Forest										
Munshigonj Forest Beat Shamnagar, Satkhira	8.18^{Aa} (0.01)	8.03^{Ac} (0.00)	8.07^{Ab} (0.01)	9.98^{Bd} (0.00)	**	7.85^{Ba} (0.00)	7.88^{Ba} (0.00)	7.84^{Ba} (0.03)	7.84^{Ca} (0.02)	ns

Table 4.4 Continued

Location	Forested Site					Homestead Site				
	0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**F-test**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**	**F-test**
Dhangmari Forest Beat Dakop, Khulna	7.97^{Bb} (0.01)	8.00^{Ab} (0.01)	8.06^{Aa} (0.02)	8.00^{Bb} (0.01)	**	7.90^{Ab} (0.01)	7.92^{Ab} (0.01)	7.96^{Aa} (0.02)	7.99^{Aa} (0.00)	**
Bogi Forest Beat Sharankhola, Bagerhat	7.74^{Cd} (0.01)	7.88^{Bc} (0.01)	7.96^{Bb} (0.01)	8.12^{Aa} (0.02)	**	6.65^{Cd} (0.02)	7.55^{Cc} (0.01)	7.75^{Cb} (0.02)	7.93^{Ba} (0.03)	**
F-test	**	**	**	**		**	**	**	**	
Coastal Afforestation										
Sonarchar, Rangabali Patuakhali	7.96^{Aa} (0.15)	8.26^{Aa} (0.06)	8.30^{Aa} (0.05)	8.24^{Aa} (0.24)	ns	7.80^{Ba} (0.05)	7.91^{ABa} (0.10)	7.96^{ABa} (0.10)	8.00^{Aa} (0.14)	ns
Kukri-Mukri, Charfashion Bhola	7.81^{Ab} (0.10)	8.00^{Bab} (0.03)	7.90^{Cab} (0.08)	8.13^{Aa} (0.14)	*	7.51^{Dc} (0.03)	7.94^{ABa} (0.08)	7.88^{Bab} (0.04)	7.69^{Bbc} (0.10)	**
Nijhumdwip Natioal Park Hatiya, Noakhali	7.96^{Ac} (0.01)	8.08^{Bb} (0.01)	8.14^{Ba} (0.01)	8.17^{Aa} (0.00)	**	7.91^{Ac} (0.03)	8.04^{Ab} (0.01)	8.08^{Ab} (0.01)	8.14^{Aa} (0.02)	**
Dumkhali, Mirersarai Chittagong	7.75^{Ad} (0.03)	7.83^{Cc} (0.02)	7.97^{Cb} (0.03)	8.06^{Aa} (0.01)	**	7.63^{Cc} (0.04)	7.80^{Bb} (0.04)	7.92^{Ba} (0.01)	8.00^{Aa} (0.00)	**
F-test	ns	**	**	ns		**	*	*	**	
Sal Forest										
Kotbari, Cumilla Sadar Cumilla	4.26^{Cd} (0.02)	4.42^{Cc} (0.00)	4.57^{Cb} (0.04)	4.64^{Ba} (0.01)	**	4.50^{Cc} (0.01)	4.61^{Cb} (0.02)	4.69^{Ca} (0.02)	4.78^{Ca} (0.05)	**
Dokhola Forest Range Madhupur, Tangail	4.87^{Ac} (0.05)	4.94^{Ac} (0.02)	5.13^{Ab} (0.04)	5.36^{Aa} (0.05)	**	5.38^{Ab} (0.04)	5.44^{Ab} (0.05)	5.58^{Aa} (0.07)	5.71^{Aa} (0.01)	**
Bhawal National Park Salna, Gazipur	4.68^{Bc} (0.03)	4.70^{Bc} (0.05)	4.90^{Bb} (0.02)	5.40^{Aa} (0.05)	**	4.75^{Bd} (0.01)	4.98^{Bc} (0.02)	5.32^{Bb} (0.00)	5.49^{Ba} (0.03)	**
F-test	**	**	**	**		**	**	**	**	

Values are the mean of triplicate measurement and values in parentheses are standard deviation. Different capital (A, B, C, D) and small letters (a, b, c, d) in superscript indicate significant differences among locations at the same depth and within a location at different soil depths, respectively.
* indicates significant at 5% level of significance ($p<0.05$), ** indicates significant at 1% level of significance ($p<0.01$) and ns indicates not significant.

Biswas et al. (2010) recorded lower pH in the soils of Chittagong Hill Tracts subjected to continuous shifting cultivation farming systems; however, the pH values were slightly higher than in the adjacent natural forests. In another study, Gafur et al. (2000) and Osman et al. (2013) recorded higher soil pH values in shifting cultivation lands compared to forested lands in this region. Akhtaruzzaman et al. (2014, 2015) recorded higher pH values at both surface and sub-surface soils of the cultivated sites compared to a planted forest and barren land. Roy et al. (2012) reported more acidic soils in banana-based agroforestry than in the Sal (*Shorea robusta*) forest because of the application of various fertilizers, growth hormones, and pesticides for better production in the agroforestry field.

Muhibbullah et al. (2007) recorded average values of 6.3, 6.5, and 6.6 in the Sharankhola, Chandpai, and Burigoalini Forest Range of Sundarban mangrove forests, respectively, and thus, these areas are slightly acidic in nature. Hassan and Razzaque (1981) obtained pH values of soil in the Sundarban mangrove forest being neutral to mildly alkaline under field conditions, but in some localities, the pH values of dried-up sub-soil dropped to 6.5. Joshi and Ghose (2014), Maniruzzaman et al. (2009), Muhibbullah (2005) and Rao and Rao (2014) reported that the soils of Sundarban were slightly saline to saline where pH ranged from 7.10 to 8.79, which substantiate the results of the present findings (Table 4.4). Osman (2013) also reported that humid temperate forests, tropical forests, and mangrove forest soils may have pH values between 3.0 and 5.0, between 4.0 and 6.0, and around 7.5, which are also in agreement with the present findings.

4.2.2. Soil organic carbon

Soil organic carbon (SOC) is a part of the global carbon cycle which involves the cycling of carbon through plants and soils. Litterfall in the forest floor is the major source of soil organic carbon and soil organic matter (SOM). The overall findings (Table 4.5 compiled from Appendix A-6) of the present study revealed that the surface soil (0–15 cm soil depth) contained a higher amount of soil organic carbon, which decreased with increasing soil depth in all locations under study. It was also found that among the locations, the forested sites possessed higher soil organic carbon compared to the homestead sites. In the Hill forest of Chittagong, SOC was found higher in Goneshpara, Thanchi, Bandarbon Hill District (1.08% to 1.25%), followed by Wasu, Matiranga, Khagrachari Hill District (0.70% to 1.26%), Baraiyadhala National Park, Sitakunda, Chittagong (0.26% to 1.06%), Kaptai National Park, Rangamati Hill District (0.41% to 0.89%), and Dulahazra Forest Beat, Chakoria, Cox's Bazar (0.36% to 0.84%) at different soil depths of the forested site. The homestead site of Goneshpara, Thanchi contained more soil organic carbon content ranging from 0.77% to 1.26% compared to other locations of the Chittagong hill forest. This phenomenon could be attributed to the fact that the site is rich in Akashmoni (*Acacia auriculifomis*) plantation. The ANOVA test revealed that there were significant differences ($p<0.01$) among the locations at different soil depths except in the forested site of Goneshpara, Thanchi where no significant difference was observed among the different soil depths.

In the Hill Forest of Sylhet, SOC was found higher in Lawachara National Park, Sreemongal, Moulavibazar (0.35% to 0.87%), followed by Satchari National Park, Chunarughat, Habigonj (0.38% to 0.62%), and Tilagarh Eco Park, Sylhet (0.08% to 0.35%). In the homestead site, it was found higher in Tilagarh Eco Park, Sylhet (0.56% to 0.96%) because the site is rich in Akashmoni (*A. auriculiformis*) plantation. In the Sal Forest area, the highest SOC content was found in Dokhola Forest Range, Madhupur, Tangail (0.43% to 0.74%), followed by Kotbari, Cumilla (0.31% to 0.62%), and Bhawal National Park, Salna, Gazipur (0.25% to 0.55%). That Dokhola Sal forest contained higher SOC could be attributed to the fact that the forest is dense compared to other two locations. In the homestead site, it was found higher in Kotbari, Cumilla (0.43% to 0.75%) compared to the Dokhola Forest range (0.27% to 0.65%), and Bhawal National Park (0.22% to 0.65%) across different soil depths. Akashmoni (*A. auriculiformis*) was found to be the dominant forest tree species in Kotbari, Cumilla. The one-way ANOVA results revealed that in most cases there were significant differences ($p<0.05$) among the locations of the forested and homestead sites of Sylhet Hill Forest.

In the Sundarban mangrove forest, Bogi Forest Beat, Sharankhola, Bagerhat possessed higher soil organic carbon compared to the other two locations in the forested and homestead sites. Soils of Bogi Forest Beat contained SOC content ranging from 0.84%–1.16% and 0.36%–0.88% in forested and homestead sites, respectively, followed by Munsigonj Forest Beat (SOC ranging from 0.69%–0.78% and 0.21%–0.58%), and Dhangmari Forest Beat (SOC ranging from 0.66%–0.75%

and 0.28%–0.50%) at different soil depths. In the coastal afforestation areas, the forested site of Sonarchar, Rangabali, Patuakhali district was found to contain higher SOC content (0.56% to 1.12%) compared to other locations. Nijhumdwip National Park contained SOC content varying from 0.34% to 0.59% at different soil depths. In the homestead site of Dumkhali, Mirersarai, Chittagong, SOC was found to range from 0.39% to 0.73%, which was higher than the other three locations. The ANOVA results showed that with one exception there were significant differences ($p<0.05$) among the locations and depths in both forested and homestead sites.

Generally, the soils of forest areas possessed high organic matter content at the surface (Shaifullah et al., 2008). This is due to the contribution of the litterfall. Subsoil also receives organic matter from the occasional death and decay of tree roots. However, soil organic matter in forest soil decreases rapidly with depth. The results of the present study support the above statement (Table 4.5). Similar findings were reported by Aktaruzzaman (2016), and Hossain and Sattar (2002). The recorded mean values of soil organic carbon in the hill forest area were found to agree with the findings of Osman et al. (2002). They found that the soil organic carbon content in Akashmoni (*Acacia auriculiformis*), Mangium (*Acacia mangium*), Eucalyptus (*Eucalyptus camaldulensis*), Pine (*Pinus caribea*), and Baittya garjan (*Dipterocarpus costatus*) plantations of Chittagong and Cox’s Bazar Forest Divisions ranging from 0.53 to 0.63%, 0.45 to 0.59%, 0.50 to 0.72%, 0.41 to 0.64%, and 0.31 to 0.55%, respectively. Akhtaruzzaman et al. (2015) recorded higher soil organic carbon in the planted forest soil compared to the adjacent barren soil and cultivated land soil. The phenomenon was ascribed to the addition of soil organic carbon from tree cover. Mia et al. (2016) also found a higher amount of soil organic carbon in a mixed forest stand in comparison to a pure forest stand. Biswas et al. (2012) reported that soil organic carbon varied from 0.54% in a slashed and burnt site to 1.55% in a forested site.

Contrary to the findings of the present study, Rahman and Bahauddin (2018) reported higher soil organic carbon in sub-surface soil than in surface soil. They found the highest mean value of soil organic carbon in the Sal (*Shorea robusta*) plantation (1.90±0.19%) and the lowest in the deforested site (0.32±0.20%) at the surface soil. However, in the sub-surface soil, the highest was found in Garjan (*Dipterocarpus turbinatus*) plantation (3.47±0.10) followed by Sal (*Shorea robusta*) plantation (2.79±0.23%).

Table 4.5. Soil organic carbon (%) at different soil depths in forested and homestead sites in different forest areas

Location	Forested Site					Homestead Site				
	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test
Chittagong hill forest										
Baraiyadhala National Park Sitakunda, Chittagong	1.06^{Ba} (1.83)	0.70^{BCb} (1.21)	0.39^{Cc} (0.65)	0.26^{Cc} (0.45)	**	0.67^{Ca} (1.15)	0.66^{Ca} (1.14)	0.51^{Ca} (0.88)	0.20^{CDb} (0.34)	**
Dulahazra Forest Beat Chakoria, Cox's Bazar	0.84^{Ca} (1.45)	0.43^{Db} (0.74)	0.36^{Cb} (0.62)	0.36^{Cb} (0.62)	**	0.32^{Da} (0.55)	0.21^{Db} (0.36)	0.17^{Db} (0.29)	0.16^{Db} (0.27)	**
Goneshpara, Thanchi Bandarban Hill District	1.25^{Aa} (2.15)	1.18^{Aa} (2.03)	1.17^{Aa} (2.02)	1.08^{Aa} (1.86)	ns	1.26^{Aa} (2.17)	1.08^{Aa} (1.86)	0.88^{Ab} (1.52)	0.77^{Ab} (1.33)	**
Kaptai National Park Rangamati Hill District	0.89^{Ca} (1.53)	0.51^{CDb} (0.86)	0.42^{Cb} (0.72)	0.41^{Cb} (0.71)	**	0.84^{Ba} (1.45)	0.55^{Cb} (0.95)	0.50^{Cb} (0.86)	0.32^{Cb} (0.55)	**
Wasu, Matiranga Chagrachari Hill District	1.26^{Aa} (2.17)	0.90^{Bb} (1.63)	0.74^{Bc} (1.75)	0.70^{Bc} (1.21)	**	0.94^{Ba} (1.62)	0.88^{Bb} (1.52)	0.68^{Bc} (1.17)	0.53^{Bd} (0.91)	**
F-test	**	**	**	**		**	**	**	**	
Sylhet Hill Forest										
Satchari National Park Chunarughat, Habigonj	0.62^{Ba} (1.07)	0.51^{Bab} (0.88)	0.41^{Ab} (0.71)	0.38^{Ab} (0.65)	**	0.46^{Ba} (0.79)	0.43^{Ba} (0.74)	0.33^{Ba} (0.57)	0.37^{Aa} (0.64)	ns
Lawachara National Park Sreemongal, Moulavibazar	0.87^{Aa} (1.50)	0.74^{Ab} (1.27)	0.52^{Ac} (0.90)	0.35^{Ad} (0.60)	**	0.63^{Ba} (1.09)	0.60^{Aa} (1.03)	0.54^{Aab} (0.93)	0.43^{Ab} (0.74)	**
Tilagarh Eco Park, Sylhet	0.35^{Ca} (0.60)	0.21^{Cb} (0.36)	0.12^{Bbc} (0.21)	0.08^{Bc} (0.14)	**	0.96^{Aa} (1.65)	0.58^{Ab} (1.00)	0.55^{Ab} (0.95)	0.56^{Ab} (1.02)	*
F-test	**	**	**	**		**	*	*	ns	
Sundarban Mangrove Forest										
Munshigonj Forest Beat Shamnagar, Satkhira	0.78^{Ba} (1.34)	0.74^{Bab} (1.27)	0.71^{Bab} (1.22)	0.69^{ABc} (1.19)	*	0.58^{Ba} (1.00)	0.29^{Cb} (0.50)	0.27^{Cb} (0.46)	0.21^{Bc} (0.36)	**

Table 4.5 Continued

Location	Forested Site					Homestead Site				
	0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**F-test**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**	**F-test**
Dhangmari Forest Beat Dakop, Khulna	0.75^{Ba} (1.29)	0.72^{Bab} (1.24)	0.66^{Bb} (1.14)	0.66^{Bb} (1.14)	*	0.50^{Ba} (0.86)	0.45^{Ba} (0.77)	0.46^{Aa} (0.79)	0.28^{ABb} (0.48)	**
Bogi Forest Beat Sharankhola, Bagerhat	1.16^{Aa} (2.00)	1.12^{Aa} (1.93)	0.87^{Ab} (1.50)	0.84^{Ab} (1.45)	**	0.88^{Aa} (1.52)	0.55^{Ab} (0.95)	0.36^{Bc} (0.62)	0.36^{Ac} (0.62)	**
F-test	**	**	**	*		**	**	**	**	
Coastal Afforestation										
Sonarchar, Rangabali Patuakhali	1.12^{Aa} (1.93)	0.77^{Ab} (1.33)	0.63^{Ab} (1.09)	0.56^{Aa} (0.96)	**	0.62^{ABa} (1.07)	0.57^{Aa} (0.98)	0.51^{Aa} (0.88)	0.52^{Aa} (0.90)	ns
Kukri-Mukri, Charfashion Bhola	0.92^{Ba} (1.59)	0.39^{Cb} (0.67)	0.33^{Cbc} (0.57)	0.23^{Cc} (0.40)	**	0.62^{ABa} (1.07)	0.40^{Ab} (0.69)	0.36^{Ab} (0.62)	0.27^{Cb} (0.46)	**
Nijhumdwip, Hatiya Noakhali	0.59^{Ca} (1.02)	0.53^{BCab} (0.91)	0.41^{BCbc} (0.71)	0.34^{BCc} (0.59)	**	0.41^{Ba} (0.71)	0.38^{Aa} (0.65)	0.33^{Aab} (0.57)	0.27^{Cb} (0.46)	**
Dumkhali, Mirersarai Chittagong	0.73^{Ca} (1.26)	0.61^{ABb} (1.05)	0.56^{ABc} (0.96)	0.44^{ABd} (0.76)	**	0.73^{Aa} (1.26)	0.53^{Ab} (0.91)	0.51^{Ab} (0.88)	0.39^{Bc} (0.67)	**
F-test	**	**	**	**		**	*	*	**	
Sal Forest										
Kotbari, Cumilla Sadar Cumilla	0.62^{ABa} (1.07)	0.36^{Bb} (0.62)	0.32^{Ab} (0.55)	0.31^{Bb} (0.53)	**	0.75^{Aa} (1.29)	0.44^{Ab} (0.76)	0.36^{Ab} (0.62)	0.43^{Ab} (0.74)	**
Dokhola Forest Range Madhupur, Tangail	0.74^{Aa} (1.27)	0.63^{Aa} (1.09)	0.46^{Ab} (0.79)	0.43^{Ab} (0.74)	**	0.65^{Aa} (1.12)	0.55^{Aab} (0.95)	0.41^{Abc} (0.71)	0.37^{Ac} (0.64)	**
Bhawal National Park Salna, Gazipur	0.55^{Ba} (0.95)	0.40^{Bab} (0.69)	0.29^{Ab} (0.50)	0.25^{Bb} (0.43)	**	0.65^{Aa} (1.12)	0.47^{Aab} (0.81)	0.26^{Abc} (0.45)	0.22^{Bc} (0.38)	**
F-test	*	**	ns	**		ns	ns	ns	**	

Values are the mean of triplicate measurement and values in parentheses are standard deviation. Different capital (A, B, C, D) and small letters (a, b, c, d) in superscript indicate significant differences among locations at the same depth and within a location at different soil depths, respectively.
* indicates significant at 5% level of significance ($p<0.05$), ** indicates significant at 1% level of significance ($p<0.01$) and ns indicates not significant.

Chowdhury (1968) reported that due to more decomposition of plant and animal residues in the mangrove area, the soil organic carbon is higher in mangrove soil than in other soil tracts. Muhibbullah et al. (2007) reported that the soil organic carbon content was in the same range at Burigoalini and Chandpai Forest Range, but the Sharankhola Forest Range contained a higher amount of soil organic carbon than the other areas. Hasan et al. (2018) reported a higher amount of soil organic carbon in the surface soil (1.65%) than in the sub-surface soil (1.45%) of the Sundarban mangrove forest. Hossain and Bhuiyan (2015), Hossain et al. (2012), and Maniruzzaman et al. (2009) found similar results which are in agreement with the findings of the present study (Table 4.5).

4.2.3. Soil total nitrogen

Nitrogen (N) is one of the major components of the atmosphere and this atmospheric nitrogen is the source of soil nitrogen, which is a key element for plant growth. The overall findings of the present study reveal that soils of the hill forest areas (Chittagong and Sylhet hill forest) contained a higher amount of total nitrogen compared to Sundarban mangrove forest, coastal afforestation, and Sal Forest areas (Table 4.6 compiled from Appendix A-7). In the hill forest of Chittagong, a higher amount of total nitrogen was obtained at Goneshpara, Thanchi (0.16%–0.28%) followed by Dulahazra Forest Beat (0.16%–0.24%), Wasu, Matiranga (0.11%–0.22%), Baraiyadhala National Park (0.11%–0.19%), and Kaptai National Park (0.07%–0.14%) at different soil depths. No specific trend in soil total nitrogen content was seen with increasing or decreasing soil depth in the studied locations of different forest areas. Tilagarh Eco Park of Sylhet Hill Forest contained more total nitrogen ranging from 0.10% to 0.23% compared to the other locations at different soil depths. The highest amount of soil total nitrogen content was found at 0–15 cm soil depth of Lawachara National Park (0.28%) and the lowest was found in Satchari National Park at 50–100 cm soil depth (0.07%). Sundarban mangrove forest, coastal afforestation, and Sal Forest areas contained lower amounts of soil nitrogen compared to the hill forest areas of Chittagong and Sylhet under study. The composition of plant residues may be associated with this phenomenon.

Table 4.6. Total nitrogen content (%) at different soil depths in forested and homestead sites of different forest areas

Location	Forested Site				F-test	Homestead Site				F-test
	0–15	15–30	30–50	50–100		0–15	15–30	30–50	50–100	
Chittagong hill forest										
Baraiyadhala National Park Sitakunda, Chittagong	0.19^{ABa} (0.01)	0.14^{Ba} (0.09)	0.11^{Aa} (0.04)	0.19^{Aa} (0.01)	ns	0.17^{Ba} (0.04)	0.15^{BCab} (0.02)	0.13^{ABab} (0.02)	0.09^{Ab} (0.01)	*
Dulahazra Forest Beat Chakoria, Cox's Bazar	0.16^{Ba} (0.02)	0.24^{ABa} (0.04)	0.18^{Aa} (0.02)	0.21^{Aa} (0.02)	ns	0.09^{Ca} (0.00)	0.07^{Da} (0.02)	0.07^{Ba} (0.04)	0.07^{Aa} (0.02)	ns
Goneshpara, Thanchi, Bandarban Hill District	0.24^{Aa} (0.04)	0.28^{Aa} (0.04)	0.16^{Aa} (0.06)	0.21^{Aa} (0.02)	ns	0.24^{Aa} (0.03)	$0.^{21Aa}$ (0.02)	0.14^{Ab} (0.01)	0.10^{Ab} (0.02)	**
Kaptai National Park, Rangamati Hill District	0.14^{Ba} (0.02)	0.11^{Bab} (0.00)	0.09^{Abc} (0.01)	0.07^{Bc} (0.00)	**	0.13^{BCa} (0.01)	0.11^{CDab} (0.00)	0.09^{ABbc} (0.01)	0.07^{Ac} (0.00)	**
Wasu, Matiranga, Khagrachari Hill District	0.19^{ABa} (0.00)	0.22^{ABa} (0.02)	0.18^{Aab} (0.02)	0.11^{Bb} (0.04)	**	0.18^{ABa} (0.02)	0.16^{Ba} (0.00)	0.15^{Aab} (0.02)	0.11^{Ab} (0.02)	**
F-test	**	**	ns	**		**	**	*	*	
Sylhet Hill Forest										
Satchari National Park Chunarughat, Habigonj	0.14^{Aab} (0.02)	0.15^{Aab} (0.04)	0.19^{Aa} (0.04)	0.08^{Ab} (0.02)	*	0.09^{Ba} (0.01)	0.09^{Ba} (0.00)	0.08^{Ba} (0.02)	0.07^{Aa} (0.02)	ns
Lawachara National Park Sreemongal, Moulavibazar	0.28^{Aa} (0.10)	0.09^{Ab} (0.00)	0.07^{Bb} (0.02)	0.18^{Aab} (0.02)	**	0.14^{Ba} (0.02)	0.12^{Ba} (0.01)	0.09^{Bab} (0.00)	0.07^{Ab} (0.02)	**
Tilagarh Eco Park, Sylhet	0.23^{Aa} (0.09)	0.20^{Aa} (0.06)	0.10^{Ba} (0.02)	0.10^{Aa} (0.09)	ns	0.28^{Aa} (0.04)	0.24^{Aa} (0.04)	0.21^{Aa} (0.03)	0.17^{Aa} (0.07)	ns
F-test	ns	ns	**	ns		**	**	**	*	
Sundarban Mangrove Forest										
Munshigonj Forest Beat Shamnagar, Satkhira	0.08^{Aa} (0.02)	0.07^{Aa} (0.02)	0.07^{Aa} (0.04)	0.07^{Aa} (0.02)	ns	0.09^{Aa} (0.04)	0.08^{Aa} (0.02)	0.08^{Aa} (0.02)	0.07^{Aa} (0.02)	ns
Dhangmari Forest Beat Dakop, Khulna	0.07^{Aa} (0.02)	0.08^{Aa} (0.02)	0.08^{Aa} (0.02)	0.09^{Aa} (0.04)	ns	0.08^{Aa} (0.02)	0.09^{Aa} (0.00)	0.08^{Aa} (0.02)	0.09^{Aa} (0.00)	ns

Table 4.6. Continued

Location	Forested Site 0–15	15–30	30–50	50–100	F-test	Homestead Site 0–15	15–30	30–50	50–100	F-test
Bogi Forest Beat Sharankhola, Bagerhat	0.09^{Aa} (0.01)	0.09^{Aa} (0.00)	0.08^{Aa} (0.02)	0.07^{aa} (0.02)	ns	0.09^{Aa} (0.02)	0.11^{Aa} (0.00)	0.09^{Aa} (0.02)	0.09^{Aa} (0.02)	ns
F-test	ns	ns	ns	ns		ns	ns	ns	ns	
Coastal Afforestation										
Sonarchar, Rangabali Patuakhali	0.11^{Ba} (0.02)	0.12^{ABa} (0.04)	0.08^{Ba} (0.02)	0.09^{ABa} (0.04)	ns	0.10^{Ba} (0.01)	0.09^{Ba} (0.01)	0.08^{Ba} (0.02)	0.08^{Aa} (0.02)	ns
Kukri-Mukri, Charfashion Bhola	0.12^{Ba} (0.02)	0.09^{Ba} (0.00)	0.08^{Ba} (0.02)	0.09^{Ba} (0.00)	ns	0.11^{Ba} (0.00)	0.09^{ABa} (0.00)	0.09^{Ba} (0.00)	0.08^{Aa} (0.02)	ns
Nijhumdwip, Hatiya Noakhali	0.15^{ABa} (0.02)	0.18^{Aa} (0.02)	0.18^{Aa} (0.02)	0.17^{Aa} (0.04)	ns	0.09^{Ba} (0.00)	0.08^{Ba} (0.02)	0.08^{Ba} (0.02)	0.07^{Aa} 0.02)	ns
Dumkhali, Mirersarai Chittagong	0.18^{Aa} (0.02)	0.17^{Aa} (0.00)	0.18^{Aa} (0.02)	0.15^{ABa} (0.02)	ns	0.17^{Aa} (0.01)	0.15^{Aa} (0.04)	0.14^{Aab} (0.02)	0.08^{Ab} (0.02)	*
F-test	*	**	**	*		**	*	**	ns	
Sal Forest										
Kotbari, Cumilla Sadar Cumilla	0.09^{Aa} (0.00)	0.07^{Ba} (0.02)	0.08^{Aa} (0.02)	0.08^{Aa} (0.02)	ns	0.18^{Aa} (0.02)	0.17^{Aa} (0.00)	0.18^{Aa} (0.02)	0.15^{Aa} (0.02)	ns
Dokhola Forest Range Madhupur, Tangail	0.09^{Aa} (0.02)	0.11^{Aa} (0.00)	0.09^{Aa} (0.02)	0.09^{Aa} (0.02)	ns	0.11^{Ba} (0.02)	0.10^{Ba} (0.01)	0.08^{Ba} (0.02)	0.07^{Ba} (0.02)	ns
Bhawal National Park Salna, Gazipur	0.08^{Aa} (0.02)	0.09^{ABa} (0.00)	0.08^{Aa} (0.02)	0.09^{Ba} (0.00)	ns	0.12^{Ba} (0.01)	0.10^{Bab} (0.02)	0.09^{Bab} (0.01)	0.07^{Bb} (0.01)	*
F-test	ns	*	ns	ns		**	**	**	**	

Values are the mean of triplicate measurement and values in parentheses are standard deviation. Different capital (A, B, C, D) and small letters (a, b, c, d) in superscript indicate significant differences among locations at the same depth and within a location at different soil depths, respectively.

*indicates significant at 5% level of significance ($p<0.05$), ** indicates significant at 1% level of significance ($p<0.01$) and ns indicates not significant.

Forest soils contain large organic nitrogen pools which have a positive impact on terrestrial carbon sequestration (Marty et al., 2017). Usually, nitrogen limitation is alleviated in agricultural systems by nitrogen fertilization. The forest soils in most underdeveloped countries are not fertilized and the nutrient demands of forest trees are mainly met by nutrient recycling (Vitousek and Sanford, 1986). As a result, soil nitrogen might be the limiting nutrient in many forests (Jiao et al., 2010). The forest soil in Bangladesh has a lower amount of total nitrogen compared to other countries which is also supported by the present study. Zaman et al. (2010) reported that due to the presence of litter and humus, the upper soil layer contained a higher amount of nitrogen which enhanced soil water-holding capacity. According to the studies of Akbar et al. (2010), Akhtaruzzaman (2014, 2015), and Haque (2014), the soils of the planted forest contain higher total nitrogen in comparison to barren and cultivated land soils. Mia et al. (2016) reported lower total nitrogen content in pure forest stand soil compared to the plantation and mixed forest stands soils. In a two-year-long study, Biswas et al. (2012) found that total nitrogen was low ranging from 0.05% to 0.13% after shifting cultivation and forested site, respectively. They also reported that burning for shifting cultivation not only destroyed organic matter, ground flora, and the major source of nitrogen in unfertilized soils but also led to a loss of native nitrogen.

In an experiment with burning rice straw, Nagarajah and Amarisiri (1977) found that the temperature reached 700 °C at the surface and in the center of the heap, the temperature was 300 °C–400 °C, resulting in 93% of nitrogen loss. With increased temperatures, carbon disappeared faster than nitrogen (Andriesse and Schelhaas, 1987). Brand and Pfund (1998) recorded a loss of 98% carbon and 95% nitrogen through the slash and burn of a five-year-old fallow land. Shaifullah et al. (2008) found that total soil nitrogen content increased due to afforestation on the coast of Bangladesh. Hasan et al. (2018) observed that the average value of soil total nitrogen (0.09%) was higher in surface soils compared to sub-surface soils of the Sundarban mangrove forest and there was a decreasing trend from the eastern part of Sundarban (Sharankhola Forest Range, Sharankhola, Bagerhat) to the western part of Sundarban (Burigoalini Forest Range, Shamnagar, Satkhira). Hossain and Bhuiyan (2015), Hossain et al. (2012), Muhibbullah et al. (2005), and Ramamurthy et al. (2012)

conducted different studies on the nutrient status of Sundarban mangrove forest soil and their results substantiate the findings of the present study (Table 4.6).

4.2.4. Soil carbon and nitrogen ratio

Soil carbon and nitrogen ratio (C/N) indicates the degree of decomposition of organic matter in soils and represents the availability of carbon and nitrogen in the soil. Soil organic matter (SOM) is a major pool for soil nitrogen content which is present in the form of nitrate (NO_3^-). The C/N ratio in the soil is the ratio of its organic carbon to total nitrogen contents. Generally, total nitrogen closely follows the trend of variation in organic matter. Usually, forest soil that is low in organic matter is also low in total nitrogen. If a soil contains a higher amount of soil organic carbon (SOC) and a lower amount of soil nitrogen (N) then the C/N ratio will be more. The results of the present study revealed that the soils of Chittagong and Sylhet hill forests contain more soil nitrogen. The C/N ratio was found lower in those forests compared to the Sundarban mangrove forest, coastal afforestation, and Sal Forest areas. A higher C/N ratio indicated that the soils contained less soil nitrogen, and soil organic carbon content was high (Table 4.7). The C/N ratio found in the Sundarban mangrove forest ranged from 17.63 to 8.13, followed by coastal afforestation (10.70–2.11) and Sal Forest (8.41–2.73). The soils of Bogi Forest Beat in the Sundarban mangrove forest contained a higher C/N ratio ranging from 12.93 to 11.64, whereas soils of Nijhumdwip National Park of coastal afforestation area and Tilagarh Eco Park of Sylhet hill forest contained a lower amount of C/N ratio ranging from 3.83 to 2.11 and 1.78 to 1.17, respectively.

In general, no significant differences were observed in the C/N ratio among different locations of a forest under study. Significant differences were obtained among different depths within a location in a few cases (Table 4.7) Soil carbon to nitrogen ratio determines whether the carbon sink in land ecosystems could be sustained over the long term (Luo et al., 2006), and a change in the amount of nitrogen in the ecosystem is a key parameter regulating long-term terrestrial carbon sequestration (Yang et al., 2011). The soil C/N ratio determines the decomposability of soil organic matter and, therefore, has an important bearing on plant nitrogen availability. In the forest floor, the C/N ratio is generally wide and decreases as decomposition occurs. In other soils, the ratio is usually much lower (Pritchett and Fisher, 1987). Findings of the Mia et al. (2016) revealed that the C/N ratio was found higher in the pure and mixed forest stands and lowest in the plantation forest stands. Biswas et al. (2012) found a higher amount of soil C/N ratio in the forested sites in comparison to other land use changes, including shifting cultivation. Rahman and Bahauddin (2018) reported that the C/N ratio decreased from plantation sites to deforested sites as well as from sub-surface soil to surface soil. But the results of the present study show that in most cases the C/N ratio is generally high in the surface soils and gradually narrows down with soil depth. This indicates the differential decomposition of soil organic matter in different depths. Some other workers also reported a decreasing C/N ratio with the depth of soil (Akhtaruzzaman, 2016; Batjes, 1996; Callesen et al., 2007).

Table 4.7. Carbon and nitrogen ratio (C/N) at different soil depths in forested and homestead sites in different forest areas

Location	Forested Site				F-test	Homestead Site				F-test
	0–15	15–30	30–50	50–100		0–15	15–30	30–50	50–100	
Chittagong hill forest										
Baraiyadhala National Park	5.72^{Aa}	6.72^{Aa}	4.00^{Ba}	1.47^{Ba}	ns	4.15^{Ba}	$4.40A^{Ba}$	4.08^{Aa}	2.30^{Ba}	ns
Sitakunda, Chittagong	(0.59)	(3.70)	(1.59)	(0.95)		(0.71)	(0.38)	(1.02)	(1.68)	
Dulahazra Forest Beat	5.16^{Aa}	1.81^{Bb}	2.04^{Bb}	1.73^{Bb}	**	3.67^{Ba}	3.09^{Ba}	3.91^{Aa}	2.45^{Ba}	ns
Chakoria, Cox's Bazar	(0.64)	(0.27)	(0.48)	(0.21)		(0.43)	(0.14)	(3.28)	(1.00)	
Goneshpara, Thanchi,	5.34^{Aab}	4.26^{ABb}	7.65^{Aa}	5.26^{ABab}	*	5.28^{ABa}	5.08^{Aa}	6.53^{Aa}	7.56^{Aa}	ns
Bandarban Hill District	(0.52)	(0.55)	(2.20)	(0.73)		(0.80)	(0.47)	(1.26)	(1.58)	
Kaptai National Park,	6.67^{Aa}	4.69^{ABa}	4.44^{ABa}	5.93^{ABa}	ns	6.37^{Aa}	5.10^{Aa}	5.25^{Aa}	4.68^{ABa}	ns
Rangamati Hill District	(1.21)	(0.89)	(1.03)	(0.88)		(0.46)	(0.99)	(1.19)	(0.80)	
Wasu, Matiranga,	6.49^{Aa}	4.05^{ABa}	4.15^{ABa}	7.36^{Aa}	ns	5.32^{ABa}	5.47^{Aa}	4.64^{Aa}	4.94^{ABa}	ns
Khagrachari Hill District	(0.06)	(0.46)	(0.58)	(3.42)		(0.65)	(0.28)	(0.62)	(1.11)	
F-test	ns	ns	**	**		**	**	ns	**	
Sylhet Hill Forest										
Satchari National Park	4.42^{Aa}	3.45^{Bab}	2.18^{Bb}	4.93^{Aa}	*	4.93^{Aa}	4.63^{Aa}	4.48^{Ba}	5.80^{Aa}	ns
Chunarughat, Habigonj	(0.82)	(0.88)	(0.30)	(0.98)		(0.90)	(0.57)	(1.87)	(2.27)	
Lawachara National Park	3.34^{ABb}	8.02^{Aa}	8.02^{Aa}	1.94^{Bb}	**	4.76^{Aa}	5.22^{Aa}	5.81^{Aa}	6.57^{Aa}	ns
Sreemongal, Moulavibazar	(0.97)	(0.40)	(2.00)	(0.27)		(0.84)	(1.07)	(0.83)	(1.42)	
Tilagarh Eco Park, Sylhet	1.78^{Aa}	1.17^{Ca}	1.21^{Ba}	1.53^{Ba}	ns	3.54^{Aa}	2.52^{Ba}	2.67^{Ba}	3.49^{Aa}	ns
	(0.94)	(0.65)	(0.24)	(1.63)		(1.04)	(0.75)	(0.38)	(0.61)	
F-test	*	**	**	*		ns	*	*	ns	
Sundarban Mangrove Forest										
Munshigonj Forest Beat	10.28^{Aa}	11.72^{Aa}	17.63^{Aa}	10.74^{Aa}	ns	7.03^{Aa}	3.83^{Aa}	3.58^{Aa}	3.31^{Aa}	ns
Shamnagar, Satkhira	(3.09)	(3.66)	(17.20)	(2.48)		(2.93)	(1.23)	(1.29)	(0.98)	
Dhangmari Forest Beat	11.72^{Aa}	9.44^{Aa}	8.69^{Aa}	8.13^{Aa}	ns	6.50^{Aa}	4.84^{Aab}	6.01^{Aab}	3.05^{Ab}	*

Table 4.7. Continued

Location	Forested Site				F-test	Homestead Site				F-test
	0–15	15–30	30–50	50–100		0–15	15–30	30–50	50–100	
Dakop, Khulna	(2.93)	(2.82)	(2.90)	(4.04)		(1.57)	(0.19)	(1.63)	(0.16)	
Bogi Forest Beat Sharankhola, Bagerhat	12.54^{Aa} (1.69)	12.05^{Aa} (0.93)	11.64^{Aa} (4.63)	12.93^{Aa} (2.73)	ns	9.94^{Aa} (2.57)	5.08^{Ab} (0.36)	4.06^{Ab} (0.88)	4.10^{Ab} (1.56)	**
F-test	ns	ns	ns	ns		ns	ns	ns	ns	
Coastal Afforestation										
Sonarchar, Rangabali Patuakhali	10.70^{Aa} (2.09)	7.14^{Aa} (2.56)	8.63^{Aa} (4.22)	7.05^{Aa} (3.69)	ns	6.52^{Aa} (2.01)	6.55^{Aa} (0.36)	6.96^{Aa} (3.57)	6.97^{Aa} (2.50)	ns
Kukri-Mukri, Charfashion Bhola	8.19^{ABa} (2.30)	4.28^{ABb} (0.46)	4.41^{ABb} (1.60)	2.54^{ABb} (0.23)	**	5.97^{Aa} (0.54)	4.35^{ABa} (1.25)	3.88^{Aa} (0.71)	3.61^{Aa} (1.44)	ns
Nijhumdwip, Hatiya Noakhali	3.83^{Ca} (0.12)	3.00^{Bab} (0.62)	2.30^{Bb} (0.15)	2.11^{Bb} (0.61)	**	4.43^{Aa} (0.49)	4.89^{ABa} (1.12)	4.40^{Aa} (1.26)	4.13^{Aa} (1.13)	ns
Dumkhali, Mirersarai Chittagong	4.13^{BCa} (0.35)	3.68^{Abab} (0.00)	3.18^{ABb} (0.32)	2.92^{ABb} (0.38)	**	4.23^{Aa} (0.32)	3.56^{Ba} (0.84)	3.60^{Aa} (0.63)	5.20^{Aa} (1.51)	ns
F-test	**	*	*	*		ns	*	ns	ns	
Sal Forest										
Kotbari, Cumilla Sadar Cumilla	6.66^{Aa} (0.50)	5.43^{ABa} (0.87)	4.34^{Aa} (2.04)	4.24^{Aa} (2.11)	ns	4.20^{Aa} (0.19)	2.64^{Bb} (0.32)	2.04^{Bb} (0.54)	2.79^{Bb} (0.29)	**
Dokhola Forest Range Madhupur, Tangail	8.41^{Aa} (2.55)	5.82^{Aa} (0.38)	5.32^{Aa} (2.33)	4.89^{Aa} (1.40)	ns	5.99^{Aa} (0.96)	5.86^{Aa} (1.62)	5.15^{Aa} (0.57)	5.45^{Aa} (1.08)	ns
Bhawal National Park Salna, Gazipur	7.02^{Aa} (0.78)	4.29^{Bb} (0.39)	3.64^{Abc} (0.45)	2.73^{Ac} (0.39)	**	5.61^{Aa} (1.24)	4.85^{ABab} (1.09)	2.89^{Bb} (1.00)	3.21^{Bab} (0.30)	*
F-test	ns	*	ns	ns		ns	*	**	**	

Values are the mean of triplicate measurement and values in parentheses are standard deviation. Different capital (A, B, C, D) and small letters (a, b, c, d) in superscript indicate significant differences among locations at the same depth and within a location at different soil depths, respectively.

* indicates significant at 5% level of significance ($p<0.05$), ** indicates significant at 1% level of significance ($p<0.01$) and ns indicates not significant.

4.2.5. Electrical conductivity of soil

All soils contain some soluble salts and some of these soluble salts are plant nutrients. But some soils accumulate salts to such levels that they are harmful to the germination of seeds and the growth of crops. When that occurs, soils are termed saline. Saline soils pose toxicity to plants. The criterion for a soil to be saline is its electrical conductivity (EC) of the saturation extract because electrical conductivity is proportional to the concentration of salts in the solution. Measurement of electrical conductivity helps to identify the level of soil salinity or alkalinity. If the electrical conductivity of the saturation extract (ECe) at 25°C is >4 dS/m (deci-Siemens per meter), then the soil is saline (Richards, 1954). The electrical conductivity at different locations of the Sundarban mangrove forest and coastal afforestation areas was measured in the study. The study data (Table 4.8 compiled from Appendix A-8) revealed that the EC was found higher in Munshigonj Forest Beat (Burigoalini Forest Range, Shamnagar, Satkhira) at all soil depths ranging from 11.21–14.14 dS/m and the highest value was recorded at 50–100 cm soil depth. This site belongs to the strongly saline zone (8–16 dS/m). On the other hand, Bogi Forest Beat (Sharankhola Forest Range, Bagerhat) exhibited lower EC values ranging from 2.73–3.22 dS/m; the area belongs to a slightly saline zone (2–4 dS/m). The results also revealed that the forested site of Sonarchar, Rangabali (9.12–11.30 dS/m), Kukri-Mukri, Charfashion (8.42–12.42 dS/m), and Nijumdwip National Park, Hatiya (8.62–12.28 dS/m) belong to strongly saline zone, whereas Dhangmari Forest beat, Dakop (6.67–8.82 dS/m) and Dumkhali, Mirersarai (5.80–8.65 dS/m) belong to moderately saline zone (4–8 dS/m). Similar results were found in the homestead site of all locations except in Munshigonj Forest Beat (Burigoalini Forest Range, Shamnagar, Satkhira). The results also showed that there were no specific trends at different soil depths in all locations. However, significant differences were observed in most cases with respect to locations and soil depth ($p<0.05$) (Table 4.8).

Rahaman et al. (2013) reported that soil salinity in the Sundarban Reserve Forest, as well as coastal plantation areas, is highly dependent on the freshwater input coming from upstream areas and the nature of the tide. They also reported that soil salinity near the coast and within the forest varies over several different timescales. During high tide, water from the Bay of Bengal enters the present estuarine zone contributing to the increasing salinity. However, during low tide, the effect of freshwater discharge from the upstream rivers lowers the salinity of the study area. Such variation in salinity with the tide was also documented in several earlier studies (Mitra et al., 2011; Mukhopadhyay et al., 2006; NEERI, 1976). Salinity along the eastern boundary of the mangrove forest is influenced by the Baleshwar River. Hence, salinity in this part is almost zero throughout the monsoon period. On the other hand, salinity in the western regions remains comparatively higher than in the other parts of the Sundarban even during monsoon season due to less freshwater influx from inland sources. According to IWM (2003), salinity in the southern part of the Bay of Bengal remains below 5% during the monsoon period and starts to increase at a steady rate up to about 15% during the dry season. Hoq et al. (2006) observed that the water salinity of the Sundarban mangrove forest steadily increases to the maximum in March following the monsoon period and starts declining from June to a minimum in the monsoon months from July to September.

Uddin and Hossain (2013) observed that soil salinity was found maximum (10.80 dS/m) at the depth of 5–15 cm in a newly accreted char land which was directly exposed to the Bay of Bengal, whereas it was a minimum (7.10 dS/m) at the depth of 0–5 cm in the stabilized coastal plantations. They also reported varied soil salinity levels at different depths in different land strips; the salinity level was lower in old plantations in comparison to grassland and newly accreted char land. Similar findings were reported by Siddiqi (2001). Soil salinity levels were found to reduce in the presence of Keora (*Sonneratia apetala*) plantations (Kabir, 2005). This was probably due to the release of various organic acids through the hydrolysis of tannin in mangrove plants and the breakdown of carbonic matter content in litter (Steinke et al., 1993).

Over 20 million hectares of land are severely affected by salinity worldwide (Rhoades and Loveday, 1990) and in Bangladesh, total saline soil has increased to about 1.056 million hectares from 0.833 million hectares in about the last four decades (SRDI, 2010).

Table 4.8. Electrical conductivity (dS m^{-1}) at different soil depths in forested and homestead sites in Sundarban Mangrove Forest and Coastal Afforestation areas

Location	Forested Site					Homestead Site				
	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test
Munshigonj Forest Beat Shamnagar, Satkhira	11.32^{Bc} (0.15)	11.72^{Ab} (0.15)	11.21^{Ac} (0.10)	14.18^{Aa} (0.07)	**	3.98^{Eb} (0.14)	6.80^{Ba} (1.00)	3.55^{Ebc} (0.05)	2.62^{Ec} (0.03)	**
Dhangmari Forest Beat Dakop, Khulna	8.82^{Ca} (0.30)	7.38^{Eb} (0.12)	6.67^{Cc} (0.10)	7.22^{Eb} (0.03)	**	9.83^{ABa} (0.11)	7.47^{Bb} (0.50)	6.68^{Dc} (0.16)	5.67^{Dd} (0.08)	**
Bogi Forest Beat Sharankhola, Bagerhat	2.73^{Dc} (0.02)	3.22^{Ga} (0.10)	2.90^{Eb} (0.05)	2.93^{Gb} (0.03)	**	2.47^{Fa} (0.11)	1.72^{Cb} (0.03)	1.78^{Fb} (0.06)	1.75^{Fb} (0.00)	**
Sonarchar, Rangabali Patuakhali	11.30^{Ba} (0.09)	9.23^{Cc} (0.06)	9.12^{Bc} (0.03)	9.98^{Bb} (0.03)	**	7.93^{Dc} (0.03)	9.25^{Aa} (0.05)	9.42^{Aa} (0.10)	8.67^{Ab} (0.06)	**
Kukri-Mukri, Charfashion Bhola	12.42^{Aa} (0.10)	8.58^{Dc} (0.12)	9.17^{Bb} (0.06)	8.42^{Dc} (0.03)	**	10.12^{Aa} (0.08)	7.72^{Bd} (0.10)	8.40^{Bc} (0.09)	8.72^{Ab} (0.12)	**
Nijhumdwip National Park Hatiya, Noakhali	12.28^{Aa} (0.08)	9.90^{Bb} (0.00)	9.32^{Bc} (0.03)	8.62^{Cd} (0.03)	**	9.07^{Ca} (0.08)	7.48^{Bbc} (0.03)	7.37^{Cc} (0.03)	7.60^{Bb} (0.09)	**
Dumkhali, Mirersarai Chittagong	8.65^{Ca} (0.09)	6.33^{Fb} (0.29)	5.80^{Dc} (0.26)	5.90^{Fbc} (0.00)	**	9.73^{Ba} (0.24)	6.67^{Bb} (0.11)	6.67^{Db} (0.08)	6.70^{Cb} (0.10)	**
F-test	**	**	**	ns		**	**	**	**	

Values are the mean of triplicate measurement and values in parentheses are standard deviation. Different capital (A, B, C, D) and small letters (a, b, c, d) in superscript indicate significant differences among locations at the same depth and within a location at different soil depths, respectively.

** indicates significant at 1% level of significance ($p<0.01$) and ns indicates not significant

4.3. Estimation of Soil Organic Carbon Stocks

Soil is the largest carbon pool in terrestrial ecosystems, and a small change in the soil carbon pool has a great impact on atmospheric CO_2 and global climate change. Soil organic carbon (SOC) is one of the most dynamic components of soils. Soil organic carbon pools are subjected to continuous and dynamic changes due to natural and human activities. Soil organic carbon stocks (t ha^{-1}) were obtained from SOC concentration (%) by multiplying with bulk density (g cm^{-3}) and soil depth (cm), as derived by Pearson et al. (2007). The study results revealed that Wasu, Matiranga contained higher SOC stock (27.31 t ha^{-1}) followed by Goneshpara, Thanchi (25.15 t ha^{-1}), Baraiyadhala National Park (21.10 t ha^{-1}) and Kaptai National Park (19.33 t ha^{-1}) at 0–15 cm soil depth in the forested site of Chittagong hill forest (Table 4.9). But at 15–30, 30–50, and 50–100 cm soil depths, the stocks were higher in Goneshpara, Thanchi (25.08, 34.05, and 79.42 t ha^{-1}, respectively) than in the other locations. Similarly, SOC stocks were found higher in the homestead site at Goneshpara, Thanchi compared to other locations. With one exception, there were significant differences ($p<0.01$) among the locations and soil depths in both forested and homestead sites in the hill forest of Chittagong Forest Division. In the hill forest of Sylhet Forest Division, SOC stocks were found higher in Lawachara National Park and lower in Tilagarh Eco Park in the forested site. But in the homestead site, the values were higher in Tilagarh Eco Park and lower in Satchari National Park. With few exceptions, significant differences ($p<0.05$) were found among the locations at all soil depths in both forest and homestead sites in that forest area.

In the Sundarban mangrove forest, Bogi Forest Beat contained maximum SOC stock at different soil depths (23.98, 23.44, 24.52, and 60.31 t ha^{-1} at 0–15, 15–30, 30–50, and 50–100 cm, respectively) in both forested and homestead site compared to other two locations. In the coastal afforestation areas, it was found higher in Sonachar, Rangabli (23.13, 15.81, 17.52 and 39.44 t ha^{-1}) followed by Dumkhali, Mirersarai (14.94, 12.71, 16.06, and 32.36 t ha^{-1}) and Nijhumdwip National Park (11.89, 10.72, 11.11, and 24.22 t ha^{-1}), respectively, and lower in Kukri-Mukri, Charfashion (16.93, 7.86, 9.04, and 15.99 t ha^{-1}) at different soil depths. Significant differences were found in both the Sundarban mangrove forest ($p<0.01$) and coastal afforestation areas ($p<0.05$ and $p<0.01$). In Sal Forest areas, SOC stocks were found higher in Dokhola Forest Range (15.54, 13.36, 13.24, and 32.22 t ha^{-1}) followed by Kotbari, Cumilla (13.51, 7.86, 9.78, and 24.36 t ha^{-1}) and Bhawal National Park (11.85, 8.67, 8.64 and 19.59 t ha^{-1}), in the forested site at different soil depths. In the homestead site, it was higher in Kotbari, Cumilla (Table 4.9).

Table 4.9. Soil organic carbon stocks (t ha^{-1}) at different soil depths in forested and homestead sites in different forest areas

Location	Forested Site					Homestead Site				
	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test	0–15 cm	15–30 cm	30–50 cm	50–100 cm	F-test
Chittagong hill forest										
Baraiyadhala National Park Sitakunda, Chittagong	21.10^{Ba} (1.61)	14.18^{Ca} (1.70)	10.53^{Ca} (1.31)	18.31^{Ca} (10.36)	ns	14.08^{Ca} (1.03)	15.00^{Ca} (1.98)	16.00^{Ca} (1.59)	15.41^{Ca} (9.16)	ns
Dulahazra Forest Beat Chakoria, Cox's Bazar	17.82^{Bb} (0.90)	9.45^{Cb} (2.48)	11.18^{Cb} (1.97)	28.77^{Ca} (6.00)	**	7.52^{Db} (0.45)	4.88^{Db} (1.19)	5.59^{Db} (1.22)	12.69^{Ca} (2.91)	**
Goneshpara, Thanchi Bandarban Hill District	25.15^{Ac} (2.53)	25.08^{Ac} (1.75)	34.05^{Ab} (2.63)	79.42^{Aa} (2.13)	**	29.32^{Ab} (2.34)	25.13^{Ab} (1.26)	27.67^{Ab} (1.77)	60.83^{Aa} (3.19)	**
Kaptai National Park Rangamati Hill District	19.33^{Bb} (0.84)	11.20^{Cc} (1.97)	12.80^{Cc} (2.20)	31.78^{Ca} (1.38)	**	18.99^{Bb} (0.78)	12.46^{Cc} (2.46)	15.74^{Cbc} (2.25)	24.72^{Ca} (1.67)	**
Wasu, Matiranga Chagrachari Hill District	27.31^{Ab} (0.03)	19.89^{Bc} (0.65)	22.40^{Bc} (0.37)	54.23^{Ba} (1.86)	**	21.24^{Bb} (0.50)	19.94^{Bb} (0.49)	20.99^{Bb} (0.67)	41.67^{Ba} (3.17)	**
F-test	**	**	**	**		**	**	**	**	
Sylhet Hill Forest										
Satchari National Park Chunarughat, Habigonj	14.83^{Bb} (1.79)	12.54^{Bb} (1.10)	13.49^{Ab} (1.18)	31.89^{Aa} (4.54)	**	11.47^{Bb} (0.91)	10.98^{Ab} (1.41)	11.43^{Bb} (1.34)	32.03^{Aa} (6.87)	**
Lawachara National Park Sreemongal, Moulavibazar	19.54^{Ab} (0.94)	17.70^{Ab} (0.55)	17.25^{Ab} (2.84)	28.81^{Aa} (3.71)	**	14.06^{Bb} (0.73)	13.43^{Ab} (0.73)	17.20^{ABb} (2.29)	36.20^{Aa} (2.92)	**
Tilagarh Eco Park, Sylhet	8.02^{Ca} (1.30)	5.10^{Cab} (0.80)	4.05^{Bb} (0.61)	6.26^{Bab} (1.96)	*	22.47^{Ab} (3.42)	14.32^{Ab} (2.09)	18.32^{Ab} (3.15)	48.75^{Aa} (15.88)	**
F-test	**	**	**	**		**	ns	*	ns	
Sundarban Mangrove Forest										
Munshigonj Forest Beat Shamnagar, Satkhira	14.18^{Bb} (0.50)	14.06^{Bb} (1.06)	17.81^{Bb} (0.42)	45.41^{Ba} (3.70)	**	10.55^{Bb} (0.38)	5.54^{Cc} (0.34)	6.86^{Bc} (0.31)	14.19^{Ba} (1.11)	**
Dhangmari Forest Beat	13.19^{Bb}	13.64^{Bb}	16.62^{Bb}	42.31^{Ba}	**	9.05^{Bc}	8.48^{Bc}	11.89^{Ab}	19.03^{Ba}	**

Table 4.9. Continued

Location	Forested Site					Homestead Site				
	0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**F-test**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**	**F-test**
Dakop, Khulna	(1.07)	(0.73)	(0.87)	(2.84)		(0.41)	(0.46)	(0.86)	(1.301)	
Bogi Forest Beat Sharankhola, Bagerhat	23.98^{Ab} (2.34)	23.44^{Ab} (2.97)	24.52^{Ab} (2.37)	60.31^{Aa} (6.20)	**	17.82^{Ab} (1.22)	11.30^{Ac} (0.76)	10.12^{Ac} (1.09)	26.03^{Aa} (3.81)	**
F-test	**	**	**	**		**	**	**	**	
Coastal Afforestation										
Sonarchar, Rangabali Patuakhali	23.13^{Ab} (1.40)	15.81^{Ab} (1.93)	17.52^{Ab} (2.84)	39.44^{Aa} (5.60)	**	12.93^{ABb} (2.99)	11.95^{Ab} (1.78)	14.38^{Ab} (3.84)	37.46^{Aa} (2.06)	**
Kukri-Mukri, Charfashion Bhola	16.93^{Ba} (1.36)	7.86^{Cb} (1.15)	9.04^{Bb} (1.97)	15.99^{Ca} (1.52)	**	12.91^{ABb} (1.51)	8.50^{ABb} (2.54)	10.22^{Ab} (1.83)	19.27^{Ca} (1.58)	**
Nijhumdwip, Hatiya Noakhali	11.89^{Cb} (1.55)	10.72^{BCb} (1.09)	11.11^{Bb} (0.75)	24.22^{Ba} (1.70)	**	8.57^{Bb} (1.19)	7.83^{Bb} (0.46)	9.63^{Ab} (0.45)	19.64^{Ca} (0.47)	**
Dumkhali, Mirersarai Chittagong	14.94^{BCbc} (0.59)	12.71^{ABc} (0.28)	16.06^{Ab} (0.64)	32.36^{ABa} (1.55)	**	15.48^{Ab} (0.22)	11.38^{ABc} (0.36)	14.51^{Abc} (1.59)	29.95^{Ba} (2.20)	**
F-test	**	**	**	**		**	*	ns	**	
Sal Forest										
Kotbari, Cumilla Sadar Cumilla	13.51^{ABb} (0.44)	7.86^{Bb} (1.03)	9.78^{Ab} (1.61)	24.36^{ABa} (4.52)	**	16.95^{Ab} (1.13)	10.14^{Ac} (1.43)	11.35^{Abc} (1.85)	34.19^{Aa} (4.39)	**
Dokhola Forest Range Madhupur, Tangail	15.54^{Ab} (0.03)	13.46^{Ab} (0.82)	13.24^{Ab} (2.43)	32.22^{Aa} (1.52)	**	13.70^{Ab} (0.13)	11.88^{Ab} (1.48)	12.05^{Ab} (2.58)	27.55^{Aa} (3.85)	**
Bhawal National Park Salna, Gazipur	11.85^{Bb} (2.40)	8.67^{Bb} (0.65)	8.64^{Ab} (2.23)	19.59^{Ba} (2.93)	**	13.81^{Aab} (2.80)	10.33^{Abc} (0.95)	7.74^{Ac} (2.01)	17.57^{Ba} (2.46)	**
F-test	*	**	ns	**		ns	ns	ns	**	

Values are the mean of triplicate measurement and values in parentheses are standard deviation. Different capital (A, B, C, D) and small letters (a, b, c, d) in superscript indicate significant differences among locations at the same depth and within a location at different soil depths, respectively.
* indicates significant at 5% level of significance ($p<0.05$), ** indicates significant at 1% level of significance ($p<0.01$) and ns indicates not significant.

The total SOC stocks were measured by summing all soil depth (up to 0–100 cm) values and the SOC density calculated for each location of different forest areas was converted to soil CO_2 mitigation after multiplication with a factor of 3.67 (C equivalent of CO_2). The values obtained demonstrated the amount of CO_2 mitigation or reducing CO_2 emission by the soil under each stratum. The overall mean value of SOC stocks and soil CO_2 mitigation in the forested site was found higher in the mangrove forest of Sundarban (103 and 379 t ha^{-1}) followed by the hill forest of Chittagong (99 and 363 t ha^{-1}) and coastal afforestation area (70 and 257 t ha^{-1}). The Hill Forest of Sylhet (60 and 220 t ha^{-1}) and the Sal forest area (60 and 219 t ha^{-1}) possessed a similar quantity of SOC stocks and soil CO_2 mitigation density in the forested site. But in the homestead site, it was found higher in the hill forest of Sylhet (84 and 307 t ha^{-1}) followed by the hill forest of Chittagong (82 and 301 t ha^{-1}), Sal forest (62 and 229 t ha^{-1}), and coastal afforestation area (61 and 224 t ha^{-1}); Sundarban mangrove forest (50 and 187 t ha^{-1}) area contained a lower amount of SOC stocks and soil CO_2 mitigation density (Figures 4.1 and 4.2). Significant differences ($p<0.01$ and $p<0.05$) were found for SOC stocks and soil CO_2 mitigation among different forest areas under study.

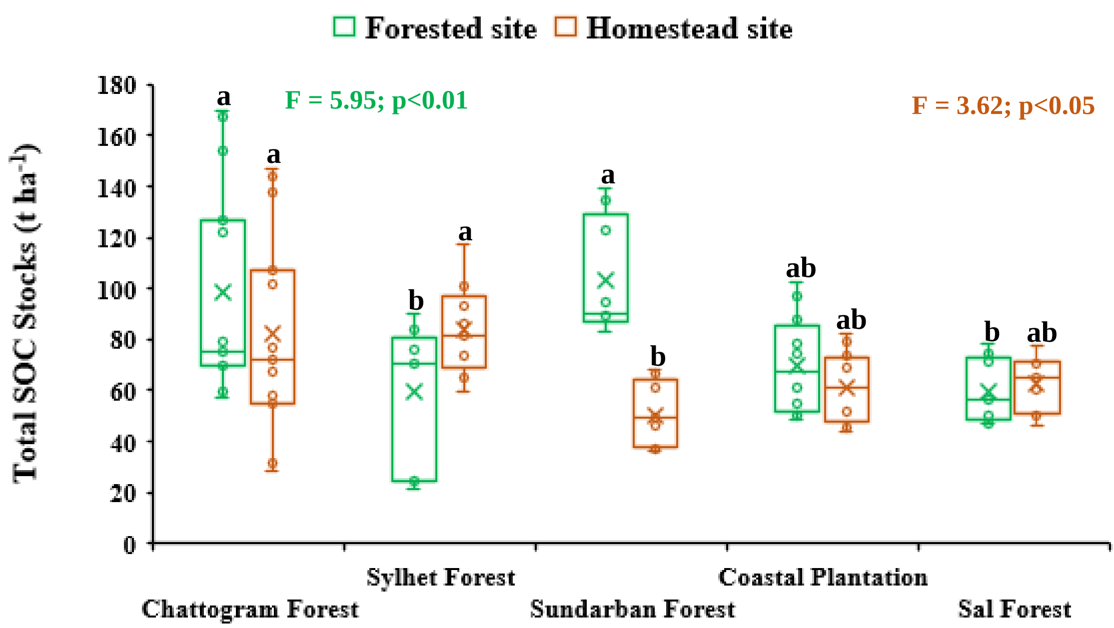


Figure 4.1. Soil organic carbon (SOC) stocks (t ha^{-1}) up to 0-100 cm soil depth in forested and homestead sites in different forest areas. Different lower-case letters indicate significant differences among the different forest areas according to Tukey's HSD test in forested and homestead sites.

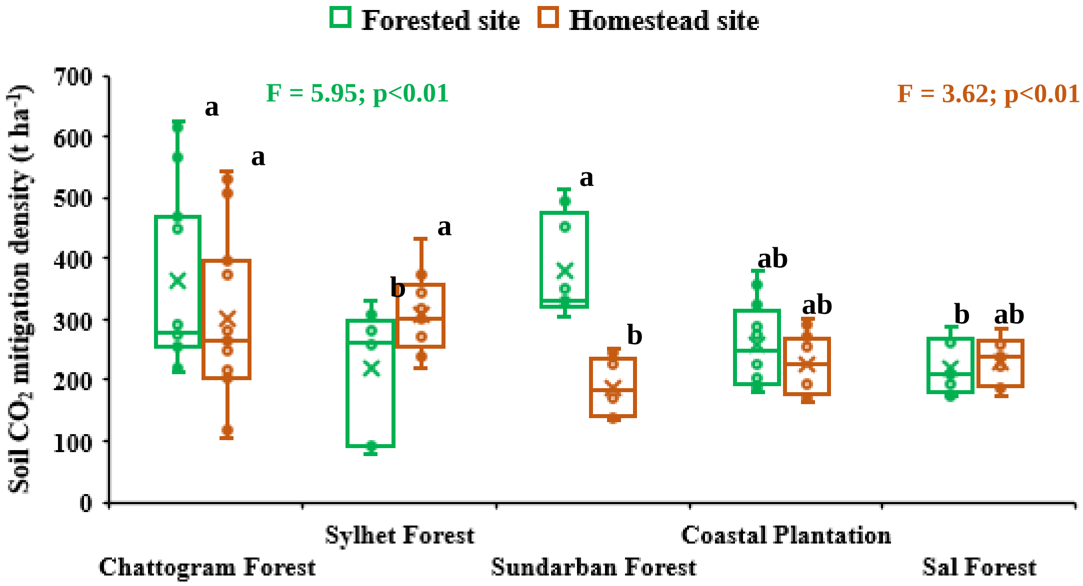


Figure 4.2. Soil CO_2 mitigation density (t ha^{-1}) up to 0-100 cm soil depth in forested and homestead sites in different forest areas. Different lower-case letters indicate significant differences among the different forest areas according to Tukey's HSD test in forested and homestead sites.

The estimated result showed that Goneshpara, Thanchi contained maximum total SOC stocks (up to 0–100 cm soil depth) and soil CO_2 mitigation density in both forested (164 and 601 t ha^{-1}) and homestead sites (143 and 525 t ha^{-1}) and lower values in the forested site of Baraiyadhala National Park, Sitakunda (64 and 235 t ha^{-1}) and homestead site of Dulahazra Forest Beat (31 and 113 t ha^{-1}) under the hill forest of Chittagong (Figures 4.3, 4.4 and 4.5). In the hill forest of Sylhet Forest Division, SOC stocks, and soil CO_2 density were found higher in Lawachara National Park (83 & 306 t ha^{-1} and 81 & 297 t ha^{-1}) followed by Satchari National Park (76 & 267 t ha^{-1} and 66 & 242 t ha^{-1}) in both forested and homestead site. But in the homestead site, it was higher in Tilagarh Eco Park (104 and 381 t ha^{-1}) compared to other sites of Sylhet hill forest. Tilagarh Eco Park was dotted with leguminous tree species Akashmoni (*A. auriculiformis*) which increased the soil organic matter due to decomposition of leaf litter. As a result, the SOC concentration was found higher in that site. In the Sundarban mangrove forest, Bogi Forest Beat contained a higher amount of SOC stocks as well as soil CO_2 mitigation density in both forested (132 and 485 t ha^{-1}) and homestead site (65 and 240 t ha^{-1}) followed by Munshigonj Forest Beat (91 & 336 t ha^{-1} and 37 & 136 t ha^{-1}) and Dhangmari Forest Beat (86 & 315 t ha^{-1} and 48 & 178 t ha^{-1}).

In coastal afforestation areas, Sonachar, Rangabali site contained a higher amount of SOC stocks and soil CO_2 mitigation density followed by Dumkhali, Mirersarai site in both forested and homestead sites. The forested site of Kukri-Mukri, Charfashion contained a lower amount of SOC stocks and CO_2 mitigation density (50 and 183 t ha^{-1}), but in the homestead site, it was found lower in Nijhumdwip National Park (46 and 168 t ha^{-1}). In sal forest, SOC stocks and soil CO_2 mitigation density were found higher in Dokhola Forest Range in both forest (74 and 273 t ha^{-1}) and homestead site (65 and 239 t ha^{-1}) followed by Kotbari, Cumilla (56 & 204 t ha^{-1} and 73 & 264 t ha^{-1}). Bhawal National Park of sal forest area contained a similar quantity of SOC stocks and soil CO_2 mitigation density in both forested and homestead sites under the study.

The overall location-specific SOC stocks and soil CO_2 mitigation density were found higher in the forested site of Goneshpara, Thanchi (164 and 601 t ha^{-1}) of Chittagong hill forest followed by Bogi Forest Beat (132 and 485 t ha^{-1}) of Sundarban mangrove forest and lower in Tilagarh Eco Park (23 and 86 t ha^{-1}) of Sylhet hill forest. But in the homestead site, it was also higher in Goneshpara, Thanchi (143 and 525 t ha^{-1}) and lower in Dulahazra Forest Beat (31 and 113 t ha^{-1}) of Chittagong hill forest. Highly significant differences ($p<0.001$) were found for SOC stocks and soil CO_2 mitigation density among all locations in the study area (Figures 4.3, 4.4 and 4.5).

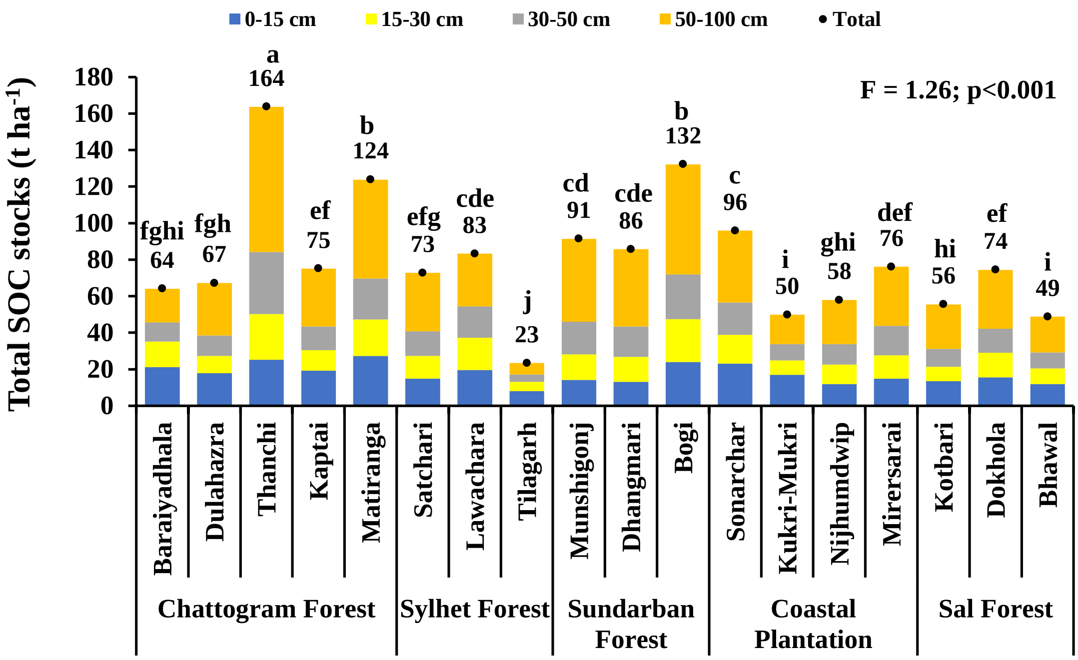


Figure 4.3. Soil organic carbon (SOC) stocks up to 0-100 cm soil depth in different locations of the forested site. Different lower-case letters indicate significant differences among the locations under different forest areas according to Tukey's HSD test.

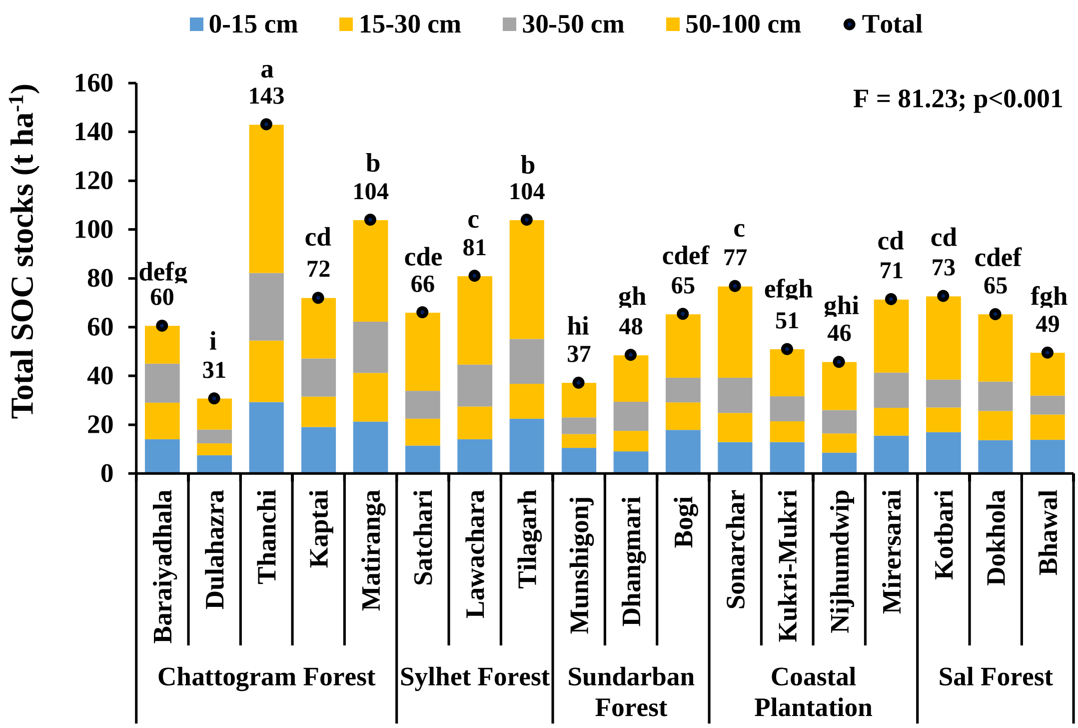


Figure 4.4. Soil organic carbon (SOC) stocks (t ha^{-1}) up to 0-100 cm soil depth in different locations of the homestead site. Different lower-case letters indicate significant differences among the locations under different forest areas according to Tukey's HSD test.

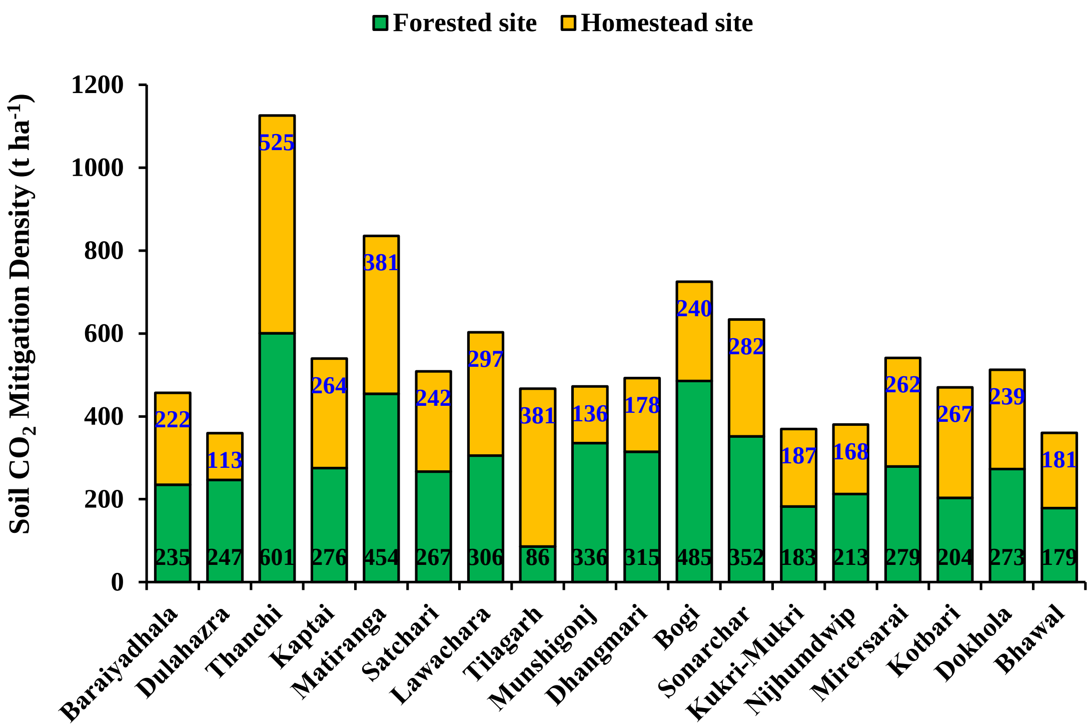


Figure 4.5. Soil CO_2 mitigation density (t ha^{-1}) at different locations in forested and homestead sites under study.

Soils represent the largest carbon reservoirs in the terrestrial ecosystem, with 11% of SOC held in forest soils worldwide (Dey, 2005; Eswaran et al., 1999; Negi et al., 2013; Yuan et al., 2013). As a result, forest soils are one of the major carbon sinks on Earth. Soil organic carbon (SOC) stocks display a high spatial variability (Cannell et al., 1999). Most of the studies concern only the topsoil (0–30 cm), although carbon sequestration or loss may also occur in deeper soil layers (Bird et al., 2002; Fontaine et al., 2007). Iqbal and Tiwari (2017) reported higher SOC stocks at the top surface layer (0–20 cm) followed by the middle depth (20–50 cm) with a decreasing trend and the least SOC stocks were found at lower soil depth (50–100 cm) among all land uses. Pandey and Bhusal (2016) reported that the highest amount of SOC stocks was found in the uppermost soil horizon in the forests of Hill and Terai Forests. They also reported that the SOC stocks were found highest at 0–20 cm (28.45 and 36.60 t ha^{-1}) and lowest at 80-100 cm (16.90 and 9.40 t ha^{-1}) in the Hill and Terai Forest, respectively. Their result also showed that the SOC density was found to have decreased from top to bottom with the increase in the soil depth. The main reason for the difference in the SOC density is because of the difference in SOC concentration and bulk density of soil. Generally, SOC concentration decreases, and bulk density increases with increasing soil depth in all forest types. Baul et al. (2021) found that the topsoil carbon was 10–25% higher than the deeper soil, depending on the altitude, due to the deposition of litterfall. Litter decomposition was significantly slower in mature forests compared with secondary forests (Sanchez-Silva et al., 2018).

The study of Shapkota and Kafle (2021) revealed that the SOC stocks in the upper soil layer (0–20 cm) were higher than in the lower soil horizon (40–60 cm). This might be due to the variation in the time of soil formation. They also reported that the newly formed upper horizon could have contained more carbon. The nutrient could have been continuously restocked by soil organic matter decomposition in the upper horizon, whereas the tree roots ingest more nutrients from the lower horizon. Nutrient leaching from the upper horizon is the source of lower horizon accumulation. Therefore, SOC stocks are lesser in the lower horizon compared to the upper one. The higher nutrient accumulation in the upper horizon may have made the soil more porous, resulting in low soil bulk density and high soil organic carbon concentration. A similar result was reported by Mishra (2010) in SOC stocks of Chapako Community Forest, Kathmandu, and Ranjitkar (2010) in the temperate forest of

Shivapuri Nagarjun National Park, Nepal. The result of this study is closely related to the above statement (Table 4.9).

The present study showed that the total SOC pool in the 100 cm soil depth in the forested site was found higher in the Sundarban mangrove forest (103 t ha^{-1}, ranging from 86–132 t ha^{-1}) followed by Chittagong hill forest (99 t ha^{-1}, ranging from 64–164 t ha^{-1}) and coastal afforestation areas (70 t ha^{-1}, ranging from 50–96 t ha^{-1}). The total SOC stocks in Sylhet Hill Forest (60 t ha^{-1}, ranging from 23–83 t ha^{-1}) and Sal forest (60 t ha^{-1}, ranging from 49–74 t ha^{-1}) were found at par in the study (Figures 4.1 and 4.3). In the homestead site, it was higher in Sylhet hill forest (84 t ha^{-1}, ranging from 66–104 t ha^{-1}) followed by Chittagong hill forest (82 t ha^{-1}, ranging from 31–143 t ha^{-1}) and lower in Sundarban mangrove forest (50 t ha^{-1}, ranging from 37–65 t ha^{-1}). Sal forest (62 t ha^{-1}, ranging from 49–73 t ha^{-1}) and coastal afforestation areas (61 t ha^{-1}, ranging from 46–77 t ha^{-1}) possessed a similar amount of SOC stocks (Figure 4.1 and 4.4). For comparison of SOC stocks, the homestead of Sylhet hill forest and Sal forest contained a higher amount of SOC stocks than the forested site of that areas because this site was covered by Akashmoni (*A. auriculiformis*) plantation which is a leguminous tree species. This species contributed a higher amount of organic carbon in the soil compared to other tree species growing in the hill forest and Sundarban mangrove forest and coastal afforestation areas. Highly significant differences ($p<0.001$) were found among all the locations in the study areas. A report on the Bangladesh Forest Inventory (BFI) (GoB, 2020) revealed that SOC stocks up to 30 cm soil depth was found higher in hill forest (91.72 t ha^{-1}) followed by Sal Forest (82.07 t ha^{-1}), mangrove forest (78.68 t ha^{-1}) and mangrove plantation (73.84 t ha^{-1}). The stocks are significantly higher compared to the present study. In their report, soil organic carbon was determined by the loss on ignition (LOI) method which may have yielded an overestimation in results; in the present study, the widely used Walkley and Black's wet oxidation method was used for organic carbon determination.

Shin et al. (2007) reported that hill forest contained 97.7 t ha^{-1} SOC stocks, whereas Chowdhury et al. (2007), Miah et al. (2009), Mukul (2014), and Ullah and Al-Amin (2012) reported 80.1 t ha^{-1}, 54 t ha^{-1}, 51 t ha^{-1} and 50.5 t ha^{-1}, respectively, which is less compared to the present study. On the other hand, Barua and Haque (2013), and Islam et al. (2001) reported that hill forest contained only 39.7 t ha^{-1} and 23.1 t ha^{-1}, respectively. In mangrove forests (including mangrove plantations), Donato et al. (2011) found 43.9 t ha^{-1} SOC stocks, whereas Rahman et al. (2014) reported it was only 33.6 t ha^{-1}. In Sal forests, Kibria and Saha (2011) found 58.5 t ha^{-1} SOC stocks, but Islam and Weil (2000) found 38.1 t ha^{-1}. Mukul et al. (2014) reported that mangrove forests contained 88.2 t ha^{-1} followed by hill forests (49.5 t ha^{-1}), Sal forests (34.5 t ha^{-1}), and mangrove plantations (19.6 t ha^{-1}). The estimated carbon storage in soil (up to 30 cm soil depth) in the country's forest is about 92.9 million tons (FAO, 2007 and 1977). The highest soil carbon density was in the mangrove forests due to the greatest concentration of organic carbon in soil and was the lowest in the mangrove plantations. The plain land Sal forests, due to their degraded nature, also have relatively lower levels of soil carbon density and stocks (Mukul et al., 2014). In the present study, a higher amount was found than that found in the previous study; this is probably due to the increasing forest coverage over time.

Iqbal and Tiwari (2017) reported that the total SOC pool in the 100 cm soil depth of forest land was highest (118.14 t ha^{-1}), followed by grassland (95.54 t ha^{-1}), agricultural land (75.70 t ha^{-1}) and lowest was found in the wasteland (57.05 t ha^{-1}). The country's mean SOC density of 85.40 t ha^{-1} in the present study is lower than the corresponding values of soils under temperate forests in the globe. Several studies on SOC density report 480 t ha^{-1} in coniferous plantation soils in northern Taiwan (Tsai et al., 2009), 280 t ha^{-1} in Swedish podzol soils (Olsson et al., 2009), 350 t ha^{-1} in podzol soils in Denmark (Vejre et al., 2003), 500 t ha^{-1} in mineral forest soils in Norway (De Wit and Kvindesland, 1999), 190 t ha^{-1} in mineral forest soils in Finland (Liski and Westman, 1995 and 1997) and 640 t ha^{-1} in 3.8% in forests and house wood lots in King County Washington, USA (Porder et al., 2012). However, some studies have reported much lower SOC densities. Hunt et al. (2010) reported a SOC density of 13–34 t ha^{-1} in managed conifer forests. Soil organic carbon density in disturbed boreal coniferous forests was reported to be 6–69 t ha^{-1} under *Pinus mariana* aged 20 years (Wang et al., 2003), 10–13 t ha^{-1} for soils under *Pinus banksiana* aged 30 years (Nalder and Wein, 1999) and 12–13 t ha^{-1} for soils under *Pinus banksiana* aged 36-52 years (Rothstein et al., 2004). Chen and Shrestha (2012) reported that SOC density increases from young age stands to mature stands. Tchimbakala and Makosso (2008) also reported an increase in SOC density with the age of *Terminalia superba* plantation. Kaul et al. (2010) also reported an increase in average SOC stocks of forest vegetation up to a certain age. The observed values of SOC density in the Indian subcontinent in the Garhwal Himalayan region of India were found in conformity with the present study. Kishwan et al. (2009) reported SOC density in Himalayan dry temperate and Himalayan moist temperate forests was 36.19 t ha^{-1} and 71.58 t ha^{-1}, respectively.

The results of this study suggest that factors such as quality and vegetation, soil physical and chemical properties influence SOC density (Burke et al., 1989; Homann et al., 1995; Kulmatiski et al., 2004; Post et al., 1982; Schimel et al., 1994; Tan et al., 2004). The varying values of SOC density within different forest areas also reflect site quality (Stendahal et al., 2010) and a coarse fraction (IPCC, 2003; Liski and Westman, 1997). The continuous biotic pressure on these forests has led to the removal of biomass and a decline in its productivity. This removal of biomass has resulted in soil organic matter (SOM) deficiencies (Carlyle and Nambiar, 2001; Morris, 1997). The differences in SOC stocks are mainly influenced by land use types. The forest soil carbon stock is affected by both natural and anthropogenic factors (Larionova et al., 2002). A natural disturbance can be a destructive event with drastic perturbation of an ecosystem, such as wind, fire, drought, insects, and diseases. Overby et al. (2003) reported that several natural disturbances are followed by changes in soil moisture and temperature regimes and succession of forest species with differences in quantity and quality of biomass returned to the soil. Fire and other natural disturbances may also change the canopy cover and thereby affect soil erosion, which also affects SOC stocks of the surface layer (Elliot, 2003). Anthropogenic factors, which may affect SOC stocks in forests include forest management activities, deforestation, afforestation of agricultural soils, and subsequent management of forest plantations. Although forestland management is generally less intensive than cropland management. Several management options may enhance or increase SOC stocks in forests. Management systems that maintain a continuous canopy cover and mimic regular natural forest disturbance are likely to achieve the best combination of high wood yield and carbon storage (Thornley and Cannell, 2000). Management activities that may impact the SOC stocks include harvesting and site preparation, soil drainage, and planting of adapted species (not invasive species) with high net primary productivity (NPP) and more below-ground biomass (Hoover, 2003). Finally, management activities can influence the labile fraction of SOC stocks (Ellert and Gregorich, 1995), and affect soil quality and productivity (Chandler, 1939; Henderson, 1995).

4.4. Comparison of Soil Physical and Chemical Properties between Forested and Homestead Sites in Different Study Areas

There were some differences in the soil's physical and chemical properties between forest and homestead sites in the study areas. The comparison was made through paired t-test analysis (Table 4.10).

4.4.1. Comparison of soil physical properties between forested and homestead sites

Soil moisture content (MC) was found higher in all forested sites than in homestead sites at different soil depths. Significant differences ($p<0.05$) were found in soil moisture content in forested and homestead sites at different soil depths in different forest types. The Sundarban mangrove forest and coastal afforestation areas contained higher moisture content in both forested and homestead sites followed by Sal Forest, and Chittagong and Sylhet forest, because continuous inundation prevailed in Sundarban mangrove forest and coastal afforestation areas. Generally, the exposed soils in the homestead site underwent different anthropogenic activities. On the other hand, the forest site was not affected by human interventions. As a result, the forested site holds more moisture content than homestead sites. Similar results were observed by some other authors (Hajabbasi et al., 1997; Lal, 1976).

Soil bulk density was found higher in the homestead site compared to the forested site at different soil depths in the study areas. The high soil bulk density indicated soil compaction to mechanical impedance. Sylhet hill forest attained maximum soil bulk density in both forested and homestead sites compared to Chittagong hill forest and sal forest areas and minimum was found in Sundarban mangrove forest and coastal afforestation areas. The significant difference in soil bulk density ($p<0.05$, $p<0.01$, and $p<0.001$) was found in Chittagong hill forest and coastal afforestation areas but it was insignificant ($p>0.05$) in Sylhet hill forest, sal forest, and Sundarban mangrove forest at different soil depths. Hajabbasi et al. (1997) reported that higher bulk density of the deforested site could result in a lower soil quality which would ultimately lead to a reduction of soil porosity and a decrease in soil permeability. Reduction of soil porosity and permeability might decrease the organic matter accumulation and soil aggregation and inversely increase soil bulk density. The soil bulk density tends to increase with increasing soil depth.

Table 4.10. Comparison of soil physical and chemical properties between forested and homestead sites at different soil depths

Soil parameter	Depth (cm)	Forested site	Homestead site	t-value	Significance level
Chittagong hill forest					
MC (%)	0-15	16.85±2.77	12.77±4.99	3.72	**
	15-30	18.64±3.60	14.64±4.62	3.52	**
	30-50	19.27±3.74	14.43±5.45	3.73	**
	50-100	18.49±5.00	15.90±7.19	2.37	*
BD (g cm^{-3})	0-15	1.30±0.06	1.50±0.06	-5.52	***
	15-30	1.44±0.06	1.53±0.04	-5.12	***
	30-50	1.48±0.07	1.57±0.05	-4.23	**
	50-100	1.51±0.08	1.58±0.05	-2.94	*
pH	0-15	5.19±0.28	5.30±0.51	-1.23	ns
	15-30	5.20±0.37	5.34±0.58	-1.58	ns
	30-50	5.43±0.26	5.44±0.62	-0.10	ns
	50-100	5.49±0.51	5.41±0.52	2.46	*
SOC (%)	0-15	1.06±0.19	0.81±0.32	4.74	***
	15-30	0.74±0.29	0.67±0.31	2.64	*
	30-50	0.61±0.32	0.55±0.25	1.55	ns
	50-100	0.56±0.31	0.40±0.24	6.93	***
Total-Nitrogen (%)	0-15	0.18±0.04	0.16±0.06	2.14	*
	15-30	0.20±0.08	0.14±0.05	2.75	*
	30-50	0.15±0.05	0.11±0.04	1.83	ns
	50-100	0.16±0.06	0.09±0.02	4.03	**
C/N Ratio	0-15	5.88±0.87	4.96±1.12	3.52	**
	15-30	4.31±2.18	4.63±0.99	-0.58	ns
	30-50	4.44±2.16	4.88±1.77	-0.75	ns
	50-100	4.36±2.80	4.39±2.27	-0.05	ns
SOC Stocks (t ha^{-1})	0-15	22.14±3.89	18.23±7.60	2.83	*
	15-30	15.95±6.17	15.48±7.22	0.79	ns
	30-50	18.19±9.46	17.20±7.62	0.79	ns
	50-100	42.50±23.11	31.07±19.08	7.01	***
Sylhet Hill Forest					
MC (%)	0-15	13.45±5.19	11.92±5.08	3.89	**
	15-30	13.04±5.45	11.63±4.80	2.68	*
	30-50	12.46±5.79	11.90±5.49	0.74	ns
	50-100	12.65±7.37	9.22±4.28	2.65	*
BD (g cm^{-3})	0-15	1.55±0.06	1.57±0.09	-0.95	ns
	15-30	1.61±0.06	1.62±0.10	-0.14	ns
	30-50	1.64±0.06	1.66±0.05	-0.68	ns

Soil parameter	Depth (cm)	Forested site	Homestead site	t-value	Significance level
	50-100	1.66±0.04	1.72±0.03	-3.04	*

Table 4.10 Continued

Soil parameter	Depth (cm)	Forested site	Homestead site	t-value	Significance level
pH	0-15	4.69±0.07	5.06±0.33	-3.52	**
	15-30	4.74±0.32	5.05±0.35	-1.88	ns
	30-50	4.82±0.10	4.86±0.35	-0.26	ns
	50-100	5.03±0.18	4.90±0.35	0.93	ns
SOC (%)	0-15	0.61±0.22	0.68±0.23	-0.55	ns
	15-30	0.49±0.23	0.53±0.09	-0.58	ns
	30-50	0.35±0.18	0.48±0.12	-1.58	ns
	50-100	0.27±0.15	0.45±0.14	-2.24	ns
Total Nitrogen (%)	0-15	0.22±0.09	0.17±0.09	1.30	ns
	15-30	0.15±0.06	0.15±0.07	0.09	ns
	30-50	0.12±0.06	0.13±0.06	-0.15	ns
	50-100	0.12±0.07	0.10±0.06	0.80	ns
C/N Ratio	0-15	3.18±1.39	4.41±1.04	-3.07	*
	15-30	4.21±3.07	4.12±1.42	0.13	ns
	30-50	3.80±3.35	4.32±1.72	-0.60	ns
	50-100	2.80±1.87	5.29±1.95	-3.43	**
SOC Stocks (t ha^{-1})	0-15	14.13±5.16	16.00±5.30	-0.59	ns
	15-30	11.78±5.54	12.91±1.99	-0.54	ns
	30-50	11.60±6.10	15.65±3.81	-1.55	ns
	50-100	22.32±12.51	38.99±11.57	-2.40	*
Sal Forest					
MC (%)	0-15	20.95±1.33	18.58±3.56	2.51	*
	15-30	22.83±1.60	19.68±3.19	2.23	ns
	30-50	25.38±1.82	20.06±2.65	4.22	**
	50-100	24.79±0.44	19.66±1.50	9.47	***
BD (g cm^{-3})	0-15	1.43±0.05	1.45±0.05	-1.19	ns
	15-30	1.45±0.03	1.48±0.05	-1.99	ns
	30-50	1.49±0.04	1.51±0.07	-1.72	ns
	50-100	1.53±0.05	1.55±0.08	-0.77	ns
pH	0-15	4.60±0.27	4.88±0.39	-4.18	**
	15-30	4.69±0.23	5.01±0.36	-6.92	***
	30-50	4.87±0.25	5.20±0.40	-6.22	***
	50-100	5.13±0.37	5.32±0.43	-4.35	**
SOC (%)	0-15	0.64±0.10	0.68±0.09	-1.31	ns
	15-30	0.46±0.13	0.49±0.07	-1.01	ns
	30-50	0.36±0.10	0.34±0.09	0.89	ns
	50-100	0.33±0.09	0.34±0.10	-0.27	ns
Total-Nitrogen	0-15	0.09±0.02	0.13±0.04	-3.46	**

(%)	15-30	0.09±0.02	0.12±0.04	-1.78	ns
	30-50	0.08±0.02	0.12±0.05	-1.72	ns
	50-100	0.09±0.02	0.10±0.04	-0.51	ns

Table 4.10 Continued

Soil parameter	**Depth (cm)**	**Forested site**	**Homestead site**	**t-value**	**Significance level**
C/N Ratio	0-15	7.36±1.58	5.27±1.14	3.24	*
	15-30	5.18±0.86	4.45±1.74	1.18	ns
	30-50	4.43±1.73	3.36±1.53	1.87	ns
	50-100	3.95±1.60	3.82±1.37	0.24	ns
SOC Stocks (t ha^{-1})	0-15	13.63±2.01	14.42±2.20	-1.48	ns
	15-30	10.00±2.72	10.79±1.41	-1.28	ns
	30-50	10.55±2.77	10.38±2.74	0.38	ns
	50-100	25.39±6.19	26.44±7.91	-0.45	ns
Sundarban Mangrove Forest					
MC (%)	0-15	33.67±8.72	16.94±3.68	7.93	***
	15-30	33.82±10.77	19.72±2.83	4.19	**
	30-50	35.92±8.42	21.30±2.64	5.30	**
	50-100	37.82±4.43	23.48±2.89	4.93	**
BD (g cm^{-3})	0-15	1.25±0.10	1.25±0.07	-0.36	ns
	15-30	1.31±0.08	1.30±0.06	0.18	ns
	30-50	1.31±0.08	1.32±0.06	-0.46	ns
	50-100	1.34±0.07	1.38±0.06	-2.57	*
pH	0-15	7.96±0.19	7.45±0.61	3.22	*
	15-30	7.97±0.07	7.78±0.18	4.94	**
	30-50	8.03±0.05	7.85±0.10	7.44	***
	50-100	8.03±0.07	7.92±0.06	3.99	**
EC (dS/m)	0-15	7.46±3.78	5.43±3.37	1.50	ns
	15-30	7.44±3.68	5.33±2.78	2.75	*
	30-50	6.93±3.61	4.01±2.15	2.44	*
	50-100	8.11±4.92	3.34±1.78	2.80	*
SOC (%)	0-15	0.92±0.20	0.66±0.18	18.95	***
	15-30	0.86±0.20	0.43±0.11	9.59	***
	30-50	0.74±0.10	0.36±0.08	8.10	***
	50-100	0.73±0.11	0.28±0.07	20.62	***
Total Nitrogen (%)	0-15	0.08±0.02	0.09±0.02	-1.32	ns
	15-30	0.08±0.02	0.09±0.01	-2.63	*
	30-50	0.08±0.03	0.08±0.02	-0.64	ns
	50-100	0.08±0.03	0.08±0.02	-0.81	ns
C/N Ratio	0-15	11.51±2.50	7.82±2.64	5.06	**
	15-30	11.07±2.66	4.58±0.87	7.56	***
	30-50	12.65±9.85	4.55±1.59	2.27	ns
	50-100	10.60±3.45	3.49±1.04	6.65	***

SOC Stocks (t ha^{-1})	0-15	17.11±5.33	12.47±4.12	10.01	***
	15-30	17.05±5.07	8.44±2.54	7.91	***
	30-50	19.65±3.90	9.62±2.32	6.97	***
	50-100	49.34±9.19	19.75±5.56	16.70	***

Table 4.10 Continued

Soil parameter	Depth (cm)	Forested site	Homestead site	t-value	Significance level
Coastal Afforestation					
MC (%)	0-15	31.06±2.75	24.16±4.51	4.56	**
	15-30	30.82±2.28	26.70±3.19	3.07	*
	30-50	32.03±1.46	28.07±2.38	5.22	***
	50-100	32.91±1.53	30.33±2.66	3.38	**
BD (g cm^{-3})	0-15	1.32±0.07	1.39±0.03	-3.37	**
	15-30	1.35±0.04	1.41±0.03	-5.84	***
	30-50	1.38±0.03	1.43±0.05	-2.98	*
	50-100	1.41±0.04	1.47±0.05	-5.44	***
pH	0-15	7.87±0.12	7.71±0.16	4.27	**
	15-30	8.04±0.16	7.92±0.11	2.72	*
	30-50	8.08±0.17	7.96±0.09	2.93	*
	50-100	8.15±0.14	7.94±0.19	3.58	**
EC (dS/m)	0-15	11.16±1.58	9.21±0.87	3.58	**
	15-30	8.51±1.41	7.78±0.98	2.27	*
	30-50	8.35±1.54	7.96±1.09	1.19	ns
	50-100	8.23±1.54	7.92±0.87	1.15	ns
SOC (%)	0-15	0.84±0.21	0.60±0.14	4.26	**
	15-30	0.58±0.15	0.47±0.10	4.07	**
	30-50	0.48±0.14	0.43±0.10	3.31	**
	50-100	0.39±0.13	0.36±0.11	2.07	ns
Total-Nitrogen (%)	0-15	0.14±0.03	0.12±0.03	2.29	*
	15-30	0.14±0.04	0.10±0.04	2.36	*
	30-50	0.13±0.05	0.10±0.03	2.16	ns
	50-100	0.13±0.04	0.08±0.02	3.77	**
C/N Ratio	0-15	6.71±3.29	5.24±1.35	1.97	ns
	15-30	4.53±2.00	4.84±1.40	-0.62	ns
	30-50	4.63±3.19	4.71±2.17	-0.16	ns
	50-100	3.65±2.62	4.98±1.99	-2.93	*
SOC Stocks (t ha^{-1})	0-15	16.72±4.43	12.47±3.00	3.50	**
	15-30	11.77±3.21	9.91±2.29	3.26	**
	30-50	13.44±3.94	12.19±3.07	2.39	*
	50-100	28.00±9.55	26.58±8.08	1.30	ns

Values are represented as mean ± standard deviation.
* = p<0.05, ** = p<0.01, *** = p<0.001 and ns = not significant

Soil aggregation changes rapidly when soil structure is disrupted through anthropogenic activities or physical mechanisms (Ohta et al., 1993). Soil aggregation and abundance of organic matter on forest floors of different forest ecosystems play a major role in the retention of water and porosity of soil (Agus et al., 1997; Murugayah et al., 2009). Gupta et al. (2010) observed that barren and cultivated land attained higher bulk density and lower porosity compared to forest land. They also reported that variation in the values of bulk density and porosity in different land use could be related to soil particles and organic matter content in soils.

4.4.2. Comparison of soil chemical properties between forested and homestead site

Although the homestead sites were located adjacent to the forest site in different locations of different forest areas, some differences occurred in the chemical properties between forested and homestead sites. There were considerable differences in soil reaction (soil pH), soil organic carbon concentration, total nitrogen, C/N ratio, and electrical conductivity (EC) in the study areas. Soil pH was found higher in the homestead site of the Sal Forest and lower in the homestead site of the Sundarban mangrove forest and coastal afforestation areas than in the forested site. Significant differences were found in soil pH ($p<0.05$, $p<0.01$, and $p<0.001$) in those areas. In Chittagong and Sylhet Hill Forest areas, soil pH was found at par in both forested and homestead sites, and the differences between them were insignificant. The surface (0–15 cm) and sub-surface (15–30 cm) soils of the homestead site in Sylhet Hill Forest contained higher soil pH than the forested site. The soil pH of Sundarban mangrove forest and coastal afforestation areas was observed higher in the forested site than in the homestead site. The acidity of Chittagong and Sylhet hill forest as well as sal forest in the soils of the forested site was significantly lower compared to the soils of the homestead site. The lower acidity in forested sites might be associated with the relatively lower value of exchangeable aluminum ion (Al^{3+}), the higher number of bases, and the organic matter content (Akhtaruzzaman, 2016). Removal of litter reduces the cycling of basic cations from above-ground vegetation, which also accelerates acidification and increases the potential Al toxicity by lowering soil pH (Greenland et al., 1992; Fisher and Binkley, 2000; Rose, 1993). On the other hand, the pH of Sundarban mangrove forest and coastal areas was higher due to seawater intrusion and salt spray in those areas.

Soil organic carbon (SOC) concentration (%) was found higher in forested site of Chittagong hill forest, Sundarban mangrove forest, and coastal afforestation areas than homestead site. On the other hand, soil organic carbon content was found higher in the homestead site of Sylhet hill forest and sal forest areas, especially in the homestead site at Tilagarh Eco Park of Sylhet hill forest, and Kotbari and Bhawal National Park of sal forest. Because these locations were surrounded by Akashmoni (*A. auriculiformis*) plantations. The leaf litter of Akashmoni plantations deposited in the surface soil of those areas and their decay products contributed to increasing soil organic matter. As a result, in those locations, the SOC concentration was high. Generally, forest soils have greater soil organic matter contents, particularly in surface soil and it decreases with increasing soil depth. The result of this study revealed that the mean soil organic carbon content in the forested site was 0.60% (SOM-1.04%) while in the homestead site, it was 0.50% (SOM-0.86%). The study results also showed that the homestead site had a significant effect on the loss of soil organic matter or soil organic carbon. Lugo and Sanchez (1986) reported that tropical deforestation lowers soil organic matter. Due to mechanical pressure on the homestead site and clearing of the surface layer, the soil organic carbon concentration was found lower compared to the forested site in the study areas. On the other hand, tree coverage was less in the homestead site, and due to this, the soil organic carbon might be lower than in the forested site. The concentration of soil organic carbon was found to differ significantly between forested and homestead sites in Chittagong hill forest, Sundarban Mangrove Forest, and the Coastal afforestation area. No significant difference was observed in other forests ($p>0.05$).

The study results revealed that the mean total-nitrogen content was found similar in both forested (0.12%) and homestead sites (0.11%) in the study areas. No significant difference in total nitrogen at the sub-surface and sub-stratum of soil, but in surface soil, significant ($p<0.05$) differences were observed in all sites of different forest areas. The mean C/N ratio was found higher in forested sites than in the homestead sites in all forest areas and it was 5.96 and 4.71, respectively. However, there was no significant difference in C/N ratio in the study areas. The forested site of the Sundarban mangrove forest had a higher value of C/N ratio than other forested site and the difference was found significant ($p<0.01$) at different soil depths except 30–50 cm soil depth. On the other hand, the homestead site of all forest areas had a similar value of C/N ratio. Post et al. (1985) reported that C/N ratio was higher in forested sites compared to other sites. They also revealed that as decomposition proceeds faster in barren conditions, easily decomposed material disappears, and soil nitrogen is immobilized in microbial biomass and decay products, leaving behind more recalcitrant material with slower decomposition rates and lower C/N ratio. A similar result was observed by Olson (1963), and he reported that at the initial stage of decomposition, there is a rapid disappearance of carbon in comparison to nitrogen. Therefore, the C/N ratio starts declining with the advancement of decomposition.

Soil organic carbon (SOC) stocks or density (t ha^{-1}) were calculated by multiplying the SOC concentration (%) by soil bulk density (g cm^{-3}) and soil depth (cm). Since SOC concentration was found higher and bulk density was lower in the forested site than in the homestead site (Table 4.5 and 4.3), the forested site contained more SOC stocks compared to the homestead site under the study areas. The mean SOC stocks up to 100 cm soil depth were found 78.24 t ha^{-1} in the forested site while it was 67.88 t ha^{-1} in the homestead site. The forested site of Sundarban mangrove forest (103 t ha^{-1}), Chittagong hill forest (99 t ha^{-1}), and coastal afforestation (70 t ha^{-1}) areas attained higher SOC stocks than the homestead site, and it was 50 t ha^{-1}, 82 t ha^{-1} and 61 t ha^{-1}, respectively up to 100 cm soil depth. On the other hand, the homestead site of Sylhet hill forest (84 t ha^{-1}) and sal forest (62 t ha^{-1}) contained a higher amount of SOC stocks than forested site, and it was 59.82 t ha^{-1} and 59.57 t ha^{-1}, respectively. Because those homestead sites were covered with more tree coverage especially Akashmoni (*A. auriculiformis*) plantation than forested site particularly in Tilagarh Eco Park of Sylhet hill forest and Kotbari sal forest. The homestead site of Sundarban mangrove forest attained lower SOC stocks (50 t ha^{-1}) than homestead site of other forest areas due to the less tree coverage. A study on carbon stocks of homestead forests across three altitudes was conducted by Baul et al. (2021) who reported that homestead forest of different altitudes (high, medium, and low) stored 52.83 t ha^{-1} SOC up to 30 cm depth, and it was highest (54.50 t ha^{-1}) at the low altitude homestead forest and the topsoil carbon was 10–25% higher than the deeper soil, depending on the altitude due to decomposition of litterfall. They also concluded that low-altitude homestead forests stored up to 5% higher total SOC compared to the relatively high-altitude homestead forests due to higher decomposition of litter and management of trees and litter in soil conservation. The homestead forest ecosystems stored a total of

89 t ha^{-1} carbon which was higher than degraded natural forests (at 10 cm soil depth), indicating a significant reservoir of carbon in the trees outside the forest (Islam et al., 2017).

The electrical conductivity (EC) of soil was determined only in Sundarban mangrove forest and coastal afforestation areas. The study result showed that the forested site of those forest area had higher electrical conductivity than the homestead site. The overall EC in the forested site was 8.27 dS m^{-1} while in the homestead site it was 6.37 dS m^{-1}. The electrical conductivity of coastal afforestation areas was found to be higher as compared to Sundarban mangrove forest areas in both forested and homestead site. In forested site, it was 9.06 dS m^{-1} (ranging from 8.23 to 11.16 dS m^{-1}) and 7.48 dS m^{-1} (ranging from 6.93 to 8.11 dS m^{-1}) in coastal afforestation and Sumdarban mangrove forest areas respectively. On the other hand, in the homestead site it was 8.21 dS m^{-1} (ranging from 7.78 to 9.21 dS m^{-1}) and 4.53 dS m^{-1} (ranging from 3.34 to 5.43 dS m^{-1}) respectively. The electrical conductivity of surface (0–15 cm) and sub-surface (15–30 cm) soils of coastal afforestation areas showed significant difference ($p<0.05$) whereas sub-surface (15–30 cm) and sub-stratum (30–50 and 50–100 cm) soil of Sundarban mangrove forest showed significant difference ($p<0.05$) of soil electrical conductivity. The surface soil of Sundarban mangrove forest and sub-stratum soil of coastal afforestation areas showed no significant difference ($p>0.05$) of electrical conductivity (Table 4.10). In the context of electrical conductivity under different forest areas, relevant information and data were not found from reviewing literature.

4.5. Soil Organic Carbon Dynamics as Affected by Physical and Chemical Properties of Soil

The soil organic carbon (SOC) dynamics in the study area were found to vary spatially within and between soil depth and locations. This variation could be attributed to different soil physical and chemical properties such as soil texture, moisture content, bulk density, pH, total-nitrogen, electrical conductivity (EC) as well as carbon and nitrogen ratio (C/N ratio). Pearson correlation matrix (Appendix A-11) was done to observe the variation of SOC dynamics with other soil properties. The relationship between SOC dynamics and other soil properties is discussed accordingly.

4.5.1. Relationship between SOC and soil texture

Interesting results were found when correlation coeffcients were calculated between SOC and different soil particles. A significantly ($p<0.05$) positive correlation was found between SOC concentration and sand% in Chittagong hill forest and coastal afforestation areas. On the other hand, as sand content increased, the concentration of SOC decreased significantly ($p<0.001$) in Sylhet Hill Forest soils. In the Sundarban mangrove forest and sal forest areas, no correlation was found (Figure 4.6). The SOC concentration increased significantly ($p<0.001$) with increased silt particles and showed a positive correlation in Sylhet hill forest, Sundarban mangrove forest, and sal forest areas. On the other hand, a negative correlation was observed in Chittagong hill forest and coastal afforestation areas between SOC concentration and silt particles ($p<0.05$ and $p<0.01$) (Figure 4.7). Soil organic carbon was found to decrease with increasing clay fraction in all forest areas except in the Sylhet Hill Forest area. A positive correlation was found in the Sylhet Hill Forest area whereas other forest areas showed a negative correlation. A significant correlation was found between SOC concentration and clay fraction in the study areas whereas the coastal afforestation area was not significant (Figure 4.8).

Gulde et al. (2008) and Hassink (2016) reported that SOC concentration was affected by soil texture and soil aggregation. They also reported that the silt and clay size fractions have the ability to protect SOC from the decomposition of SOM by binding with silt and clay-forming aggregates. Hassink (2016) found no relationship between soil organic carbon and clay + silt content, but there was an increase in the soil carbon stored in the <20 µm size fraction with an increase in clay + silt content.

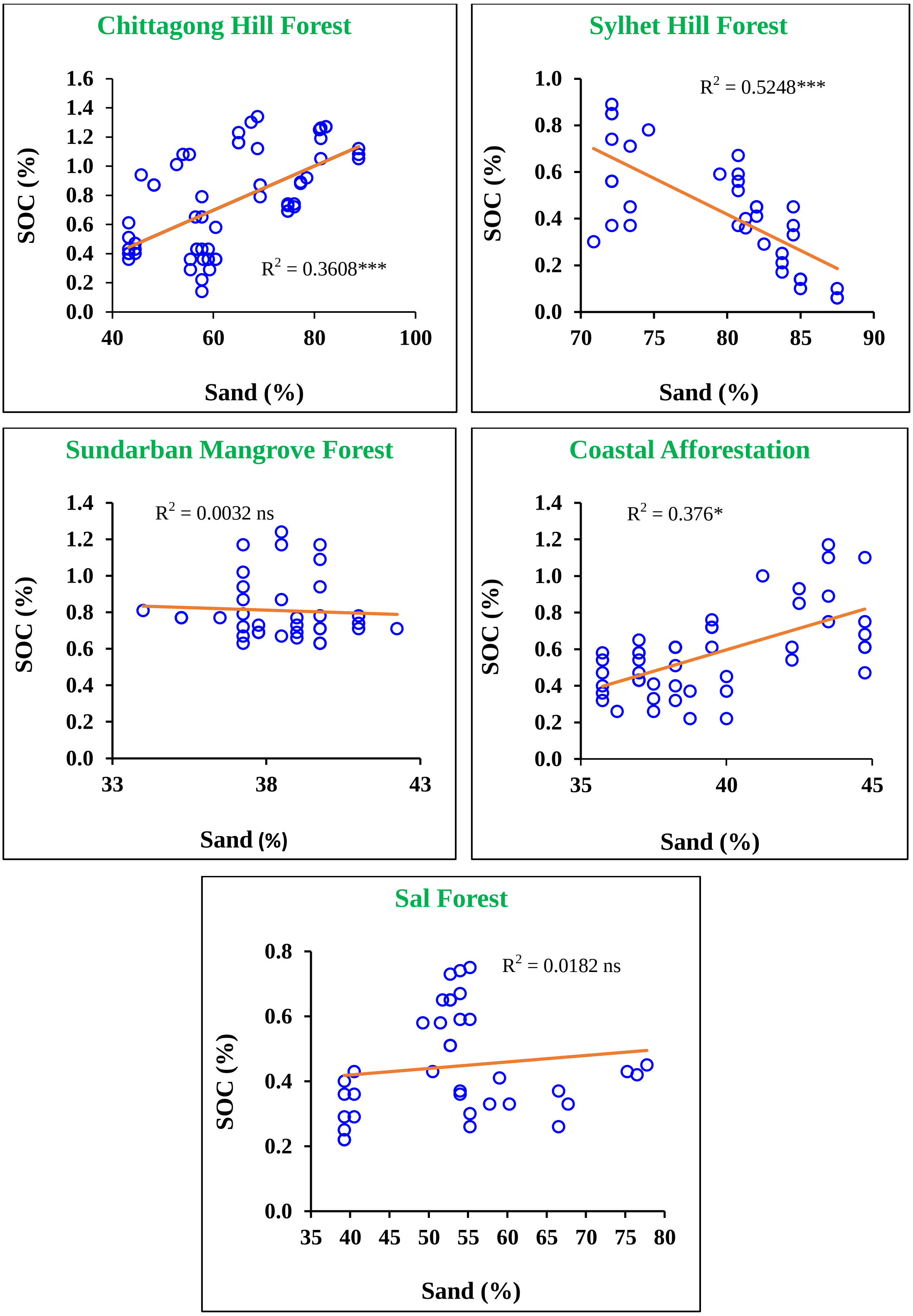


Figure 4.6. Relationship between soil organic carbon (SOC) and sand particle (%) in different forest areas (* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, and ns = not significant)

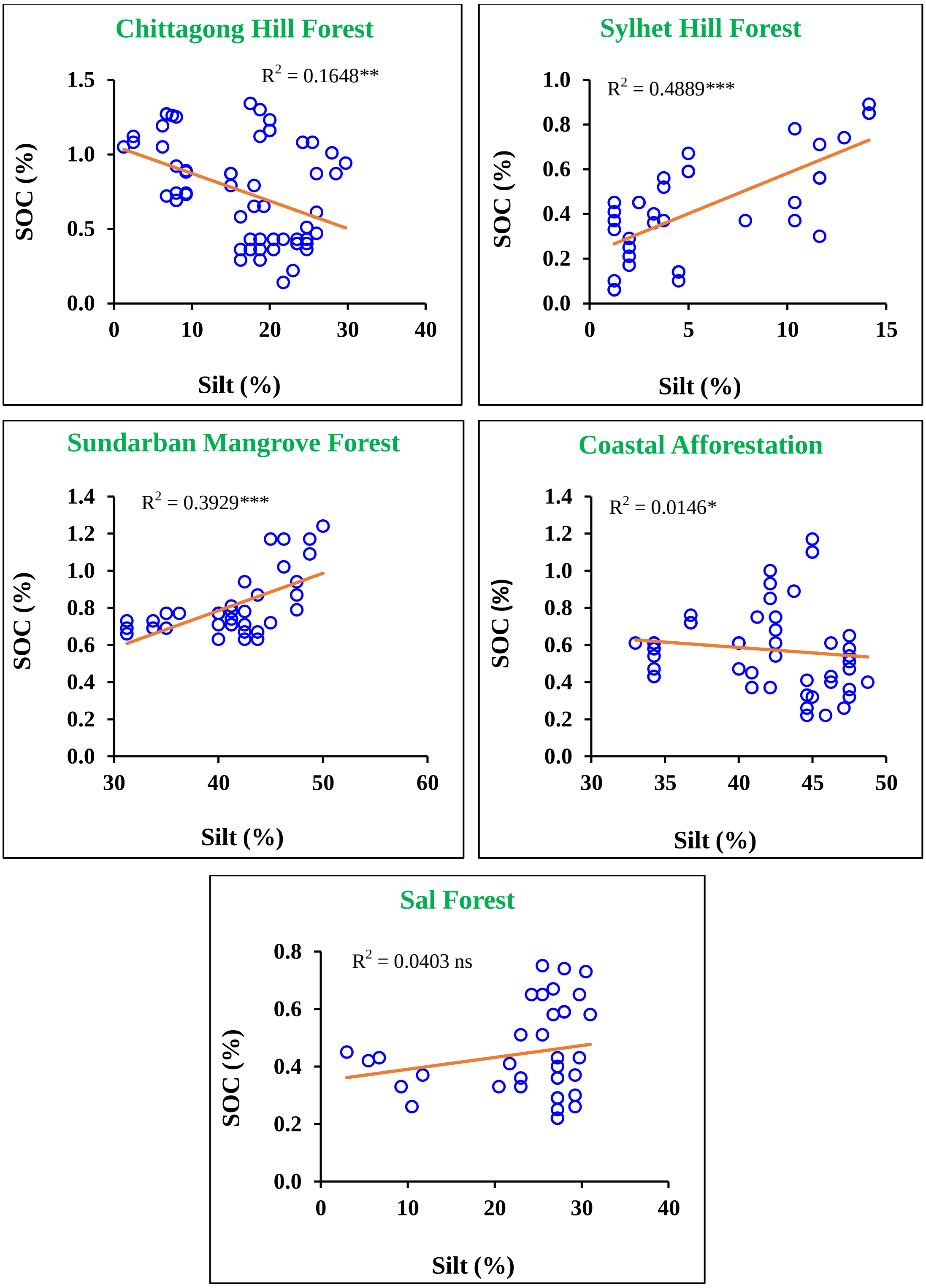


Figure 4.7. Relationship between soil organic carbon (SOC) and silt particle (%) in different forest areas (* = p<0.05, ** = p<0.01, *** = p<0.001, and ns = not significant)

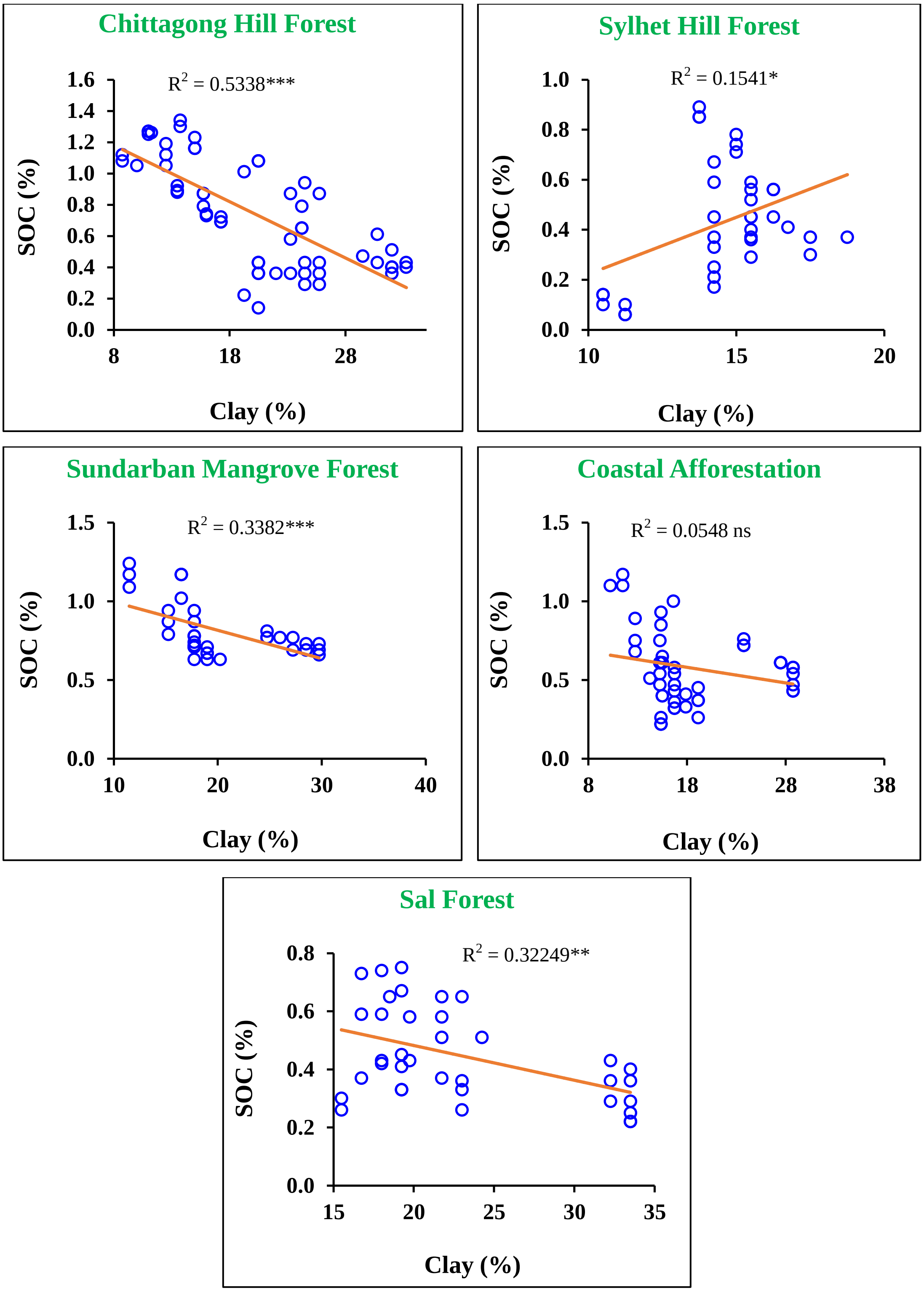


Figure 4.8. Relationship between soil organic carbon (SOC) and clay particle (%) in different forest areas (* = p<0.05, ** = p<0.01, *** = p<0.001, and ns = not significant)

Soil organic carbon is higher in silt and clay-sized fractions than in sand-sized fractions and is generally highest in the clay-sized fractions (Dalal and Mayer, 1986; Jolivet et al., 2003; Tiessen and Stewart, 1983; Zaho et al., 2006). Buschiazzo et al. (1991) studied the relationship between SOC and the texture of the soil parent material on plain sites of the Pampean semi-arid region of La Pampa, Argentina and reported that SOC content was found higher with increasing proportions of the fine mineral fraction (<50 µm). They also concluded that finer texture of the parent material produced more humification, probably because of a better humidity regime which increased biological activity and humus formation. The findings of the present study did not support the above statements. The association between higher sand content and higher SOC may be attributed to the coatings of iron and alumnium oxides minerals on sand particles.

4.5.2. Relationship between SOC and moisture content

A correlation procedure was performed on SOC concentration and soil moisture content (MC) (Figure 4.9). The findings of the study revealed that Sylhet hill forest showed positive correlation between soil organic carbon and moisture content whereas other forest areas showed negative correlation. Soil organic carbon content in the Sylhet hill forest increased significantly ($p<0.001$) with increasing moisture content, but in other forest areas (Chittagong hill forest, Sundarban mangrove forest, coastal afforestation and sal forest), SOC was decreased significantly ($p<0.05$, $p<0.01$ and $p<0.001$) with increasing moisture content (Figure 4.9). Canarini et al. (2017) and Craine and Gelderman (2011) reported that soil moisture strongly affects SOC decomposition through soil aeration, substrate supply, and microbial activity. They also reported that the optimum soil moisture for SOC decomposition is usually at an intermediate level, and the SOC decomposition rate would decrease above or below this level. Parajuli and Duffy (2013) found that carbon content is not influenced by soil moisture content, but it could be influenced by soil organic carbon. Fang et al. (2022) concluded that rising temperature and soil moisture stimulates SOC decomposition to some extent, but it is highly influenced by soil substrate availability and microbial metabolic activity.

4.5.3. Relationship between SOC and bulk density

The study result showed that SOC decreased significantly ($p<0.05$, $p<0.01$ and $p<0.001$) with increasing soil bulk density (BD) and found a negative correlation in all forest areas except in Sundarban mangrove forest. A slightly positive correlation was found in the Sundarban mangrove forest and showed a significant relationship between SOC and BD of soil under the study area (Figure 4.10). A similar correlation was observed by Huntington et al. (1989), and Perie and Quimet (2008) in their study.

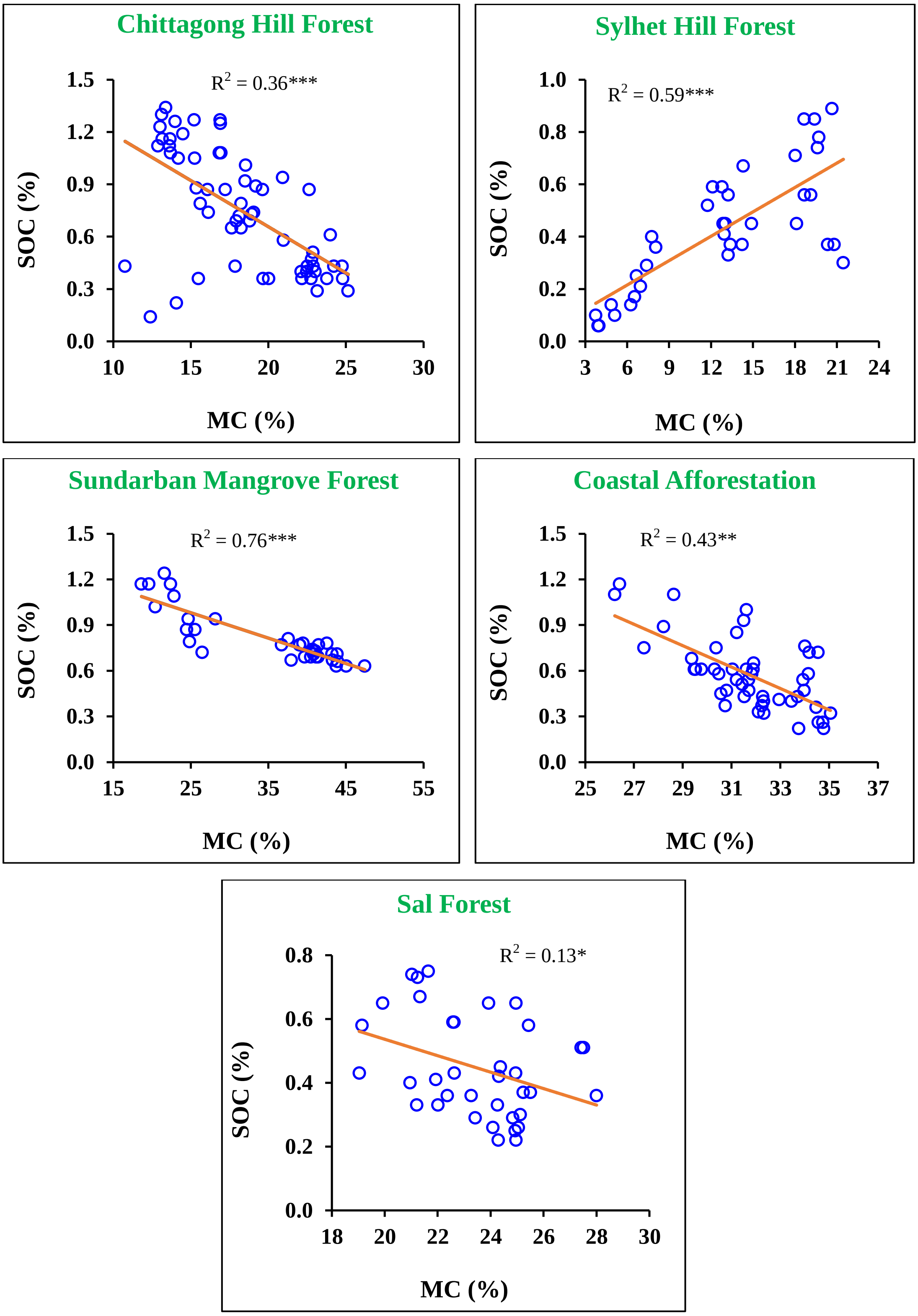


Figure 4.9. Relationship between soil organic carbon (SOC) and moisture content (MC) in different forest areas (* = p<0.05, ** = p<0.01, and *** = p<0.001)

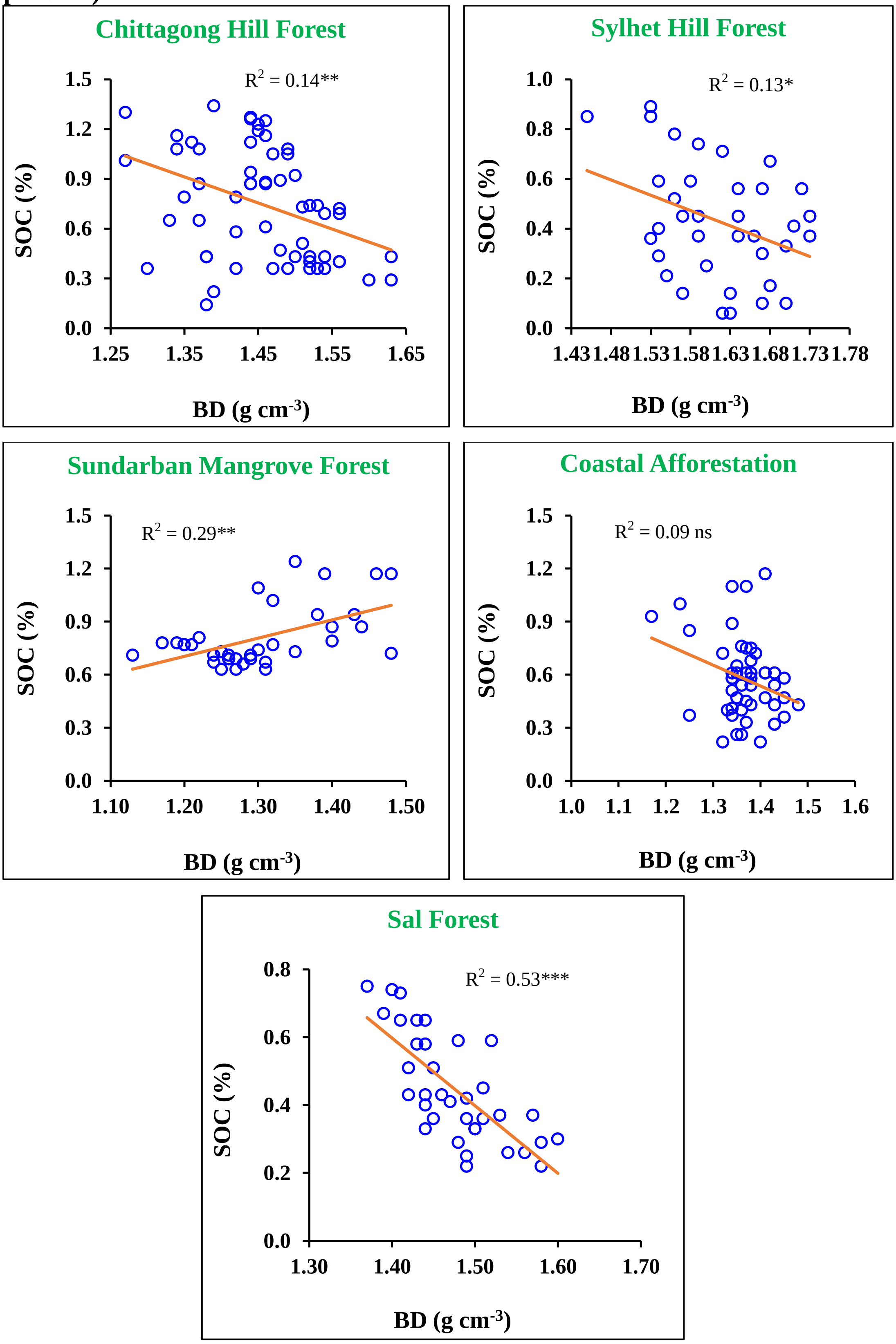


Figure 4.10. Relationship between soil organic carbon (SOC) and bulk density (BD) in different forest areas (* = p<0.05, ** = p<0.01, *** = p<0.001, and ns = not significant)

4.5.4. Relationship of SOC with soil pH and electrical conductivity

The regression analysis showed that SOC decreased significantly with increasing soil pH and was negatively correlated with SOC and soil pH. The relationship was found significant (p<0.01 and p<0.001) in the hill forest of Chittagong and Sylhet, and Sundarban mangrove forest whereas it was found not significant in coastal afforestation and sal forest areas. On the other hand, the relationship between SOC and electrical conductivity (EC) showed both positive and negative correlation in coastal afforestation and Sundarban mangrove forest areas. The relationship was found significant (p<0.001) in Sundarban mangrove forest whereas it was insignificant in coastal afforestation areas (Figure 4.11). The correlations of soil pH and EC with SOC in the present study was found consistent with the results reported by Yu et al. (2014) in the saline soil region of Songnen Plain in the Jilin province of China, Shi et al. (2012) in the topsoil of Mongolian and Tibetan grassland and Zu et al. (2011) in the northeast China. Soil pH controls soil properties which is affected by climate, soil buffering system, plants, etc. (Hong et al., 2019). Zhao et al. (2018b) reported that topsoil pH values are affected by precipitation and evaporation, and abundant rainfall causes the leaching of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions which lowers soil pH value. Another study of Zhao et al. (2018a) revealed that when rainfall is relatively lower, and evaporation exceeding precipitation causes serious soil salinization in sandy soils which lead to higher soil pH value. In general, pH values in the forest soils are lower (especially in topsoil) because forest soils are rich in organic matter and during decomposition of organic matter more organic acids are produced which leads to lowering the soil pH value. The results of the present study revealed that soil organic carbon is negatively correlated with soil pH, which indicating that relatively low pH benefits the accumulation of soil organic matter.

Electrical conductivity (EC) is commonly measured to indicate the total salt content in the soil (Yuan and Zhang, 2010). High salt content in soils leads to increase the electrical conductivity of soil, which is reduced the soil porosity and microbial activity, thus reduced the carbon input into the soil (Geng and Dai, 2011). Duchicela et al. (2013) reported that increasing electrical conductivity as well as soil salinity can destroy the structure of soil aggregates resulting the reduction of soil organic carbon. Yu et al. (2013) found that lowering of above and below-ground biomass consequently lowering the soil organic carbon concentration in the saline grassland area of China.

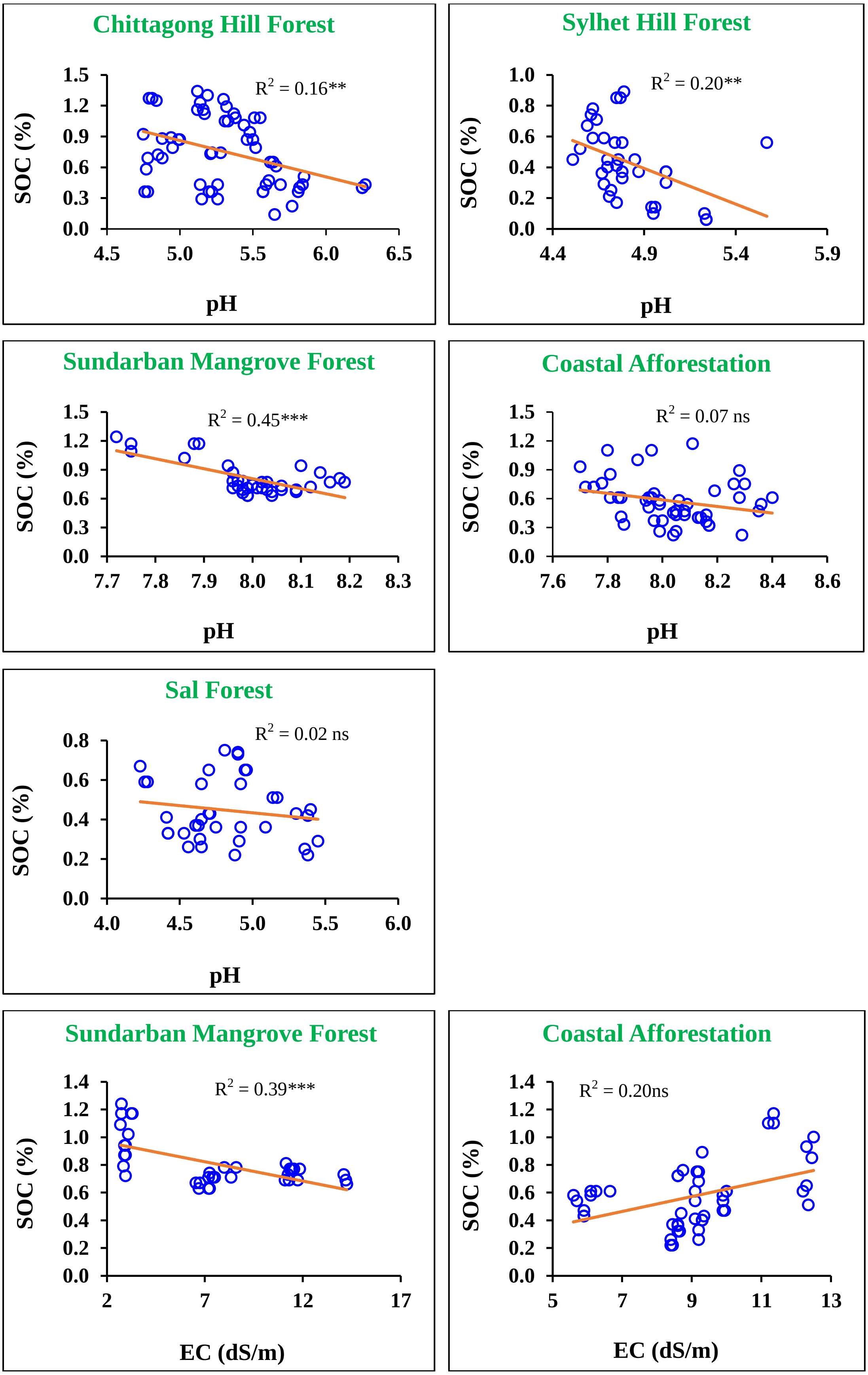


Figure 4.11. Relationship between soil organic carbon (SOC) and soil pH in different forest areas and between SOC and EC in Sundarban mangrove forest

and coastal afforestation areas (= p<0.01, ***= p<0.001 and ns = not significant)**

4.5.5. Relationship of SOC with total nitrogen and C/N ratio

Based on correlation analysis (Appendix A-11), the regression lines in Figures 4.12 and 4.13 describe the relationship of SOC with soil total nitrogen (Total-N) and C/N ratio under different forest areas. The correlation between SOC and Total-N showed positive correlation, but the relationship was found weak and not significant, except Chittagong hill forest. No correlation or almost 'zero' correlation was found in coastal afforestation areas. On the other hand, the relationship between SOC and C/N ratio showed good correlation under the study area, except Sundarban mangrove forest. Chittagong hill forest showed highest correlation coefficient (0.679) followed by coastal afforestation (0.5658), sal forest (0.5604) and Sylhet hill forest (0.3627), respectively and this relationship was found highly significant ($p<0.001$).

Soil organic carbon and total nitrogen varied from forest and vegetation types, site conditions, climatic and edaphic factors as well as microbial community. Li et al. (2009) reported that root nodule bacteria and litter decomposition generate and secrete carbon and nitrogen and added into the soil, which satisfied the requirements of plant growth. Soil organic carbon and total nitrogen was found significantly higher at surface in all locations and it was decreased with increasing soil depth under the present study. Similar results were reported by Celik (2005) and Ross et al. (1999) in their studies.

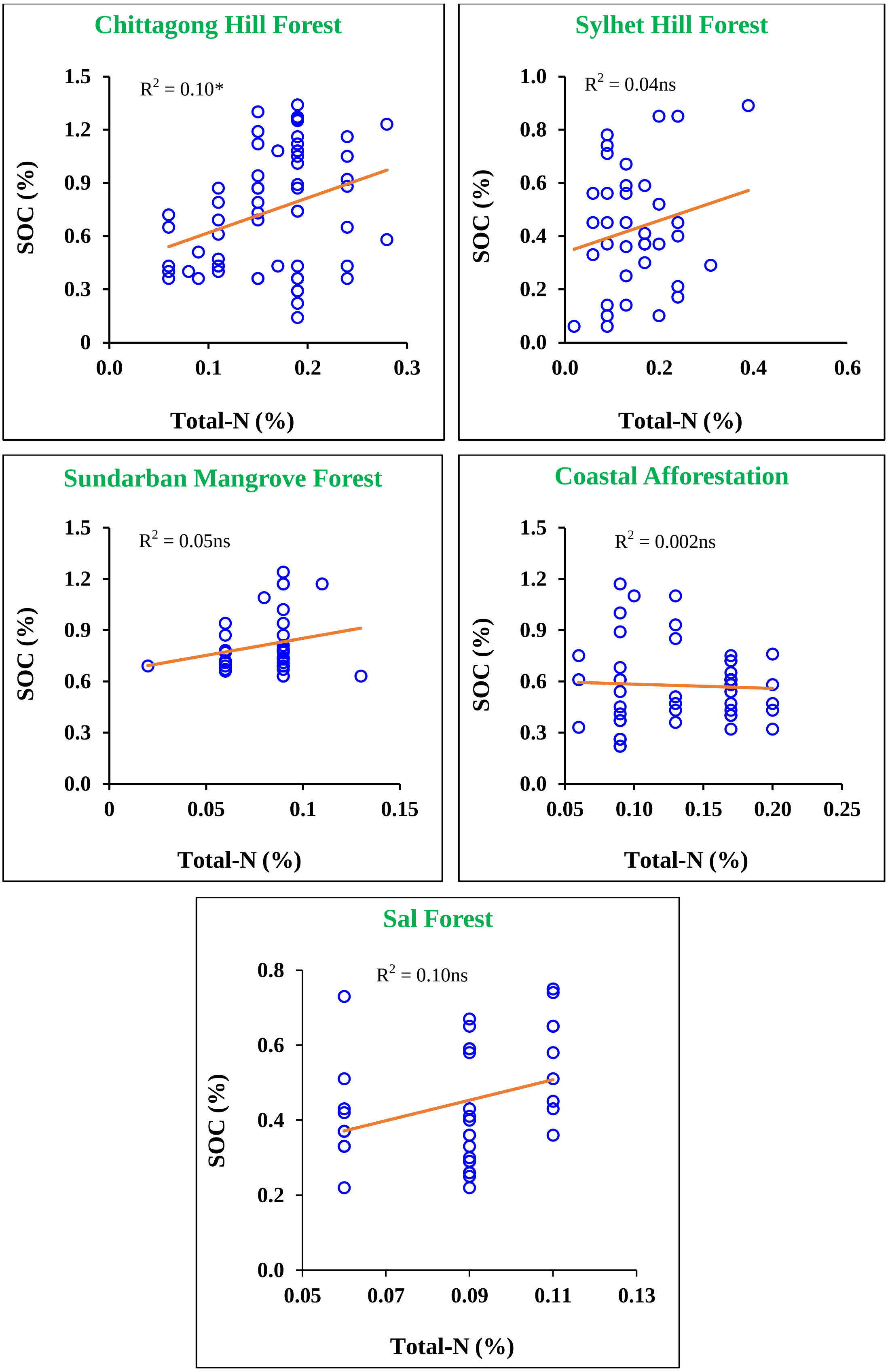


Figure 4.12. Relationship between soil organic carbon (SOC) and total nitrogen (Total N) in different forest areas (* = p<0.05 and ns = not significant)

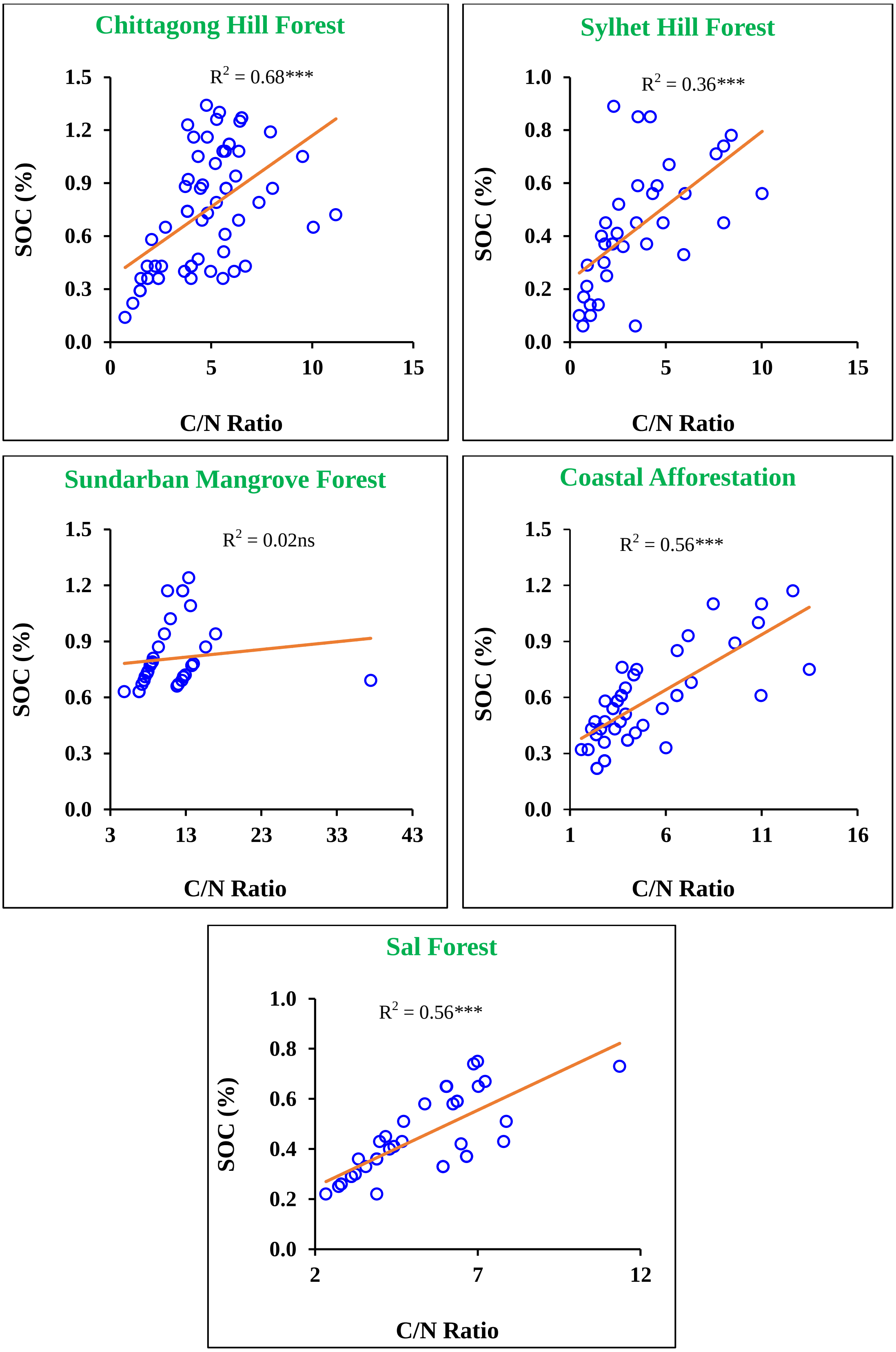


Figure 4.13. Relationship between soil organic carbon (SOC) and carbon and nitrogen ratio (C/N ratio) in different forest areas (= p<0.01, *** = p<0.001, and ns = not significant)**

4.5.6. Relationship between SOC stocks and SOC concentration and bulk density

Soil organic carbon (SOC) stocks were calculated by multiplying the SOC concentration by bulk density (BD) as well as respective soil depth under the study areas. The findings of the present study revealed that the topsoil layer (0−15 cm) had a higher SOC concentration and it gradually decreased with increasing soil depth in all locations under the study areas. On the other hand, the BD was found to have increased from top to bottom with increasing soil depth in all forest areas. Based on the Pearson correlation matrix (Appendix A-11), highly significant positive correlation (the adjusted R^2 values were found very close to 1) was found between SOC stocks and SOC concentration at different soil depth (0−15, 15−30, 30−50 and 50−100 cm) in all forest areas. On the other hand, the relationship between SOC stocks and BD was found negatively correlated at different soil depths in all forest areas and the relationship was found insignificant ($p>0.05$). The correlations of soil SOC concentration and BD with SOC stocks in the present study were found consistent with the results obtained by Pradhan et al. (2012) and Shapkota and Kafle (2021).

Soil compaction and consolidation affect the bulk density of soil. Generally, the topsoil possessing lower BD indicates that the soil was better for plant growth compared to other soil depths which could be attributed to the higher SOC concentration in the top layer of soil. Chaudhary et al. (2013) reported that though soil BD was found to be negatively correlated with SOC content; as the soil organic matter increases, the BD of soil decreases which is required for the proper growth of the plants. The higher nutrient accumulation in the forest floor makes the surface layer of soil more porous and permeable, resulting in lower soil bulk density. Similar findings were observed by Mishra (2010) in SOC stocks of Chapako Community Forest, Kathmandu, Nepal, and Ranjitkar (2010) in the temperate forest of Shivapuri Nagarjun National Park, Nepal. The findings of the present study concluded that the soil organic carbon (SOC) stocks are governed by the concentration of soil organic carbon and bulk density of soil. Similar findings were also obtained from the study of Ghimire et al. (2019).

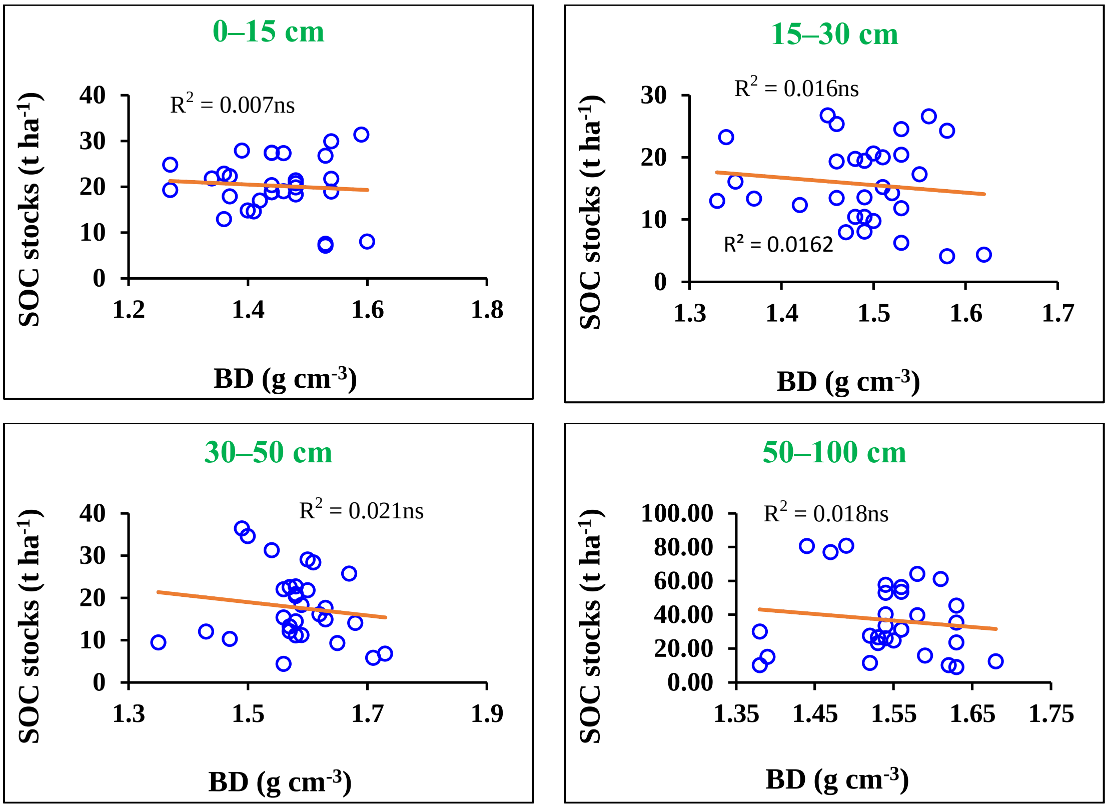


Figure 4.14. Relationship of soil organic carbon stocks (t ha^{-1}) with bulk density (g cm^{-3}) at different soil depths (cm) of Chittagong hill forest areas (* = p<0.001 and ns = not significant)**

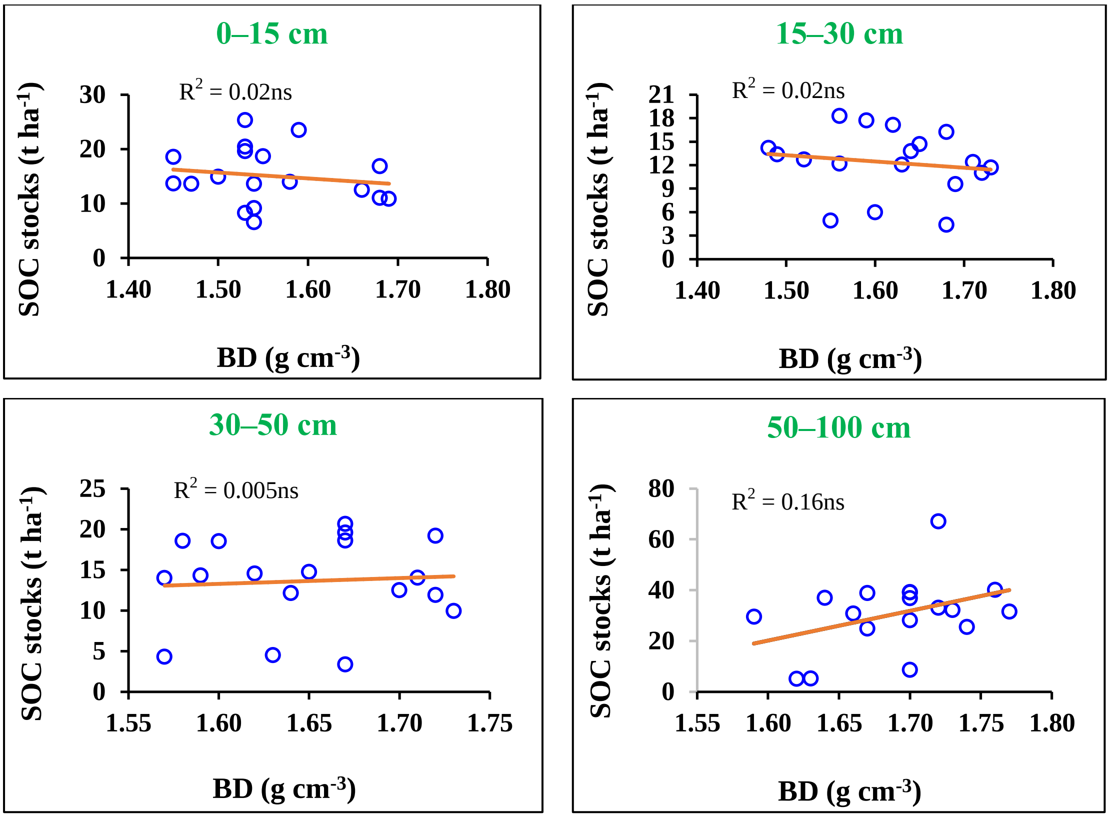


Figure 4.15. Relationship of soil organic carbon stocks (t ha^{-1}) with bulk density (g cm^{-3}) at different soil depths (cm) of Sylhet hill forest areas (* = p<0.001 and ns = not significant)**

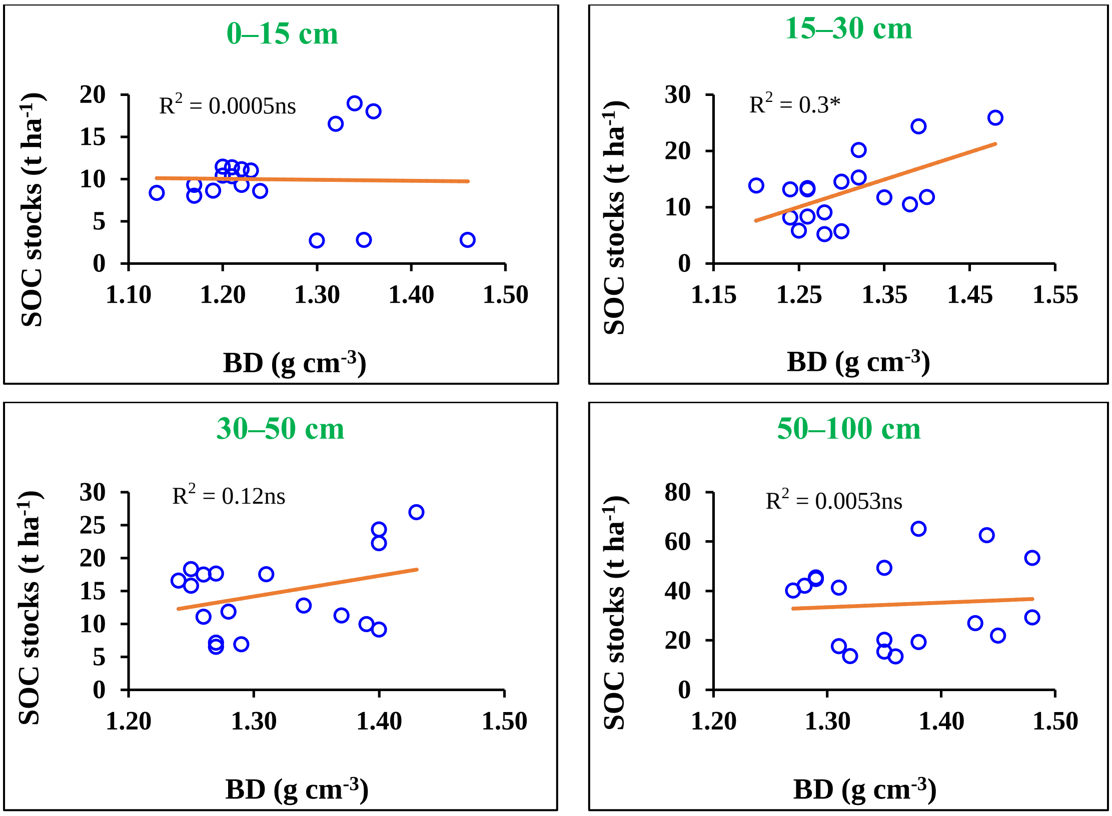


Figure 4.16. Relationship of soil organic carbon stocks (t ha^{-1}) with bulk density (g cm^{-3}) at different soil depths (cm) of Sundarban mangrove forest areas (* = $p<0.05$ and ns = not significant)

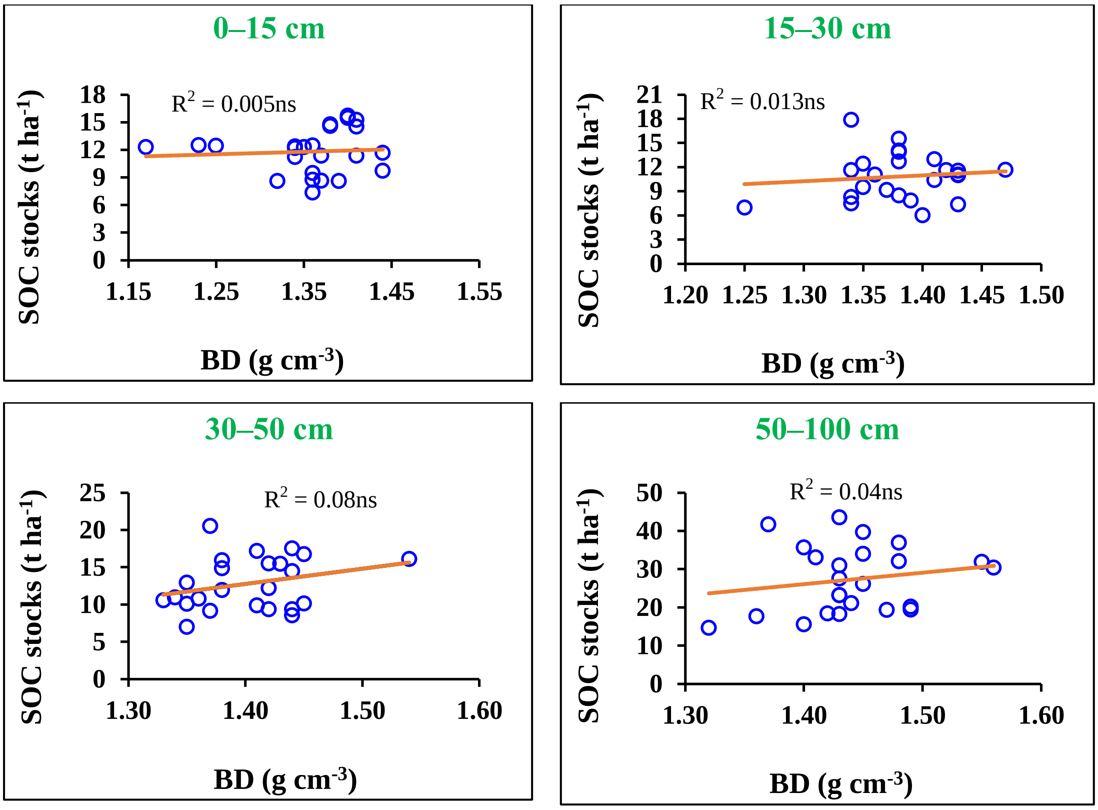


Figure 4.17. Relationship of soil organic carbon stocks (t ha^{-1}) with bulk density (g cm^{-3}) at different soil depths (cm) of coastal afforestation areas (ns = not significant)

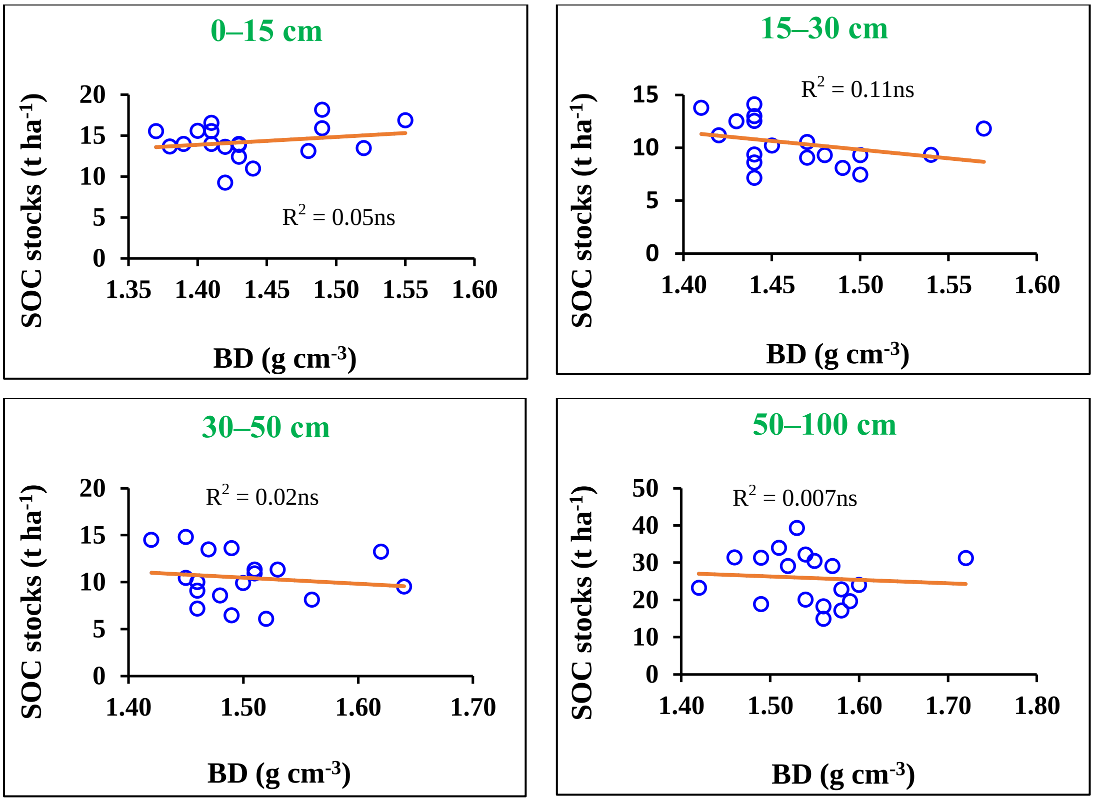


Figure 4.18. Relationship of soil organic carbon stocks (t ha^{-1}) with bulk density (g cm^{-3}) at different soil depths (cm) of Sal Forest areas (ns = not significant)

4.6. Changes in Soil Organic Carbon During 2019 and 2022 Under the Study

The soil samples were collected from January to March in the year 2019 and 2022 at the same locations and sampling points in all forest areas under the study. The locations and sampling points were confirmed by GPS readings recorded in 2019. The analytical results (Table 4.11 compiled from Appendix A-12) from 2019 and 2022 revealed that soil organic carbon concentration did not change much during the study period in all forest areas. Although some changes were observed in some sampling points, the change is not statistically significant. Soil organic carbon concentration was found somewhat higher in 2022 than 2019. Changes of soil organic carbon in coastal afforestation areas showed comparatively higher changes of soil organic carbon content than other forest areas whereas sal forest areas showed slower changes of soil organic carbon content. Surface soil (0−15 cm) of Bogi Forest Beat and Nijhumdwip National Park showed higher changes of soil organic carbon than other locations. Sub-surface soil (15−30 cm) of Kukri-Mukri exhibited higher changes of soil organic carbon whereas lower depth (50−100 cm) of Bhawal National Park showed little changes in soil organic carbon compared to other locations under the study. Surprisingly, soil organic carbon contents were found to decrease at 50−100 cm soil depth in Wasu, Matiranga and Kaptai National Park of Chittagong hill forest, and Dhangmari Forest Beat of Sundarban mangrove forest (Table 4.11). Soil organic matter may have leached from these sites in the form of dissolved carbon.

Table 4.11. Comparison between 2019 and 2022 vis-à-vis soil organic carbon (SOC) concentration in different locations of the forest areas under study

Location	Depth (cm)	SOC (%)		t-value	Significance level
		2019	2022		
Chittagong Hill Forest					
Baraiyadhala National Park, Sitakunda, Chittagong	0−15	1.06±0.04	1.10±0.05	-5.90	*
	15−30	0.70±0.08	0.73±0.09	-3.19	ns
	30−50	0.38±0.04	0.40±0.02	-0.92	ns
	50−100	0.26±0.15	0.27±0.16	-2.54	ns
Dulahazra Forest Beat, Chakoria, Cox's Bazar	0−15	0.84±0.05	0.86±0.07	-1.11	ns
	15−30	0.43±0.13	0.43±0.08	0.02	ns
	30−50	0.36±0.07	0.37±0.05	-0.61	ns
	50−100	0.36±0.07	0.36±0.03	-0.12	ns
Goneshpara, Thanchi, Bandarban Hill District	0−15	1.25±0.12	1.32±0.14	-3.12	ns
	15−30	1.18±0.04	1.24±0.03	-6.05	*
	30−50	1.17±0.11	1.24±0.17	-1.70	ns
	50−100	1.08±0.03	1.11±0.04	-4.00	ns
Kaptai National Park Rangamati Hill District	0−15	0.89±0.04	0.93±0.04	-9.33	*
	15−30	0.50±0.09	0.53±0.10	-7.00	*
	30−50	0.42±0.07	0.45±0.08	-7.00	*
	50−100	0.41±0.02	0.41±0.03	0.47	ns
Wasu, Matiranga, Khagrachari Hill District	0−15	1.26±0.01	1.30±0.01	-6.93	*
	15−30	0.90±0.02	0.93±0.01	-2.08	ns
	30−50	0.74±0.00	0.76±0.10	-7.00	*
	50−100	0.70±0.02	0.67±0.02	4.00	ns
Mean					
Sylhet Hill Forest					
Satchari National Park, Chunarughat, Habigonj	0−15	0.62±0.05	0.64±0.06	-2.65	ns
	15−30	0.51±0.06	0.52±0.05	-5.52	*
	30−50	0.41±0.04	0.43±0.06	-1.53	ns
	50−100	0.38±0.06	0.41±0.09	-1.25	ns
Lawachara National Park, Sreemongal, Moulavibazar	0−15	0.86±0.02	0.88±0.03	-3.37	ns
	15−30	0.74±0.03	0.76±0.04	-3.86	ns
	30−50	0.52±0.06	0.55±0.06	-5.20	*
	50−100	0.35±0.04	0.36±0.03	-0.97	ns
Tilagarh Eco Park, Sylhet	0−15	0.35±0.06	0.36±0.05	-1.11	ns
	15−30	0.21±0.04	0.22±0.03	-0.71	ns
	30−50	0.12±0.02	0.13±0.01	-0.55	ns
	50−100	0.07±0.02	0.08±0.01	0.00	ns
Mean					
Sundarban Mangrove Forest					
Munshigonj Forest Beat, Shamnagar, Satkhira	0−15	0.78±0.02	0.82±0.02	-5.77	*
	15−30	0.74±0.04	0.77±0.04	-8.00	*
	30−50	0.70±0.02	0.73±0.03	-5.20	*
	50−100	0.69±0.03	0.72±0.13	-0.39	ns

Table 4.11. Continued

Dhangmari Forest Beat, Dakop, Khulna	0−15	0.76±0.04	0.77±0.02	-0.53	ns
	15−30	0.72±0.01	0.74±0.03	-2.31	ns
	30−50	0.65±0.02	0.67±0.04	-0.54	ns
	50−100	0.66±0.04	0.65±0.02	0.22	ns
Bogi Forest Beat, Sharankhola, Bagerhat	0−15	1.17±0.07	1.26±0.08	-15.59	**
	15−30	1.12±0.09	1.18±0.08	-10.39	**
	30−50	0.87±0.07	0.91±0.15	-0.93	ns
	50−100	0.84±0.11	0.88±0.16	-1.31	ns
Mean					
Coastal Afforestation					
Sonarchar, Rangabali, Patuakhali	0−15	1.12±0.04	1.17±0.03	-5.04	*
	15−30	0.77±0.11	0.81±0.12	-5.24	*
	30−50	0.63±0.11	0.66±0.12	-2.65	ns
	50−100	0.56±0.08	0.58±0.06	-1.15	ns
Kukri-Mukri, Charfashion, Bhola	0−15	0.93±0.07	0.97±0.07	-3.65	ns
	15−30	0.40±0.04	0.43±0.03	-3.59	ns
	30−50	0.33±0.07	0.34±0.08	-2.22	ns
	50−100	0.23±0.02	0.24±0.03	-1.49	ns
Nijhumdwip National Park, Hatiya, Noakhali	0−15	0.59±0.07	0.63±0.07	-13.00	**
	15−30	0.53±0.05	0.56±0.06	-5.20	*
	30−50	0.41±0.01	0.43±0.02	-0.69	ns
	50−100	0.33±0.02	0.34±0.00	-0.70	ns
Dumkhali, Mirersarai, Chittagong	0−15	0.73±0.02	0.76±0.06	-1.00	ns
	15−30	0.61±0.00	0.65±0.01	-6.93	*
	30−50	0.57±0.02	0.60±0.03	-1.13	ns
	50−100	0.44±0.02	0.46±0.01	-0.90	ns
Mean					
Sal Forest					
Kotbari, Cumilla	0−15	0.61±0.04	0.63±0.04	-4.05	ns
	15−30	0.35±0.04	0.37±0.04	-7.11	*
	30−50	0.32±0.05	0.32±0.04	-0.17	ns
	50−100	0.31±0.05	0.32±0.03	-0.50	ns
Dokhola Forest Range, Madhupur, Tangail	0−15	0.74±0.01	0.75±0.02	-0.59	ns
	15−30	0.62±0.04	0.64±0.10	-0.32	ns
	30−50	0.46±0.09	0.47±0.11	-0.65	ns
	50−100	0.43±0.01	0.44±0.02	-0.92	ns
Bhawal National Park, Salna, Gazipur	0−15	0.55±0.11	0.56±0.10	-0.85	ns
	15−30	0.39±0.03	0.40±0.04	-0.76	ns
	30−50	0.29±0.07	0.29±0.08	-0.50	ns
	50−100	0.25±0.03	0.25±0.03	-0.00	ns
Mean					

Values are represented as mean value ± standard deviation.
* = $p<0.05$, ** = $p<0.01$ and ns = not significant

4.7. Estimation of Forest Biomass and Biomass Carbon Density

Forest can act as both a sink and source of carbon when it is conserved and destroyed respectively. It plays an important role in carbon sequestration from the atmosphere. Plant communities sequester carbon during the process of photosynthesis and store it in the form of biomass. Estimation of biomass in a forest ecosystem is an important tool for assessing stock and sequestration of carbon. Estimation of trees and forest biomass can be measured by applying destructive, semi-destructive and non-destructive methods. Destructive methods are more accurate compared to other methods, but this method is usually avoided due to violating forest management policies from regional and/or national level. An allometric equation or model is an effective tool for estimating biomass of trees and forest ecosystem in a non-destructive way. There are various allometric models or equations which are used for forest biomass estimation. Some models are species-specific, and some are regional and pan-tropical. Several allometric models were used for estimating forest biomass and biomass carbon density under the study which are mentioned in the materials and methods (Chapter 3) section. The findings of this study were given in Figures 4.19–4.23 and Tables 4.12 & 4.13 and discussion was stated below accordingly.

4.7.1. Estimation of forest biomass density of different pools

Forest carbon is stored in different carbon pools. The pools are i) above-ground biomass of trees and saplings (AGBTS), ii) below-ground biomass of trees and saplings (BGBTS), iii) Leaf litter, herb and grass (LHG), iv) Dead wood and fallen stumps (DW) and v) Soil organic carbon (SOC). Biomass estimation of dead wood and fallen stumps was not measured in the study. Soil organic carbon stocks were discussed in the previous heading (4.3). Forest biomass depends on diameter at breast height (DBH) and height of trees and in some cases, it also depends on trees wood density. Location-wise estimated results for forest biomass under the study revealed that Kaptai National Park attained higher total biomass density (TBD) of forest followed by Dulahazra Forest Beat, Goneshpara of Thanchi, Baraiyadhala National Park and Wasu, Matiranga in the hill forest of Chittagong. The values were 861 t ha^{-1}, 804 t ha^{-1}, 548 t ha^{-1}, 415 t ha^{-1} and 241 t ha^{-1}, respectively (Figure 4.19). Trees above-ground biomass (TAGB) and trees below-ground biomass (TBGB) were also found higher in Kaptai National Park (726 t ha^{-1} and 116 t ha^{-1}, respectively) compared to other locations. Saplings above-ground biomass (SAGB) and saplings below-ground biomass (SBGB) were found higher in Dulahazra Forest Beat (13.99 t ha^{-1} and 3.87 t ha^{-1}, respectively) followed by Goneshpara, Thanchi (8.05 t ha^{-1} and 2.11 t ha^{-1}, respectively) and lower in Wasu, Matiranga. There was found significant difference ($p<0.05$ and $p<0.01$) of above-ground biomass and below-ground biomass of saplings among the locations of Chittagong hill forest areas. Leaf litter, herb and grass (LHG) was found higher in Goneshpara, Thanchi compared to other locations, but it showed insignificance ($p>0.05$). Diameter at breast height (DBH) of height of trees was found higher in Kaptai National Park (26.41 cm and 23.92 m) followed by Goneshpara, Thanchi (20.27 cm and 15.29 m) and lower in Wasu, Matiranga (12.24 cm and 8.09 m). Significant difference ($p<0.05$) was found in height of trees, but it was insignificant in DBH of trees among the locations. The overall mean value of DBH and height of trees in Chittagong hill forest was 18.46 cm (ranging from 5.85 cm to 32.15 cm) and 15.24 m (ranging from 3.92 m to 30.75 m), respectively (Table 4.12).

In the Sylhet hill forest, total biomass density (TBD) was found highest in Satchari National Park (1121 t ha^{-1}) followed by Lawachara National Park (337 t ha^{-1}) and Tilagarh Eco Park (235 t ha^{-1}), respectively (Figure 4.19) and it was found statistically significant ($p<0.01$). Trees above-ground biomass (TAGB) and trees below-ground biomass (TBGB) were also found higher in Satchari National Park compared to other two locations and it was significant at 1% level of significance. On the other hand, saplings above-ground biomass (SAGB), sapling below-ground biomass (SBGB), and leaf litter, herb and grass (LHG) were found higher in Lawachara National Park than other locations and the values were 13.24 t ha^{-1}, 3.94 t ha^{-1} and 17.93 t ha^{-1}, respectively which was not significant. Significant difference was found in DBH ($p<0.01$) and height of trees ($p<0.001$) among the locations of Sylhet hill forest areas. Satchari National Park attained higher DBH (33.15 cm) and height (17.88 m) and it was lower in Lawachara National Park (12.52 cm and 8.48 m). The overall mean value of DBH and height of trees in Sylhet hill forest were 22.98 cm (ranging from 9.93 cm to 40.38 cm) and 13.35 m (ranging from 7.47 m to 19.72 m), respectively (Table 4.12).

In the Sundarban mangrove forest areas, all biomass pools (TAGB, TBGB, SAGB, SBGB and LHG) was found higher in Dhangmari Forest Beat compared to others. Total biomass density (TBD) of Dhangmari Forest Beat was 483 t ha^{-1} followed by Bogi Forest Beat (407 t ha^{-1}) and Munshigonj Forest Beat (231 t ha^{-1}) (Figure 4.19). Diameter at breast height (DBH) and height of trees were also found higher in Dhangmari Forest Beat. The mean value of DBH and height of trees in Sundarban mangrove forest was 12.04 cm (ranging from 5.93 cm to 16.09 cm) and 9.96 m (ranging from 1.52 m to 51.0 m), respectively. There was found not significant variation in different biomass pools among the locations of Sundarban mangrove forest areas (Table 4.12).

Total biomass density (416 t ha^{-1}) as well as TAGB (339 t ha^{-1}), TBGB (60 t ha^{-1}), DBH (19.94 cm) and height of trees (15.58 m) was found higher in Nijhumdwip National Park followed by Dumkhali, Mirersarai (332 t ha^{-1}, 271 t ha^{-1} and 48 t ha^{-1}), Kukri-Mukri, Charfashion (250 t ha^{-1}, 178 t ha^{-1} and 34 t ha^{-1}) and Sonarchar, Rangabali (248 t ha^{-1}, 173 t ha^{-1} and 32 t ha^{-1}). But the variation was found not significant ($p>0.05$). On the other hand, SAGB (8.21 t ha^{-1}), SBGB (2.67 t ha^{-1}) and LHG (32.76 t ha^{-1}) was found higher in Sonarchar, Rangabali compared to other locations of coastal afforestation areas, and it was found significant difference ($p<0.05$). The mean value of DBH and height of trees in coastal afforestation areas was 16.05 cm (10.27─22.70 cm) and 13.41 m (8.41─18.25 m), respectively (Figure 4.19 and Table 4.12).

Kotbari, Cumilla of sal forest areas attained higher in total biomass density (555 t ha^{-1}), TAGB (458 t ha^{-1}) TBGB (76 t ha^{-1}), SAGB (9.60 t ha^{-1}), SBGB (2.78 t ha^{-1}), DBH (24.90 cm) and height of trees (18.18 m) compared to other locations. Leaf litter, herb and grass (LHG) was found higher in Dokhola Forest Range (9.87 t ha^{-1}) and it was not significant. Significant variation was found in SAGB ($p<0.05$), SBGB ($p<0.05$) and height of trees ($p<0.01$) whereas TAGB, TBGB and DBH was found not significant (Figure 4.19 and Table 4.12).

The location-wise overall mean value of total biomass density (TBD) was found higher in Satchari National Park (1121 t ha^{-1}) of Sylhet hill forest followed by Kaptai National Park (861 t ha^{-1}) and Dulahazra Forest Beat (804 t ha^{-1}) of Chittagong hill forest respectively, and lower in Wasu, Matiranga (242 t ha^{-1}) of Chittagong hill forest followed by Tilagarh Eco Park (235 t ha^{-1}) of Sylhet hill forest and Munshigongonj Forest Beat (231 t ha^{-1}) of Sundarban mangrove forest respectively (Figure 4.19). Chittagong hill forest area attained maximum (555 t ha^{-1}) total biomass density, on the other hand coastal afforestation area attained minimum (284 t ha^{-1}) total biomass density under the study (Figure 4.20). There was found significant difference ($p<0.01$) of total biomass density among the locations, but it was found insignificant ($p>0.05$) among different forest areas under the study.

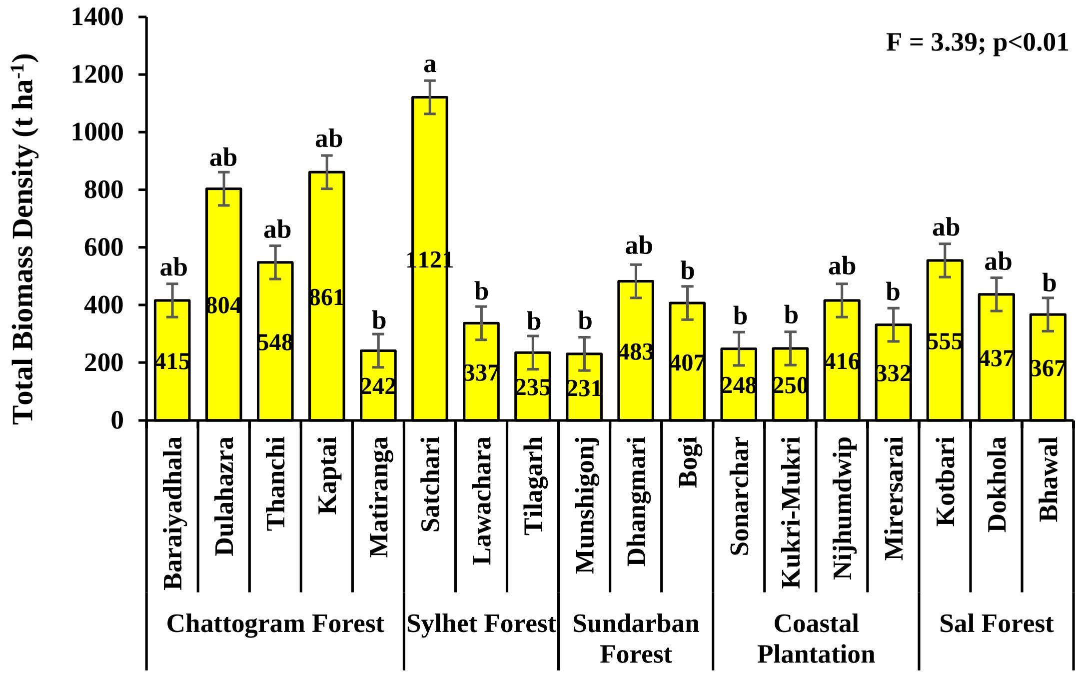


Figure 4.19. Total biomass density at different locations of the forest areas. Different lower-case letters indicate significant differences among the different locations under different forest areas according to Tukey's HSD test.

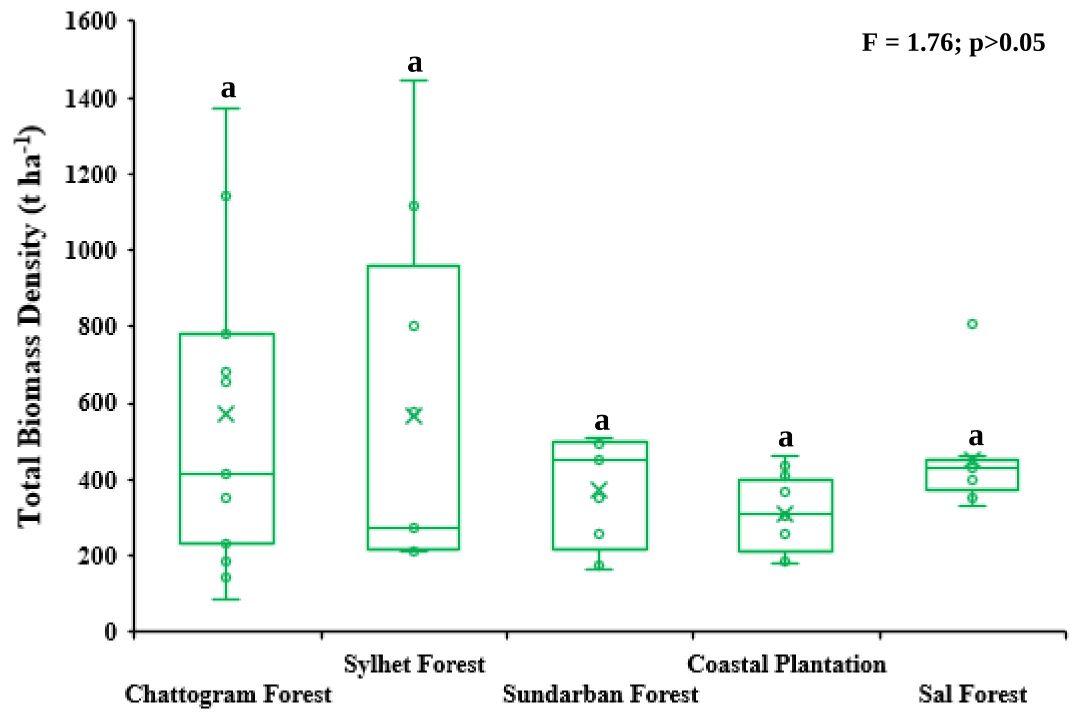


Figure 4.20. Total biomass density of different forest areas under the study. Different lower-case letters indicate significant differences among the different forest areas according to Tukey's HSD test.

Table 4.12. Total biomass density of different biomass pools at different locations in the study areas

Location	DBH (cm)	Height (m)	TAGB	TBGB	SAGB	SBGB	LHG	TBD
			(t ha^{-1})					
Chittagong hill forest								
Baraiyadhala National Park	15.34±6.66a	13.96±5.81ab	343±222a	59±34.10a	5.47±1.09ab	1.49±0.28b	6.59±2.84a	415±259a
Dulahazra Forest Beat	18.04±6.63a	14.96±2.44ab	674±447a	102±64.60a	13.99±2.03a	3.87±0.47a	9.96±6.55a	804±518a
Goneshpara, Thanchi	20.27±10.72a	15.29±3.58ab	451±463a	73±70.90a	8.05±6.40ab	2.11±1.41ab	13.29±0.89a	548±540a
Kaptai National Park	26.41±3.46a	23.92±6.82a	726±223a	116±35.40a	6.03±2.82ab	1.72±0.74b	11.18±3.22a	861±257a
Wasu, Matiranga	12.24±6.20a	8.09±4.51b	194±91.90a	36±12.49a	3.0±0.94b	0.88±0.25b	8.36±2.76a	241±103a
Mean	18.46±6.73 (5.85–32.15)	15.24±4.63 (3.92–30.75)	478±289.38 (56–1165)	77±43.49 (11–174)	7.31±2.66 (1.92–16.32)	2.02±0.63 (0.60–4.42)	9.88±3.25 (4.90–17.52)	574±335.40 (85–1372)
F-test	ns	*	ns	ns	*	**	ns	ns
Sylhet Hill Forest								
Satchari national Park	33.15±6.84a	17.88±1.84a	945±280a	146±42.60a	9.60±3.73a	2.78±0.97a	17.40±17.5a	1121±324a
Lawachara National Park	12.52±2.94b	8.48±1.22c	261±180b	41±18.20b	13.24±2.88a	3.94±0.84a	17.93±11.6a	337±207b
Tilagarh Eco Park	23.25±1.83ab	13.69±0.72b	186±29.70b	34±4.43b	7.09±3.49a	1.92±0.98a	6.36±1.46a	235±33.5b
Mean	22.98±3.87 (9.93–40.38)	13.35±1.26 (7.47–19.72)	464±163.23 (154–1235)	74±21.74 (30–191)	9.98±3.37 (3.46–16.52)	2.88±0.93 (0.92–4.91)	13.89±10.19 (5.03–37.59)	598±188.17 (209–1447)
F-test	**	***	**	**	ns	ns	ns	**
Sundarban Mangrove Forest								
Munshigonj Forest Beat	10.16±1.51a	8.15±1.26b	171±93.0b	34±13.21b	4.54±2.56a	1.51±0.77a	19.53±4.72a	231±106.0b
Dhangmari Forest Beat	13.90±1.60a	11.16±0.75a	397±32.3a	72±1.80a	5.55±0.50a	1.78±0.17a	6.97±3.07a	483±30.0a

Table 4.12 Continued

Location	DBH (cm)	Height (m)	TAGB	TBGB	SAGB	SBGB	LHG	TBD
			(t ha^{-1})					
Bogi Forest Beat	12.05±1.51a	10.57±1.14b	310±108.0ab	60±20.3b	6.20±5.27a	1.95±1.61a	28.82±14.6a	407±132.3a
Mean	12.04±2.10 (9.07–15.67)	9.96±1.67 (7.27–11.87)	293±122.7 (117–425)	55±20.78 (25–76)	5.43±2.78 (1.53–11.91)	1.75±0.85 (0.52–3.69)	18.44±7.46 (3.88–43.70)	374±97.44 (164–508)
F-test	ns	*	*	*	ns	ns	ns	*
Coastal Afforestation								
Sonarchar, Rangabali	13.04±0.67a	11.74±0.13a	173±63.70a	32±10.92a	8.21±2.34a	2.67±0.77a	32.76±15.72a	248±63a
Kukri-Mukri, Charfashion	13.51±4.43a	12.67±1.85a	178±50.30a	34±9.48a	7.99±2.88a	2.59±0.93a	26.99±0.70ab	250±63a
Nijhumdwip National Park	19.94±2.42a	15.58±2.32a	339±34.30a	60±7.12a	6.02±1.34ab	1.85±0.38ab	8.52±1.78b	416±43a
Dumkhali, Mirersarai	17.72±3.77a	13.66±4.61a	271±106.1a	48±19.60a	1.91±0.32b	0.62±0.09b	9.23±0.81b	332±125a
Mean	16.05±2.82 (10.27–22.70)	13.41±2.23 (8.41–18.25)	240±63.60 (112–374)	44±11.78 (22–68)	6.03±1.72 (1.63–10.83)	1.93±0.54 (0.53–3.51)	19.38±4.75 (6.57–46.23)	311±73.5 (182–462)
F-test	ns	ns	ns	ns	*	*	*	ns
Sal Forest								
Kotbari, Cumilla	24.90±4.14a	18.18±2.68a	458±189a	76±28.00a	9.60±3.73a	2.78±0.05a	8.21±2.33a	555±222a
Dokhola Forest Range	20.45±0.16a	17.28±0.73a	355±5.02a	64±0.47a	7.09±3.49ab	1.92±0.98ab	9.87±1.04a	437±6.53a
Bhawal National Park	22.53±1.91a	11.87±1.16b	302±37.0a	56±6.07a	1.08±0.17b	0.35±0.05b	7.91±0.99a	367±43.6a
Mean	22.63±2.07 (20.32–29.66)	15.78±1.52 (10.85–20.52)	372±77.0 (272–675)	65±11.51 (51–108)	5.92±2.46 (0.90–12.33)	1.69±0.36 (0.30–3.50)	8.66±1.45 (5.52–10.69)	453±90.71 (333–809)
F-test	ns	**	ns	ns	*	*	ns	ns

Values are presented as mean value ± standard deviation. Values in parentheses are range values. Different lower-case letters within a pool and forest indicate significant differences (* = p<0.05, ** = p<0.01, *** = p<0.001, and ns = not significant) [DBH = diameter at breast height, TAGB = tree above-ground biomass, TBGB = tree below-ground biomass, SAGB = sapling above-ground biomass, SBGB = sapling below-ground biomass, LHG = leaf litter, herb and grass, and TBD = total biomass density].

4.7.2. Estimation of forest biomass carbon and CO_2 mitigation density

Forest biomass carbon of different carbon pools was measured by using zone-wise and species-specific allometric models or equations as well as Intergovernmental Panel on Climate Change (IPCC) guideline mentioned in the materials and methods section (Chapter-3). The study result showed that in Chittagong Hill Forest, total carbon density (TCD) was found higher in Kaptai National Park (494 t ha^{-1}) followed by Dulahazra Forest Beat (461 t ha^{-1}), Goneshpara of Thanchi (430 t ha^{-1}), Baraiyadhala National Park (264 t ha^{-1}) and Wasu of Matitanga (241 t ha^{-1}) in the hill forest of Chittagong (Table 4.13). Similarly, trees above-ground biomass carbon (CTAGB) and trees below-ground biomass carbon (CTBGB) was also found higher in Kaptai National Park and lower in Wasu, Matiranga and it was found not significant. Carbon in saplings above-ground biomass (CSAGB) and below-ground biomass (CSBGB) were found higher in Dulahazra Forest Beat followed by Goneshpara, Thanchi and lower in Wasu, Matiranga. The variation of CSAGB and CSBGB among the locations was found statistically significant at 5% and 1% level of significance, respectively. Carbon in leaf litter, herb and grass (CLHG) and soil organic carbon (SOC) stocks was found higher in Goneshpara, Thanchi compared to other locations of Chittagong hill forest. The variation in SOC stocks among the locations showed significant difference ($p<0.001$).

In Sylhet Hill Forest, Satchari National Park forest had maximum TCD (620 t ha^{-1}) CTAGB (461 t ha^{-1}) and CTBGB (73 t ha^{-1}) followed by Larachara National Park (247 t ha^{-1}, 127 t ha^{-1} and 20 t ha^{-1}) and Tilagarh Eco Park (147 t ha^{-1}, 100 t ha^{-1} and 17 t ha^{-1}), respectively and it was found significant difference ($p<0.01$). Carbon in sapling above-ground biomass (CSAGB), carbon in sapling below-ground biomass (CSBGB), CLHG and SOC stocks was found higher in Lawachara National Park and lower in Tilagarh Eco Park of Sylhet hill forest (Table 4.13). The variation of SOC stocks among the locations showed significant difference ($p<0.001$).

Bogi Forest Beat of Sundarban mangrove forest showed higher magnitude of different carbon pools than other locations. The variation of different carbon pools was found not significant, but exception for SOC stocks and it was found significant difference ($p<0.001$) among the locations of Sundaban mangrove forest (Table 4.13).

Nijhumdwip National Park of coastal afforestation areas showed maximum amount of TCD (267 t ha^{-1}), CTAGB (170 t ha^{-1}) and CTBGB (30 t ha^{-1}) followed by Dumkhali, Mirersarai (243 t ha^{-1}, 137 t ha^{-1} and 24 t ha^{-1}), Sonarchar, Rangabali (223 t ha^{-1}, 90 t ha^{-1} and 16 t ha^{-1}) and Kukri-Mukri, Charfashion (177 t ha^{-1}, 90 t ha^{-1} and 16 t ha^{-1}), respectively, but the variation was found not significant (Table 4.13). On the other hand, Sonarchar, Rangabali showed higher amount of CSAGB (3.79 t ha^{-1}), CSBGB (1.33 t ha^{-1}), CLHG (15.40 t ha^{-1}) and SOC stock (107 t ha^{-1}) compared to other locations, and it was found significant difference ($p<0.05$, $p<0.01$ and $p<0.001$).

In sal forest areas, total carbon density (TCD), carbon in trees above-ground biomass (CTAGB), carbon in trees below-ground biomass (CTBGB), carbon in saplings above-ground biomass (CSAGB) and carbon in sapling below-ground biomass (CSBGB) were found higher in Kotbari sal forest of Cumilla followed by Dokhola Forest Range of Madhupur and Bhawal National Park of Gazipur. Soil organic carbon (SOC) stocks and carbon in leaf litter, herb and grass (CLHG) was found higher in Dokhola Forest Range and lower in Bhawal National Park. The variation of CSAGB, CSBGB and SOC stocks showed significant difference ($p<0.05$ and $p<0.001$) whereas other carbon pools (CTAGB and CTBGB) as well as TCD showed not significant difference (Table 4.13). The location-wise overall total carbon density under the different forest areas was found maximum and minimum in Satchari National Park (620 t ha^{-1}) and Tilagarh Eco Park (147 t ha^{-1}) of Sylhet hill forest respectively under the study (Figure 4.21). Chittagong hill forest (378 t ha^{-1}) attained higher amount of total carbon density followed by Sylhet hill forest (338 t ha^{-1}) whereas coastal afforestation areas (227 t ha^{-1}) attained lower amount of total carbon density under the study (Figure 4.22).

Total carbon dioxide (CO_2) mitigation density of a forest area was measured by using total carbon density (TCD) by multiplication with a factor of 3.67 (C equivalent of CO_2). Among the locations under the study areas, the highest total CO_2 mitigation density was found in Satchari National Park (2277 t ha^{-1}) of Sylhet hill forest followed by Kaptai National Park (1812 t ha^{-1}), Dulahazra Forest Beat (1692 t ha^{-1}) and Goneshpara, Thanchi (1579 t ha^{-1}) of Chittagong hill forest, and Kotbari (1284 t ha^{-1}) of sal forest and Bogi Forest Beat (1237 t ha^{-1}) of Sundarban mangrove forest. Tilagarh Eco Park of Sylhet Forest possessed the minimum amount of CO_2 mitigation density (541 t ha^{-1}) as compared to other locations under different forest areas (Figure 4.23). Considering the total biomass (Table 4.12), total carbon density and total CO_2 mitigation density (Table 4.13) of different forest areas, the hill forest areas of Chittagong and Sylhet possessed maximum forest biomass, and biomass carbon and CO_2 mitigation density as compared to sal forest, Sundarban mangrove forest and coastal afforestation areas.

Table 4.13. Total carbon density and CO_2 mitigation density of different carbon pools at different locations in the study areas

Location	CTAGB	CTBGB	CSAGB	CSBGB	CLHG	SOC stock	TCD	CO_2 Density
	(t ha^{-1})							
Chittagong hill forest								
Baraiyadhala National Park	164±108a	29±17.07a	2.40±0.48ab	0.74±0.14b	3.09±1.34a	64±9.44c	264±124.1a	969±445a
Dulahazra Forest Beat	330±221a	51±32.30a	6.10±0.91a	1.94±0.24a	4.68±3.08a	67±4.00c	461±258a	1692±949a
Goneshpara, Thanchi	219±225a	36±35.5a	3.94±3.13ab	1.06±0.70ab	6.25±0.42a	164±8.32a	430±269a	1579±987a
Kaptai National Park	352±109a	58±17.70a	2.62±1.24ab	0.86±0.37b	5.25±1.51a	75±4.21c	494±128.1a	1812±470a
Wasu, Matiranga	93±45.4a	18±6.25a	1.30±0.41b	0.44±0.12b	3.93±1.30a	124±2.67b	241±53.8a	883±197a
F-test	ns	ns	*	**	ns	***	ns	ns
Sylhet Hill Forest								
Satchari National Park	461±137a	73±21.30a	4.16±1.64a	1.39±0.49a	8.18±8.24a	73±4.0a	620±158.8a	2277±583a
Lawachara National Park	127±94b	20±9.09b	5.70±1.24a	1.97±0.42a	8.43±5.47a	83±6.95a	247±101.1b	906±371b
Tilagarh Eco Park	100±16b	17±2.22b	3.60±1.76a	0.96±0.49a	2.99±0.69a	23±1.99b	147±18.50b	541±67.9b
F-test	**	**	ns	ns	ns	***	**	**
Sundarban Mangrove Forest								
Munshigonj Forest Beat	86±45.4b	17±6.61b	2.14±1.23a	0.75±0.38a	9.18±2.22a	91±2.85b	206±52.8b	756±185b
Dhangmari Forest Beat	198±17.0a	36±0.90a	2.63±0.14a	0.89±0.08a	3.28±1.44a	86±3.35b	327±17.7ab	1199±64.9ab
Bogi Forest Beat	157±53.5ab	30±10.16ab	3.08±2.65a	0.97±0.80a	13.54±6.90a	132±8.47a	337±62.3a	1237±229a
F-test	*	*	ns	ns	ns	***	*	*
Coastal Afforestation								
Sonarchar, Rangabali	90±32.50a	16±5.46a	3.79±1.11a	1.33±0.39a	15.40±7.39a	96±7.57a	223±35.1a	818±128.8a

Table 4.13. Continued

Location	CTAGB	CTBGB	CSAGB	CSBGB	CLHG	SOC stock	TCD	CO_2 Density
	(t ha^{-1})							
Kukri-Mukri, Charfashion	92±22.40a	17±4.74a	3.70±1.32a	1.29±0.46a	12.68±0.33ab	50±1.14c	177±27.5a	650±101.1a
Nijhumdwip National Park	170±16.65a	30±3.56a	3.24±0.77ab	0.93±0.19ab	4.01±0.83b	58±2.90c	267±23.6a	980±86.7a
Dumkhali, Mirersarai	137±53a	24±9.78a	0.93±1.70b	0.31±0.05b	4.34±0.38b	76±1.87b	243±64.4a	891±236a
F-test	ns	ns	*	*	**	***	ns	ns
Sal Forest								
Kotbari, Cumilla	247±108.1a	38±15.98a	4.16±1.64a	1.39±0.49a	3.86±1.10a	56±4.52b	350±121.7a	1284±447a
Dokhola Forest Range	192±2.55a	32±0.23a	3.60±1.76ab	0.96±0.49ab	4.64±0.49a	74±3.53a	307±5.60a	1127±20.6a
Bhawal National Park	161±19.20a	28±3.04a	0.58±0.09b	0.18±0.02b	3.72±0.47a	49±3.10b	243±22.1a	890±81.2a
F-test	ns	ns	*	*	ns	***	ns	ns

Values are presented as mean value ± standard deviation. Values in parentheses are range values. Different lower-case letters within a pool and forest indicate significant differences (* = p<0.05, ** = p<0.01, *** = p<0.001, and ns = not significant) [CTAGB = carbon in tree above-ground biomass, CTBGB = carbon in tree below-ground biomass, CSAGB = carbon in sapling above-ground biomass, CSBGB = carbon in sapling below-ground biomass, CLHG =carbon in leaf litter, herb and grass, SOC = soil organic carbon and TCD = total carbon density].

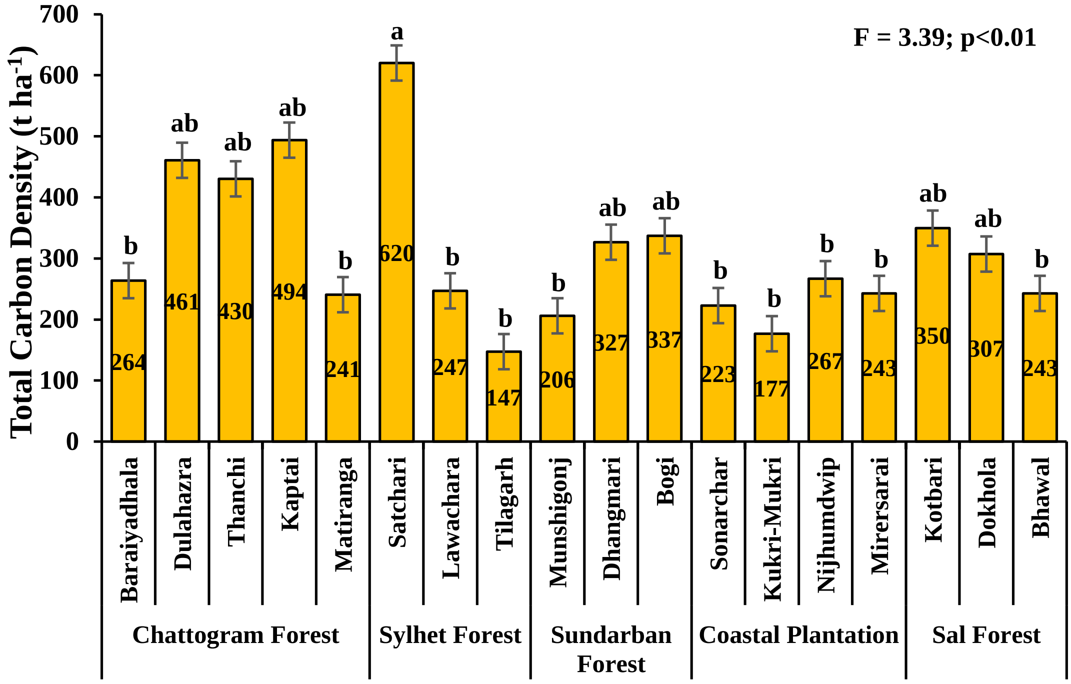


Figure 4.21. Total carbon density at different locations of different forest areas. Different lower-case letters indicate significant differences among the different locations under the study areas according to Tukey's HSD test.

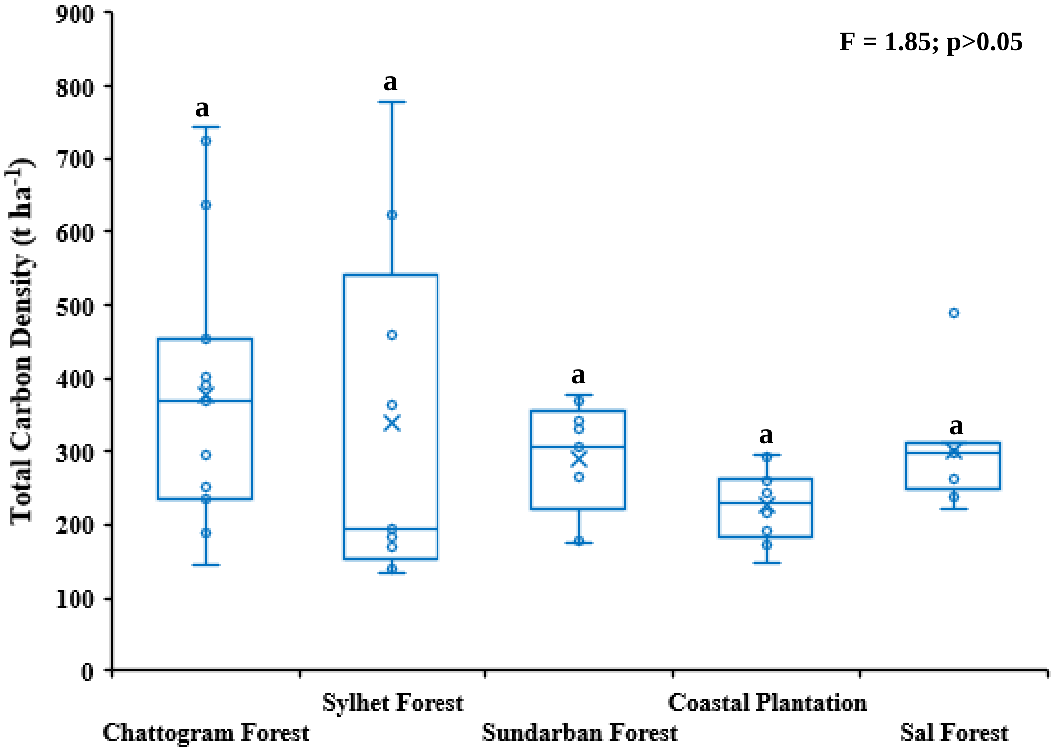


Figure 4.22. Total carbon density of different forest areas under the study. Different lower-case letters indicate significant differences among the different forest areas according to Tukey's HSD test.

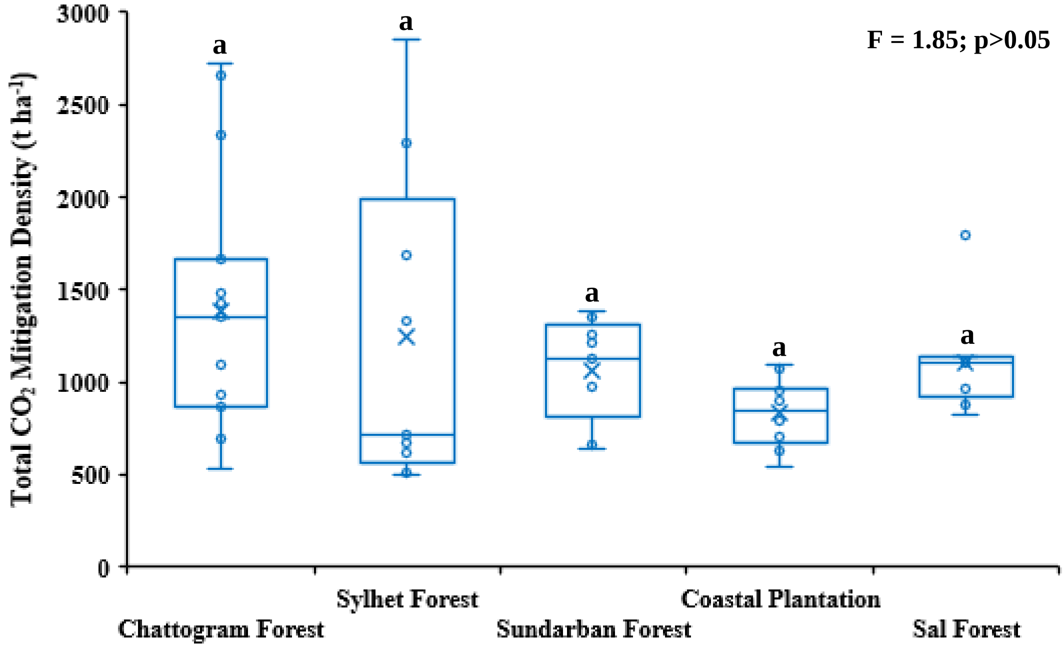


Figure 4.23. Total CO_2 mitigation density of different forest areas under the study. Different lower-case letters indicate significant differences among the different forest areas according to Tukey's HSD test.

Forest biomass may be varied by different factors, such as tree species, climatic conditions, site conditions, forest types with its composition and management practices which ultimately influence the architecture of tree and biomass partitioning. Bangladesh Forest Inventory (BFI) report on "Tree and Forest Resources of Bangladesh-2000" indicated that the national average of total carbon density (TCD) including all carbon pools across the different zones (hill, sal, Sundarban, coastal and village zones) was 248.97 t ha^{-1} (GoB, 2020) whereas this study indicated it was 289.20 t ha^{-1} (SOC stocks up to 100 cm soil depth). Considering the SOC stocks up to 30 cm soil depth, this report also indicated that Sundarban zone attained highest value of total biomass carbon density (163.70 t ha^{-1}) followed by sal zone (121.10 t ha^{-1}), hill zone (120.46 t ha^{-1}), coastal zone (92.98 t ha^{-1}) and village (homestead) zone (86.82 t ha^{-1}), whereas the national average total carbon density was 94.84 t ha^{-1}. Soil organic carbon (SOC) stocks up to 30 cm soil depth was 89.97 t ha^{-1} in hill zone, 84.05 t ha^{-1} in sal zone, 78.68 t ha^{-1} in Sundarban zone and 65.77 t ha^{-1} in coastal zone. In this report, it was mentioned that SOC was determined by loss on ignition (LOI) without removing inorganic carbonates which typically results in higher value than other methods. Carbon in different pools was found higher under the study than the

BFI report. The reason behind that the study was conducted sporadically very few locations but BFI report included the total areas of Bangladesh.

Mukul et al. (2014) reported that the average carbon density in Bangladesh forest was 175.5 t ha^{-1} (considering SOC stocks up to 30 cm soil depth) which was closely related to this study result. They also reported that carbon density in sal forest was 202.2 t ha^{-1} (biomass 153.9 t ha^{-1} and soil 48.3 t ha^{-1}), 170.6 t ha^{-1} (biomass 131.8 t ha^{-1} and soil 38.8 t ha^{-1}) in mangrove forest including mangrove plantation and 153.7 t ha^{-1} (biomass 96.1 t ha^{-1} and soil 57.6 t ha^{-1}) in hill forest areas. National level biomass carbon of Forest Department (FD) managed forests in Bangladesh was estimated by many researchers. Based on satellite data, Saatchi et al. (2011) reported that estimation of biomass carbon in FD-managed forests of Bangladesh was 70.5 t ha^{-1} whereas based on forest inventory data, Brown (1997) and Gibbs and Brown (2007) reported that it was 92 t ha^{-1} and 158 t ha^{-1} respectively. DeFries et al. (2002), Gibbs et al. (2007) and IPCC (2006) reported that the biomass carbon estimation of Bangladesh forest was 137 t ha^{-1}, 93 t ha^{-1} and 65 t ha^{-1}, respectively by using harvest data.

Shin et al. (2007) reported that biomass carbon in hill forest of Bangladesh was 92 t ha^{-1}. On the other hand, Alamgir and Al-Amin (2007), Mukul (2014) and Ullah and Al-Amin (2012) reported biomass carbon in hill forest of Bangladesh was 73.6 t ha^{-1}, 115.6 t ha^{-1} and 103.4 t ha^{-1}, respectively. Biomass carbon in mangrove forest (including mangrove plantation) of Bangladesh was found 126.7 t ha^{-1} and 98.9 t ha^{-1}, respectively reported by Donato et al. (2011) and Rahman et al. (2014). Kibria and Saha (2011) reported biomass carbon in sal forest of Bangladesh was 153.9 t ha^{-1}. Sahu et al. (2016) reported that the overall mean of carbon stock in natural mangrove and plantation mangrove was 143.4 t ha^{-1} (biomass 89.1 t ha^{-1} and soil 54.3 t ha^{-1}) and 151.5 t ha^{-1} (biomass 90.6 t ha^{-1} and soil 60.9 t ha^{-1}) up to 30 cm soil depth which was comparable and slightly lower than the present study value. Total biomass carbon density was higher in sal plantation (216.68 t ha^{-1}) than natural sal forest (167.64 t ha^{-1}) was recorded by Banik et al. (2018) which was closely related to the present study.

4.7.3. Contribution of different carbon pools in different forest areas

Measurement of different carbon pools varied from different ecosystems due to vegetation types, species composition, and site conditions as well as climatic and edaphic factors. The study result revealed that carbon in tree biomass (CTB) in all forest areas contributed almost 61–79% total carbon density under the study. Soil organic carbon (SOC) stocks contributed about 18–35% and rest of them are carbon in leaf litter, herb and grass (CLHG) ranging from 1.22% to 4.16% and carbon in saplings biomass (CSB) ranging from 1.15% to 1.93% under the study. The contribution of CTB in Sylhet hill forest and sal forest was found highest (78%) followed by Chittagong hill forest (72%), coastal afforestation areas (63%) and Sundarban mangrove forest (61%). Similarly, the contribution of SOC stocks was found highest in Sundarban mangrove forest area (35%) followed by coastal afforestation area (31%), Chittagong hill forest (25%), sal forest (20%) and Sylhet hill forest (18%) (Figure 4.24). On the other hand, the contribution of carbon in leaf litter, herb and grass (CLHG) and carbon in sapling biomass (CSB) was found higher in coastal afforestation area and it was 4.16% and 1.79%, respectively, followed by Sundarban mangrove forest (2.88% and 1.20%) whereas it was lower in Chittagong hill forest (the value was 1.22% and 1.15%). The higher value of CLHG and CSB in the Sundarban and coastal zones may indicate lower pressure from collection due to more difficult access from other forest areas. Pandey and Bhusal (2016) conducted a study on carbon stock densities in two different ecological regions of Nepal and reported that both the above-ground biomass (AGB) and SOC stocks contributed 48% of carbon and below-ground biomass (BGB) was 4% carbon in Hilly sal forest areas whereas in Terai sal forest areas it was 72% in AGB followed by SOC stocks (21%) and the least 7% in the BGB carbon in their study.

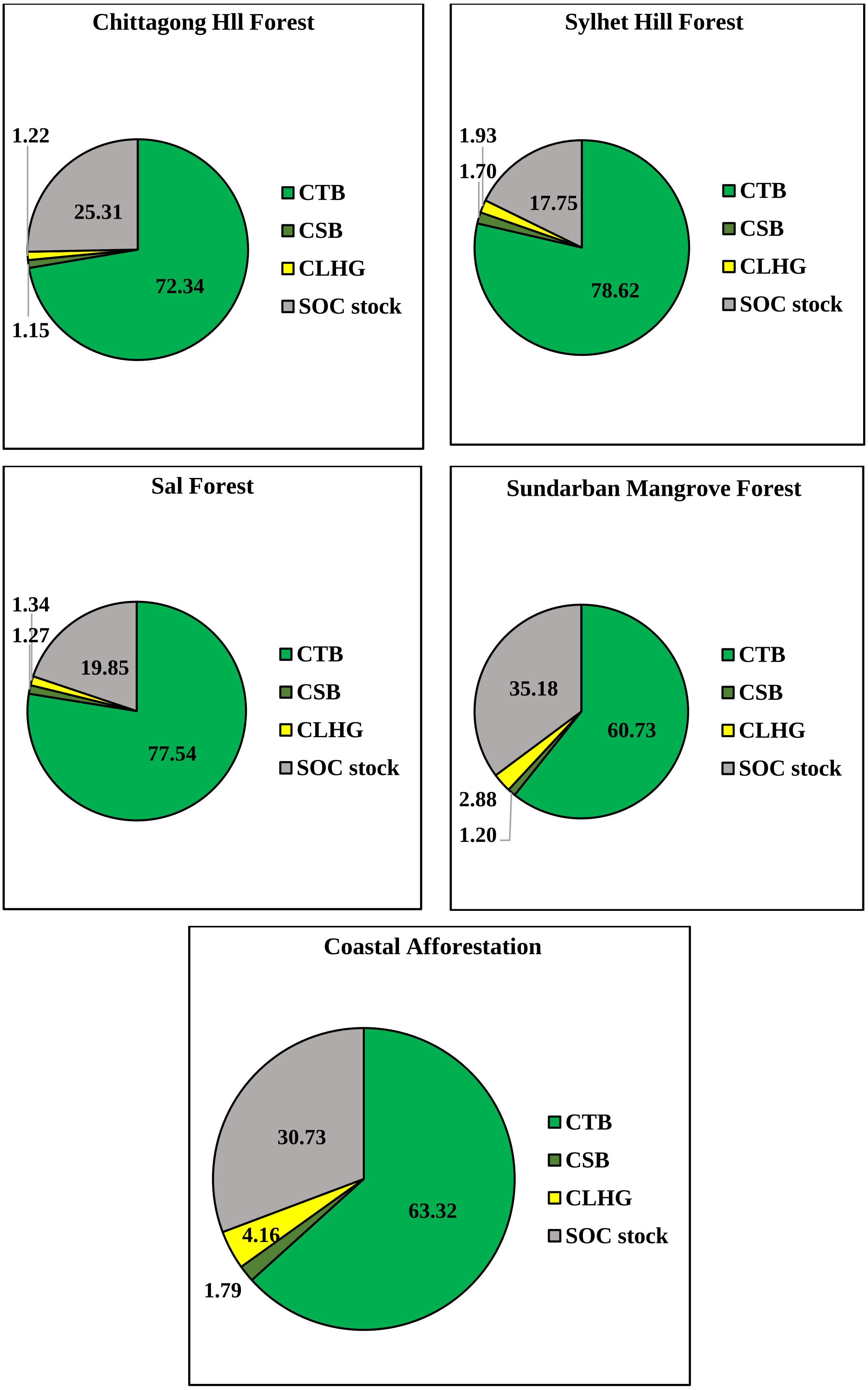


Figure 4.24. Contribution of different carbon pools in different forest areas under study. CTB: carbon in tree biomass, CSB: carbon in saplings biomass,

CLHG: carbon in leaf litter, herb and grass, SOC stocks: Soil organic carbon stocks

4.7.4. Trees biomass and biomass carbon allocation by different species

Forest biomass and biomass carbon depend on diameter at breast height (DBH) and height of trees, and wood density (wood specific gravity) in some cases. A total of ninety-seven (97) different trees (trees are stems with a diameter >5 cm) and saplings (saplings are stems with diameter 1–5 cm) were recorded from different forest areas under the study (Appendix A-13). Among the trees, the highest mean value of DBH was found in Lohakat (*Xylia xylocarpa*) followed by Chapalish (*Artocarpus chama*) and lowest in Bohera (*Termanalia bellerica*) and Lotkon (*Baccaurea ramiflora*). Similarly, the highest mean value of height was found in Pine (*Pinus caribaea*) followed by Lohakat (*Xylia xylocarpa*) and lowest in Amloki (*Phyllanthus emblica*). Among the saplings, Bhadi (*Lanea coromandilica*) attained the highest mean value of DBH (4.30 cm, ranging from 4.14 cm to 4.45 cm) and height (5.50 m) whereas Goran (*Ceriops decandra*) attained the lowest mean value of DBH (1.50 cm, ranging from 1.27 cm to 2.23 cm) and height (1.96 m, ranging from 1.80 to 2.40 m) (Appendix A-14). According to DBH, the order of top twenty (20) tree species was: Lohakat (*X. xylocarpa*) > Chapalish (*A. chama*) > Pine (*P. caribaea*) > Awal (*Vitex pubescens*) > Raintree (*Samanea saman*) > Kadam (*Neolamarckia cadamba*) > Dharmara (*Stereospermum personatum*) > Chikrashi (*Chukrassia velutina*) > Khudijam (*Syzygium balsameum*) > Dumur (*Ficus hispida*) > Silkoroi (*Albizia procera*) > Dhakijam (*Syzygium grande*) > Civit (*Swintonia floribunda*) > Kanak (*Schima wallichi*) > Segun (*Tectona grandis*) > Jarul (*Lagerstroemia speciosa*) > Hybrid acacia (*A. auriculiformis x A. mangium*) > Sal (*Shorea robusta*) > Kalojam (*Syzygium cumini*) > Keora (*Sonneratia apetala*). According to height of trees, the order was found little bit changed and it was: Pine (*P. caribaea*) > Lohakat (*X. xylocarpa*) > Silkoroi (*Albizzia procera*) > Kadam (*N. cadamba*) > Ranitree (*S. saman*) > Chapalish (*A. chama*) > Dharmara (*S. personatum*) > Awal (*V. pubescens*) > Khudijam (*S. balsameum*) > Kalojam (*S. cumini*) > Dhakijam (*S. grande*) > Chikrashi (*C. velutina*) > Dumur (*F. hispida*) > Segun (*T. grandis*) > Hybrid acacia (*A. auriculiformis x A. mangium*) > Keora (*S. apetala*) > Jarul (*L. speciosa*) > Civit (*S. floribunda*) > Sal (*S. robusta*) > Kanak (*S. wallichi*) (Figure 4.25).

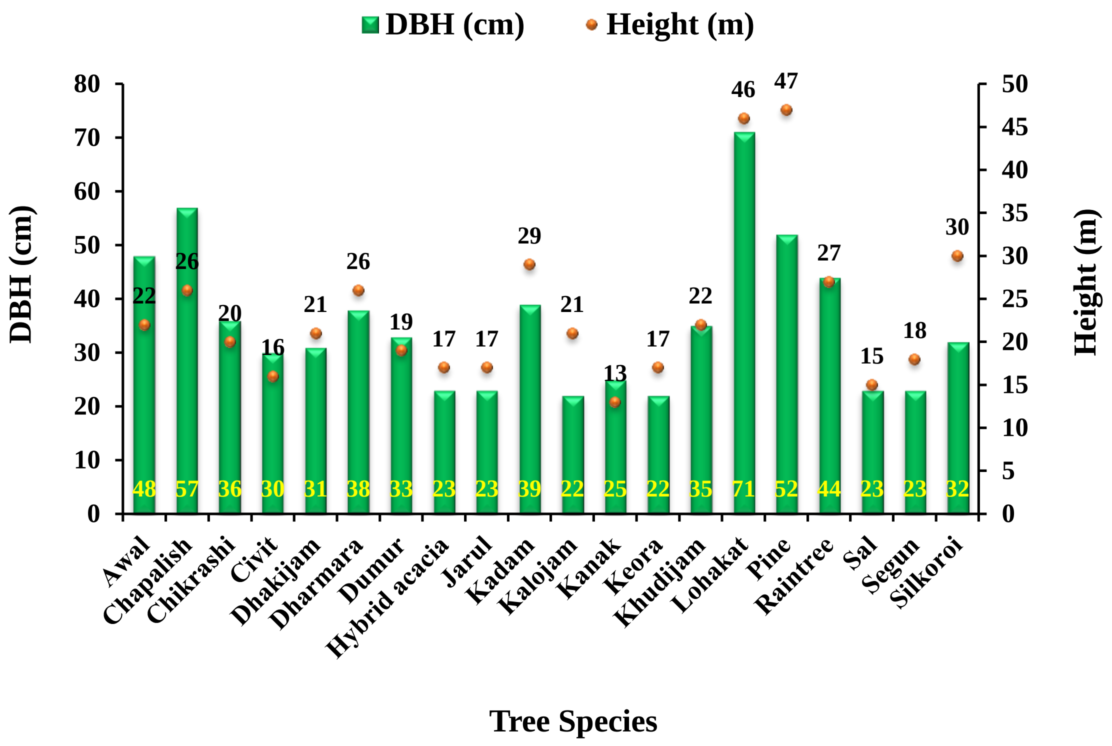


Figure 4.25. Diameter at breast height (DBH) and height of the top twenty tree species in the study areas

Individual tree or sapling biomass (TB) and tree or sapling biomass carbon (TBC) density was calculated by summing up the above ground biomass (AGB) and below ground biomass (BGB) of that respective tree or sapling. Trees CO_2 mitigation potential was also calculated by multiplying with the factor of 3.67. According to the tree's biomass, trees carbon density and trees CO_2 mitigation potential, the order of top (20) tree species was: Lohakat (*X. xylocarpa*) > Pine (*P. caribaea*) > Chapalish (*A. chama*) > Dharmara (*S. personatum*) > Raintree (*S. saman*) > Awal (*V. pubescens*) > Dhakijam (*Syzygium grande*) > Silkoroi (*A. procera*) > Khudijam (*S. balsameum*) > Kadam (*N. cadamba*) > Chikrashi (*C. velutina*) > Garjan (*Dipterocarpus turbinatus*) > Dumur (*F. hispida*) > Segun (*T. grandis*) > Civit (*S. floribunda*) > Jarul (*L. speciosa*) > Kalojam (*S. cumini*) > Eucalyptus (*Eucalyptus camaldulensis*) > Kanak (*S. wallichi*) > Hybrid acacia (*A. auriculiformis x A. mangium*) (Figure 4.26–4.28). Considering the saplings biomass carbon, it was found higher in Rong (*Morinda angustifolia*) followed by Bhadi (*L. coromandilica*) and lower in Goran (*C. decandra*), and the value was 0.96 t ha^{-1}, 0.56 t ha^{-1} and 0.03 t ha^{-1}, respectively under the study area (Appendix A-15).

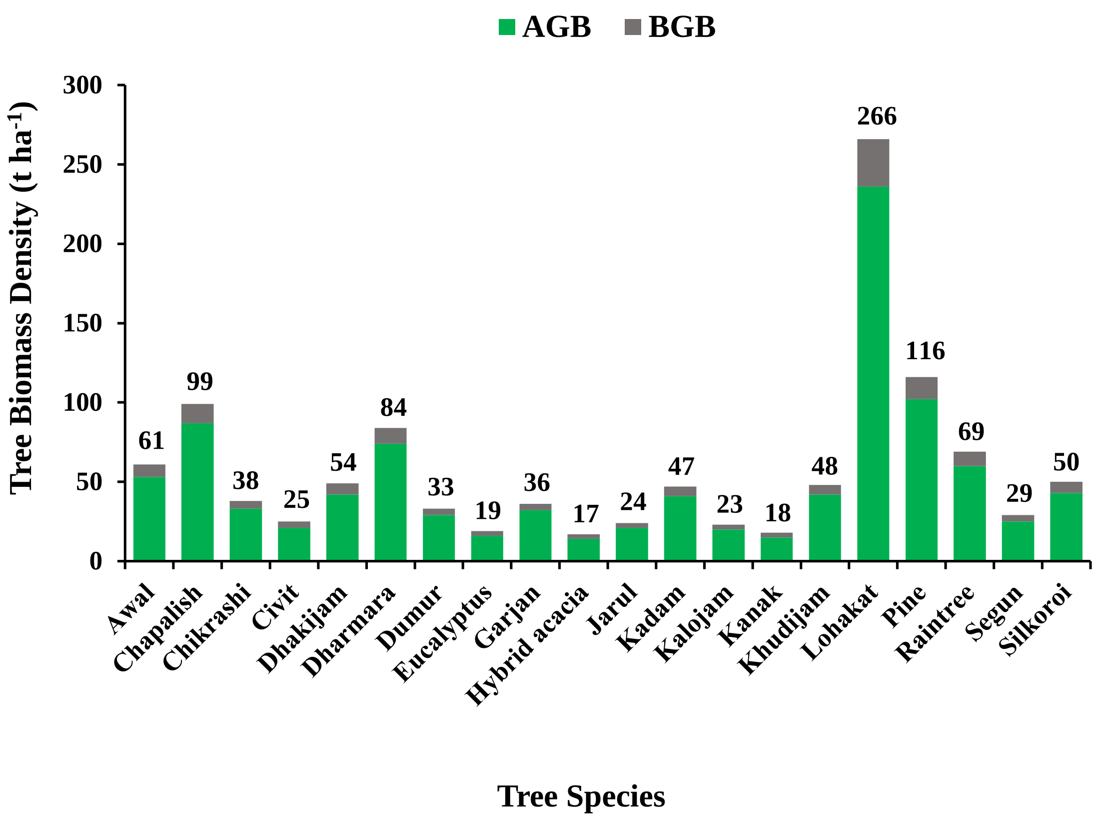


Figure 4.26. Trees biomass density (t ha^{-1}) of the top twenty tree species in the study areas

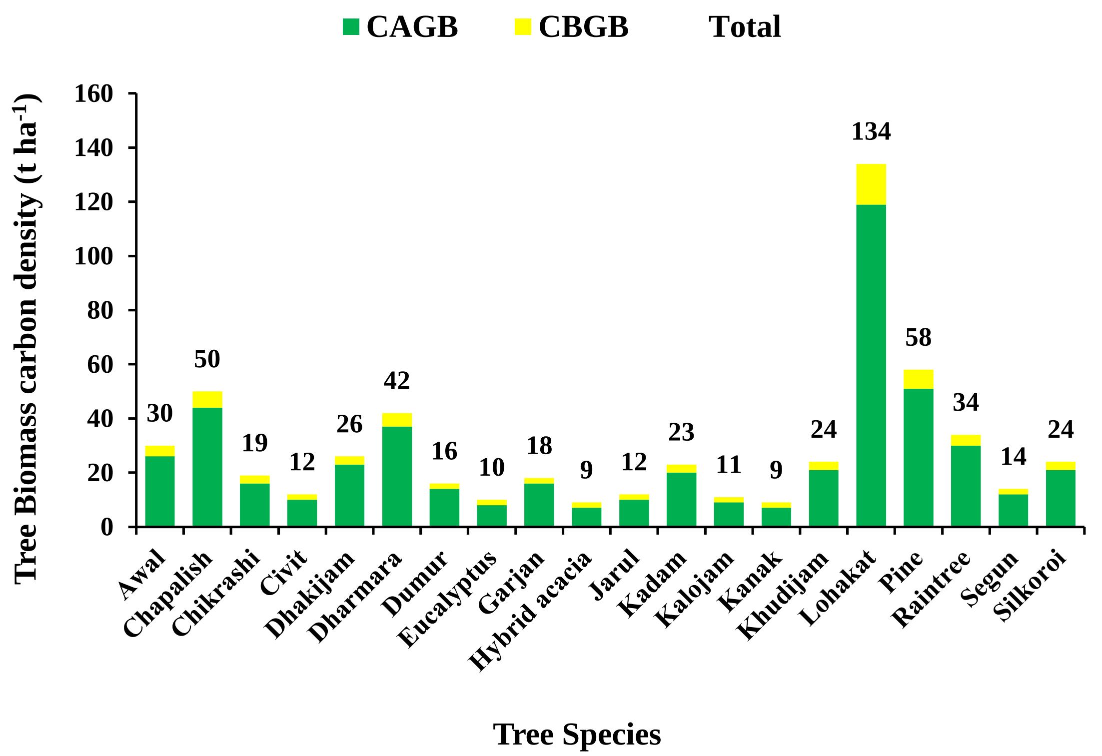


Figure 4.27. Trees biomass carbon density (t ha^{-1}) of the top twenty tree species in the study areas

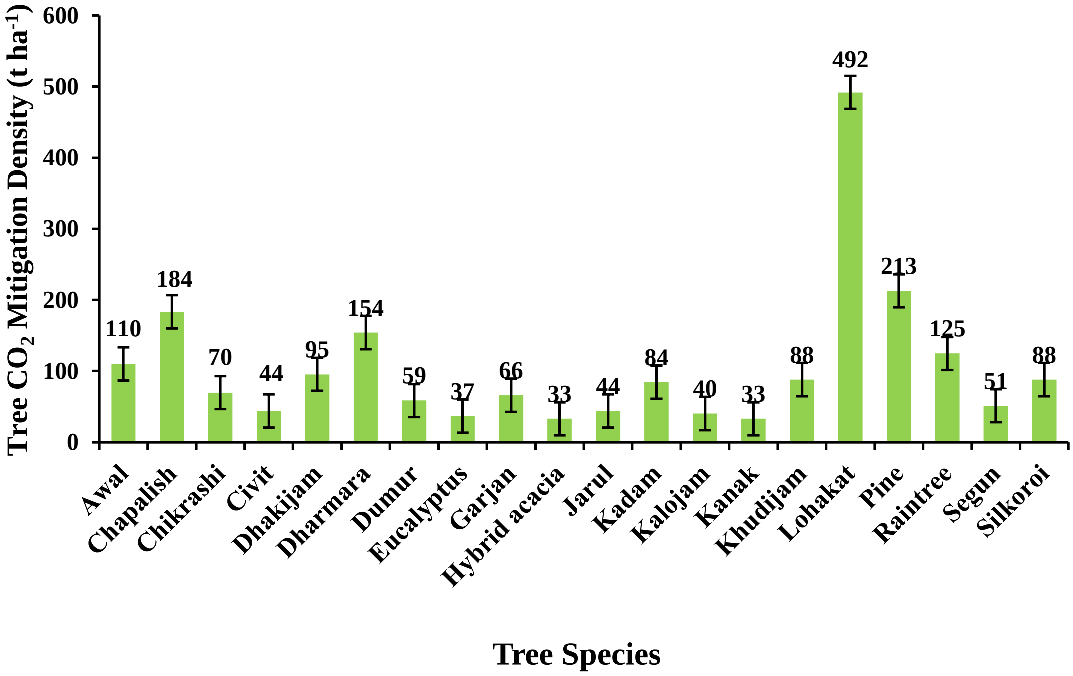


Figure 4.28. Trees CO_2 mitigation density (t ha^{-1}) of the top twenty tree species in the study areas

Bangladesh Forest Inventory (BFI) report on "Tree and Forest Resources of Bangladesh-2000" revealed that diameters and heights are varied across different forest zones which are indicating the growth performance of the dominant tree species. In this report, the highest DBH was found in Simul (*Bombax ceiba*) followed by Botgach (*Ficus benghalensis*), Bandarhola (*Duabanga grandiflora*) and Baen (*Avicennia officinalis*), and the value was 190 cm, 182 cm 175 cm and 164 cm, respectively. Considering the height of dominant tree species, Civit (*Swintonia floribunda*) and Baittya Garjan (*Dipterocarpus costatus*) found in hill forest area attained highest value of height and it was 45.3 m (GoB, 2020). The mean DBH and height of most important tree species are Segun (*Tectona grandis*), Akashmoni (*A. auriculiformis*), Anjir/Dumur (*Ficus carica*), Gamar (*Gmelina arborea*), Sal (*Shorea robusta*) Mahagony (*Swietenia mahagoni*), Raintree (*S. saman*), Gewa (*Excoecaria agallocha*), Goran (*C. decandra*), Keora (*Sonneratia apetala*), Sundari (*Heritiera fomes*) Aam (*Mangifera indica*), Kanthal (*Artocarpus heterophyllus*), etc. and the values were 15.2 cm & 7.0 m, 15.2 cm & 11.6 m, 11.2 cm & 6.2 m, 25.9 cm & 12.6

m, 19.1 cm & 11.7 m, 18.9 cm & 11.4 m, 35.7 cm & 14.8 m, 9.6 cm & 7.0 m, 2.8 cm & 3.1 m, 78.7 cm & 16.8 m, 13.0 cm & 9.5 m, 27.8 cm & 10.0 m and 26.6 cm & 9.9 m, respectively. In this report, it also indicated that the average value of above-ground biomass (AGB) was found in Segun (*T. grandis*) followed by Gamar (*G. arborea*) Silkoroi (*A. procera*), Dholi Garjan (*D. alatus*) and Akashmoni (*A. auriculiformis*), and the value was 5.74 t ha^{-1}, 1.45 t ha^{-1}, 1.25 t ha^{-1}, 1.24 t ha^{-1} and 1.03 t ha^{-1}, respectively in the hill forest zone. In the Sundarban and coastal zone, the higher values were found in Sundari (*H. fomes*) followed by Keora (*S. apetala*), Baen (*A. officinalis*), Goran (*C. decandra*) and Passur (*Xylocarpus mekongensis*), and the values were 56.01 t ha^{-1}, 20.52 t ha^{-1}, 5.70 t ha^{-1}, 4.72 t ha^{-1} and 2.80 t ha^{-1}, respectively. Gewa (*E. agallocha*) was found in both zones attained mean value of AGB 23.17 t ha^{-1} and 2.21 t ha^{-1} in Sundarban and coastal zone respectively.

The AGB estimation of this study was found to be significantly different from the BFI report because this report was prepared based on national level inventory whereas this study was confined only some locations of different forest areas. On the other hand, below-ground biomass and individual tree species-wise tree biomass carbon was not included in that report.

Sahu et al. (2016) reported that the mean DBH value of Baen (*A. officinalis*), Keora (*S. apetala*), Gewa (*E. agallocha*), Sundari (*H. fomes*) and Goran (*C. decandra*) were 48.42 cm, 45.54 cm, 25.11 cm, 17.39 cm and 13.38 cm, respectively, in their study. They also reported that the AGB was found in Baen (30.58 t ha^{-1}) followed by Gewa (29.42 t ha^{-1}) whereas Sundari, Keora and Goran attained 2.61 t ha^{-1}, 1.01 t ha^{-1} and 0.45 t ha^{-1} of AGB, respectively. They also found that the lowest value of DBH and AGB was in Khalshi (*Aegiceras corniculatum*), and the value was 10.80 cm and 0.01 t ha^{-1}, respectively. In this study, the mean DBH value was found in Keora (21.59 cm), Sundari (13.97 cm), Baen (11.81 cm), Gewa (8.27 cm), Passur (8.11 cm) and Khalshi (5.80 cm) whereas the mean values of AGB were 9.0 t ha^{-1}, 8.53 t ha^{-1}, 20.48 t ha^{-1}, 0.66 t ha^{-1}, 0.98 t ha^{-1} and 0.30 t ha^{-1}, respectively which was found significantly different.

4.7.5. Relationship of tree biomass carbon with diameter at breast height (DBH) and height of trees

The biomass and biomass carbon depend on the diameter at breast height (DBH) and the height of trees in a forest ecosystem. Increasing or decreasing DBH and height of trees directly affects the estimation of tree biomass and biomass carbon. The relationship between tree biomass carbon and DBH and height was performed by Pearson correlation analysis (Table 4.14). The study result showed that tree biomass carbon positively correlated with DBH and the height of trees. Tree biomass carbon increased significantly ($p<0.05$, $p<0.01$ and $p<0.001$) with increasing DBH and height of trees in all forest areas. Although the tree biomass carbon of Sundarban mangrove forest was found positively correlated with DBH but was not significant (Figure 4.29). On the other hand, the relationship between tree biomass carbon and the height of sal forest areas showed insignificant differences (Figure 4.30). The result of the present study was found to be consistent with the result revealed by Baul et al. (2021). They reported that tree biomass carbon stocks revealed a significantly strong positive relationship with DBH, height and basal area (BA) of trees. They also mentioned that an increase in BA and DBH by 1 m^2 and 1 cm, increased the tree biomass carbon density by 2 and 4 t ha^{-1}, respectively.

The relationship between tree biomass carbon density and soil organic carbon (SOC) stocks in all forest areas revealed no significant difference (Table 4.14). The dependency of SOC stocks on tree biomass carbon density is shown in Figure 4.31. Sylhet hill forest and Sundarban mangrove forest only showed a nearly positive correlation between tree biomass carbon density and SOC stocks, but contrary to expectations this relationship was not found significant. Similar result was observed by Omoro et al. (2013) and concluded that soil organic carbon levels in plantation forest areas are not in equilibrium with inputs of soil organic matter.

Table 4.14. Pearson correlation matrix of diameter at breast height (DBH), height and tree biomass carbon, and soil organic carbon (SOC) stock in different forest areas

Parameter	DBH (cm)	Height (m)	Tree Biomass Carbon (t ha^{-1})	SOC stock (t ha^{-1})
Chittagong hill forest				
DBH (cm)	-			
Height (m)	0.872***	-		
Tree Biomass Carbon (t ha^{-1})	0.844***	0.685**	-	
SOC stock (t ha^{-})	-0.108 ns	-0.311 ns	-0.278 ns	-
Sylhet Hill Forest				
DBH (cm)	-			
Height (m)	0.988***	-		
Tree Biomass Carbon (t ha^{-1})	0.720**	0.693**	-	
SOC stock (t ha^{-1})	-0.286 ns	-0.338 ns	0.247 ns	-
Sundarban Mangrove Forest				
DBH (cm)	-			
Height (m)	0.901***	-		
Tree Biomass Carbon (t ha^{-1})	0.841***	0.868***	-	
SOC stock (t ha^{-1})	0.302 ns	0.256 ns	0.062 ns	-
Coastal Afforestation				
DBH (cm)	-			
Height (m)	0.882***	-		
Tree Biomass Carbon (t ha^{-1})	0.903***	0.853***	-	
SOC stock (t ha^{-1})	-0.310 ns	-0.299 ns	-0.287 ns	-
Sal Forest				
DBH (cm)	-			
Height (m)	0.272 ns	-		
Tree Biomass Carbon (t ha^{-1})	0.838 **	0.631 ns	-	
SOC stock (t ha^{-1})	-0.436 ns	0.461 ns	0.065 ns	-

Values in Table are Pearson correlation coefficient (r) values.
** = p<0.01, *** = p<0.001 and ns = not significant

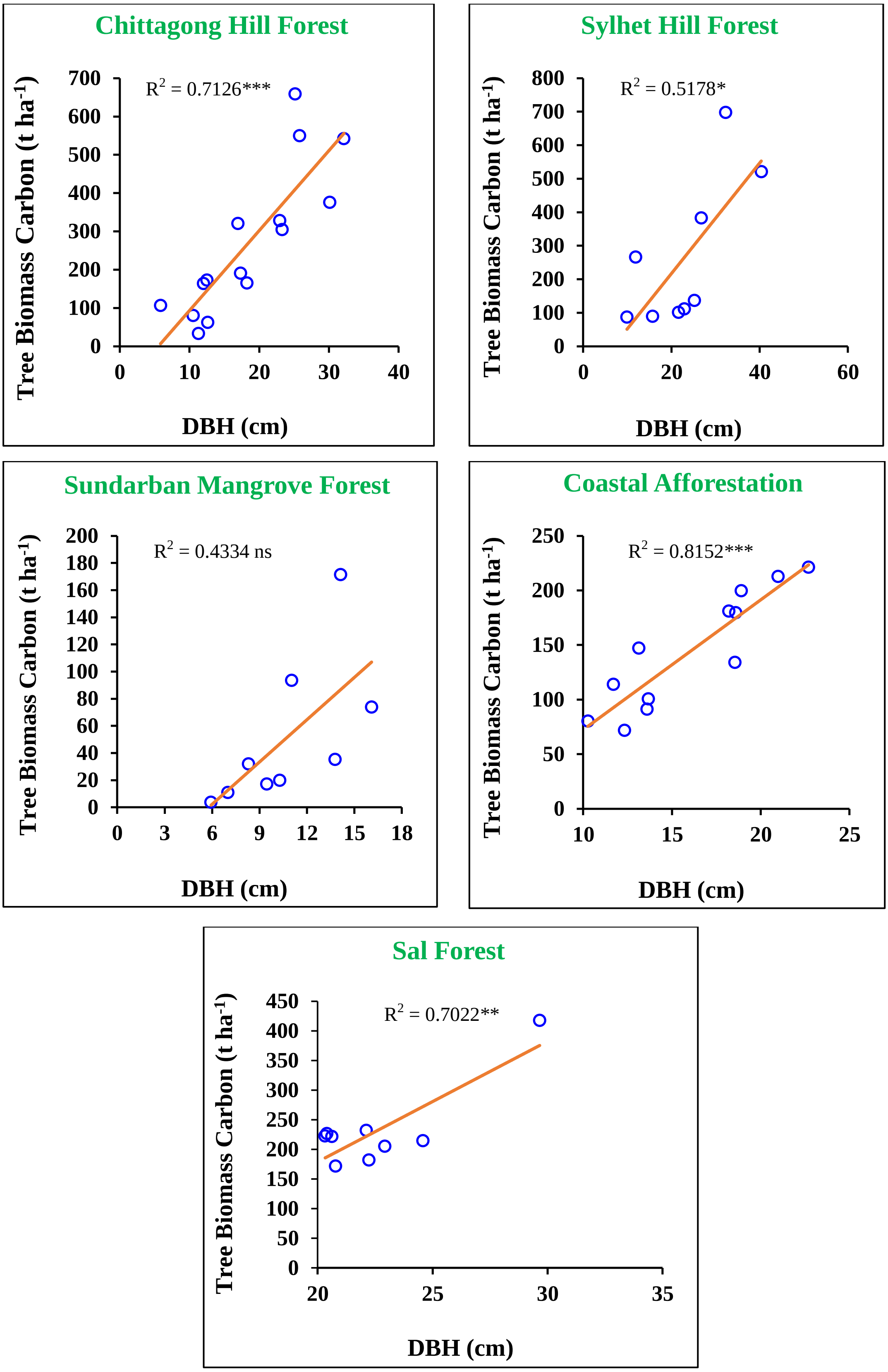


Figure 4.29. Relationship between tree biomass carbon and DBH of trees in the study area (* = p<0.05, ** = p<0.01, *** = p<0.001, and ns = not significant)

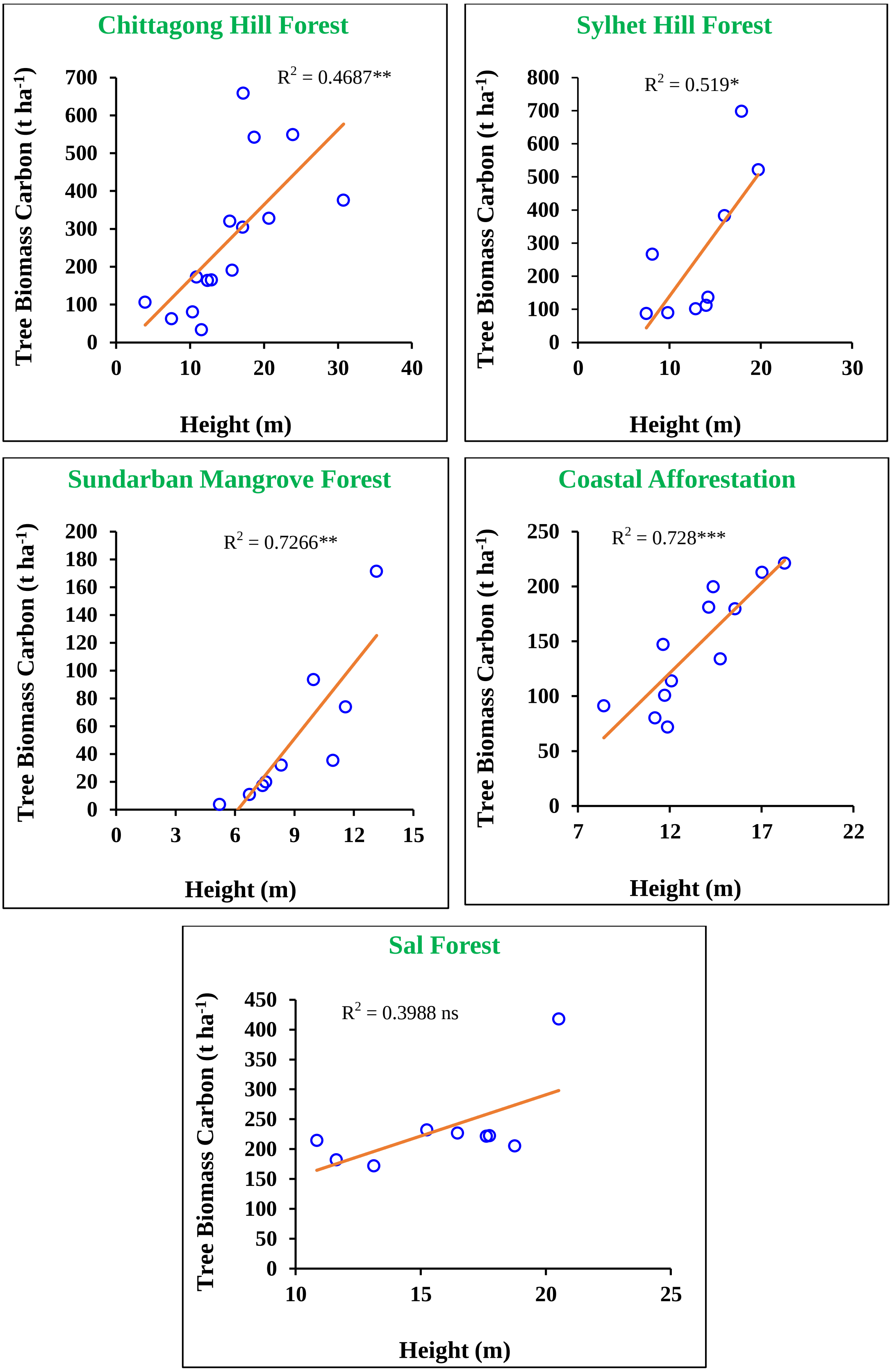


Figure 4.30. Relationship between tree biomass carbon and height of trees in the study area (* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, and ns = not significant)

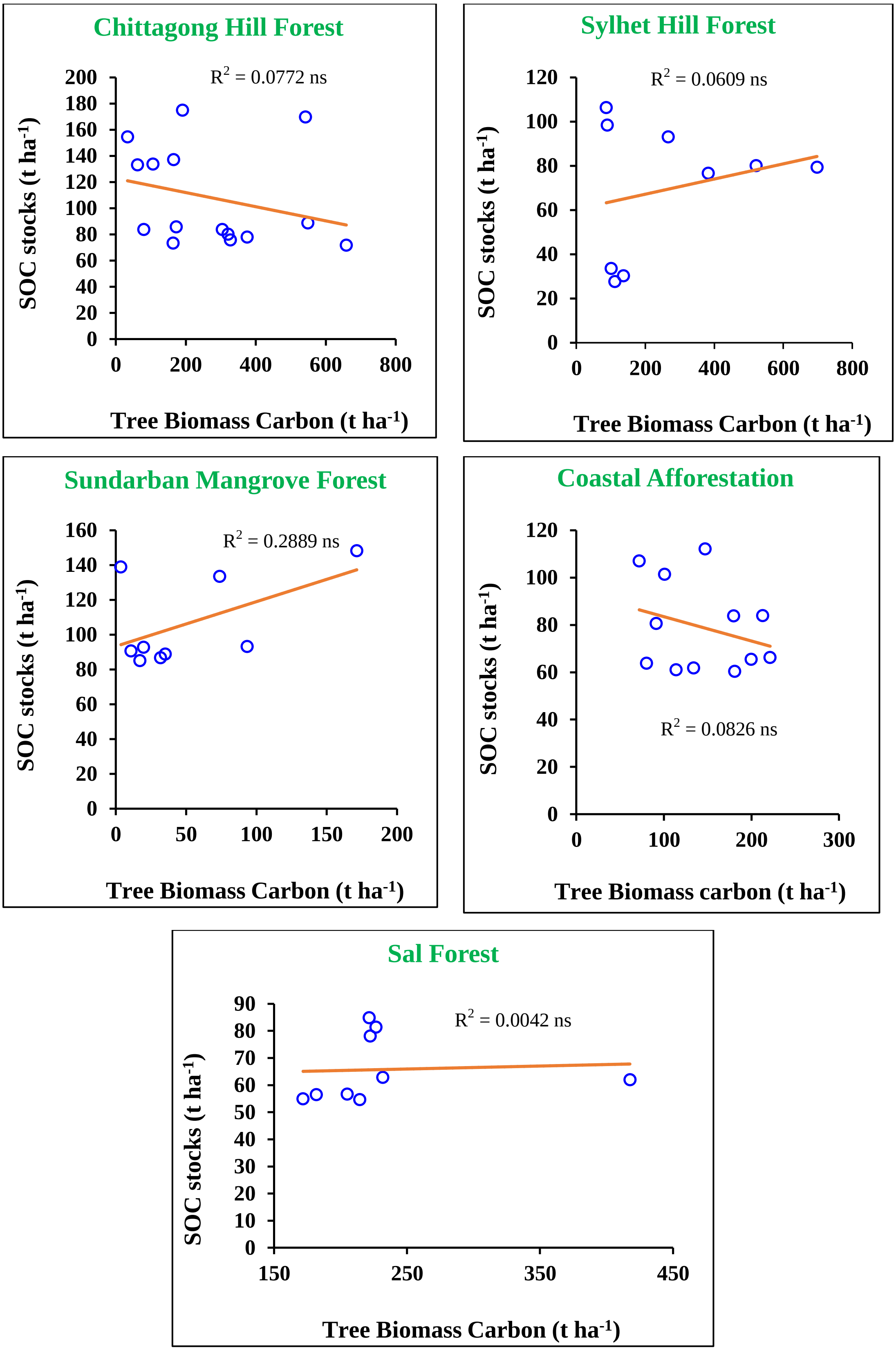


Figure 4.31. Relationship between soil organic carbon (SOC) stocks and tree biomass carbon in the study area (ns = not significant)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The present study highlighted some physical and chemical properties of soils in relation to soil organic carbon dynamics under different forest areas of Bangladesh. The study covered 18 locations in different forest areas at different soil depths. Soil physical (texture, moisture content, and bulk density) and chemical (pH, organic carbon, total nitrogen, and electrical conductivity) properties under different soil depths in both forested and homestead sites were analyzed, and a comparison was made among the locations and soil depth. Location- and depth-wise soil organic carbon stock in different forest areas was estimated under the study. Forest biomass and biomass carbon density in different carbon pools (above-ground and below-ground biomass of trees and saplings, leaf litter, herb, and grass) were also estimated by using different allometric models or equations under the study.

The study results revealed that the texture of soil varied from location to location as well as soil depths. Sand is the dominant fraction in the soils of hill (Chittagong and Sylhet) and sal forest, while silt is the major fraction in the soils of mangrove and coastal areas. The textural class of hill and sal forest areas was found sandy loam to sandy clay loam whereas it was loam in Sundarban mangrove forest and coastal areas. Besides, loamy sand and clay loam texture were found at lower soil depth in some locations under the study areas. Soil moisture content was found higher in mangrove and coastal areas compared to hill and sal forest areas because continuous wetting conditions (i.e. inundation) prevailed in these areas because of ebb and flow tide. The forested site contained maximum moisture content than the homestead site. Soil moisture content increased with increasing soil depths in most of the locations, but decreasing trends were observed at lower soil depths (50−100 cm) in some locations under study. The study results revealed that soil moisture content did not show any trend of variation with soil depths. Soil moisture content depends on the colloidal (clay and humus) content, and the rate of evapotranspiration and percolation, and evaporation is also related to vegetation cover, solar radiation and other soil properties.

Soil bulk density was found increasing trends with increasing soil depths, while reverse trends were observed for soil organic carbon in all locations under the study areas. Likewise, the forested site showed higher soil organic carbon whereas soil bulk density was observed higher in the homestead site in all locations. Soil texture greatly affected the soil bulk density and soil organic carbon. Loose soils have lower bulk density and higher soil organic carbon, on the other hand, it is *vice-versa* in compacted soils. Forest soils have lower bulk density and higher soil organic carbon than cultivated soil due to more porosity. Similarly, disturbed and degraded soils have lower soil organic carbon and higher bulk density than virgin or undisturbed soils. Soil pH showed increasing trends, but soil electrical conductivity was decreasing with increasing soil depths in most cases under the study. The Hill forests of Chittagong and Sylhet areas attained maximum soil total nitrogen compared to other forest areas because litter fall deposition was higher in hill forest areas than that in other locations.

The overall mean value of soil organic carbon (SOC) stocks and equivalent CO_2 mitigation potential was found higher in the forested site of Sundarban mangrove forest (103 t ha^{-1} and 379 t ha^{-1}) followed by Chittagong hill forest (99 t ha^{-1} and 363 t ha^{-1}), while forested site of Sylhet hill forest (60 and 220 t ha^{-1}) and sal forest (60 and 219 t ha^{-1}) showed lower SOC stocks and equivalent CO_2 mitigation potential up to 100 cm soil depth. Similarly, homestead site of Sylhet hill forest areas showed higher SOC stocks (84 t ha^{-1}) and equivalent CO_2 mitigation potential (307 t ha^{-1}) followed by Chittagong hill forest (82 t ha^{-1} and 301 t ha^{-1}) whereas homestead site of Sundarban mangrove forest showed lower value of SOC stoks (50 t ha^{-1}) equivalent CO_2 mitigation potential (187 t ha^{-1}) up to the same soil depth. Goneshpara, Thanchi of Bandarban hill district attained maximum SOC stocks in both forested (164 t ha^{-1}) and homestead (143 t ha^{-1}) site whereas forested site of Tilagarh Eco Park of Sylhet district and the homested site of Munshigonj Forest Beat of Shamnagar, Satkhira district attained minimum SOC stocks, and the value was 23 t ha^{-1} and 37 t ha^{-1} respectively. The SOC stocks decreased with increasing soil depth across all forest areas. This study reveals a positive correlation between SOC stocks and SOC concentration under different soil depths in all forest areas whereas negative correlation was observed with soil bulk density. Forest vegetation significantly affected SOC stocks in the soil profiles, which also suggests that conditions favorable to more vegetative cover with least disturbance from anthropogenic activities leads to high SOC storage in the soil. Change of SOC concentration was also observed under the study but significant and remarkable change was not found during the study period (2019 and 2022). Soil organic carbon concentration was found little bit higher in 2022 than 2019 and the change was almost 2−5%. Coastal afforestation areas showed comparatively higher change of SOC concentration than other forest areas, while sal forest areas showed lower change of SOC concentration. Surface soil (0−15 cm) of Bogi Forest Beat (7.72%) showed highest positive change, while Wasu, Matiranga of Chittagong hill forest (-5.80%) showed highest negative change of SOC concentration at 50−100 cm soil depth.

Forest carbon is stored in different carbon pools, such as above ground biomass (AGB), below ground biomass (BGB), leaf litter, herb and grass (LHG), dead wood (DW), and SOC. Forest biomass depends on diameter at breast height (DBH) and height of trees and in some cases, it also depends on tree wood density (WD). Total biomass density (TBD) was found higher in Chittagong hill forest (555 t ha^{-1}) followed by Sylhet hill forest (537 t ha^{-1}), whereas coastal afforestation areas showed lower TBD (248 t ha^{-1}) under the study. Accordingly, total carbon density (TCD) and total CO_2 mitigation density was also found higher in Chittagong hill forest (378 t ha^{-1} and 1387 t ha^{-1}) followed by Sylhet hill forest (338 t ha^{-1} and 1241 t ha^{-1}), while coastal afforestation areas showed the lower values of TCD (227 t ha^{-1}) and total CO_2 mitigation density (834 t ha^{-1}). Total carbon density (TCD) in Sundarban mangrove forest areas showed lower amount compared to Bangladesh Forest Inventory (BFI) report-2020 because the study was conducted sporadically very few locations (only 3 locations x 3 plots) but BFI report included the whole areas of Sundarban. Satchari National Park of Chunarughat, Habigonj district attained maximum amount of TBD (1121 t ha-1), TCD (620 t ha^{-1}) and total CO_2 mitigation density (2277 t ha^{-1}) followed by Kaptai National Park of Rangamati hill district (861 t ha^{-1}, 494 t ha^{-1} and 1812 t ha^{-1}) whereas Tilagarh Eco Park of Sylhet district attained minimum amount of TBD (235 t ha^{-1}), TCD (147 t ha^{-1}) and total CO2 mitigation density (541 t ha^{-1}) under the study.

The study result was also revealed that tree biomass carbon (CAGB and CBGB) in all forest areas contributed almost 61−79% of total carbon density (TCD) whereas SOC stocks contributed about 18−35% and rest of them are carbon in leaf litter, herb and grass (CLHG) and carbon in saplings biomass. Considering the individual tree biomass carbon (both AGB and BGB), tree species of Lohakat (*Xylia xylocarpa*) attained highest tree biomass carbon (134.12 t ha^{-1}) followed by Pine (*Pinus caribea*) and the value was 58 t ha^{-1}. Whereas considering the individual sapling biomass carbon, it was found higher in Rong (*Morinda angustifolia*) followed by Bhadi (*Lanea coromandilica*) and lower in Goran (*Ceriops decandra*) and the value was 0.96 t ha^{-1}, 0.56 t ha^{-1} and 0.03 t ha^{-1} under the study. The overall findings of this research provide an insight which would be useful to policy makers, environmental activists, researchers and academicians at national and global heights. So, it is imperative to develop a legacy of sustainable forest and land resources management policy that will protect the future generations thereafter.

Recommendations

There is no doubt that soil organic carbon (SOC) plays a key role in maintaining the crop productivity of soils. The future of SOC will depend on climate change, land use and land cover, and feedback within and between these complex factors. Change in land cover and land use generally leads to decrease in SOC. Of late, tropical forests are experiencing a concentration of land use change where large-scale forest clearing is taking place. Any management practices (inevitable or irregular) are primarily responsible for gain or loss of SOC storage in soil. The SOC dynamics in soil is dictated by a balance between input and output of carbon in the soil, and carbon sequestration occurs only when the input exceeds the output. Soil erosion is the most widespread form of soil degradation and has a great impact on the global carbon cycle which partially accountable for climate change and global warming. Therefore, SOC losses must be minimized through appropriate land use practices and following steps should be taken under consideration for addressing climate change and proposing climate mitigation strategies.

- Research is needed to measure and assess the better supplies and benefits of SOC for productivity, water, biodiversity, bioenergy and climate regulation.
- The contribution of organic resources to SOC will vary with the accompanying management and quality of the resources. So, integration of different qualities of organics is needed to achieve both immediate soil fertility and maintenance and crop improvement in the long term.
- The country's hill forest areas are severely degraded due to illicit logging and shifting cultivation, and indiscriminant and unsustainable forest resources collection by forest dwellers are also common phenomena in the hill forest areas.

So, restoration of degraded forests using locally available species (native species) may be an ideal strategy for forest carbon enhancement in the country.

- Afforestation and/or reforestation program should be taken by planting native and at least 10−15% of medium and fast-growing exotic tree species in the newly accreted char land, barren land and degraded land of the country. Further, nitrogen-fixing forest tree species can also be included in this plantation program.
- Protection of degraded forests to allow natural regeneration and avoiding deforestation may be another key strategy for increasing both soil and forest carbon.
- Land tenure policies which are favorable for increasing forest and soil resources should be implemented, particularly at the catchment level.
- Forest as well as soil management policies or strategies can be varied according to the environmental, social and economic conditions of any region. So, policies or strategies should be accompanied by political and economic actions that favor their implementation.
- In Bangladesh, forests and trees play a crucial role in the country's plans towards sustainable development. Ideally, these natural resources should be managed in such a way that balances commercial production, food security and sustainable livelihoods with protection of biological diversity, conservation of plant, soil and water resources, and mitigating climate change. Therefore, achieving this balance innovative and forward-thinking approaches in tree and forest assessment, monitoring and management is required.

CHAPTER 6

REFERENCES

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REFERENCES

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APPENDICES

APPENDICES

A-1. Latitude and Longitude of selected locations under different forest areas

Sl. No.	Forest Area	Location	Latitude and Longitude
01.	Chittagong hill forest	Baraiyadhala National Park Sitakunda, Chittagong	N-22º40'452" E-91º38'704"
02.			N-22º40'676" E-91º38'691"
03.			N-22º41'228" E-91º38'674"
04.		Dulahazra Forest Beat Fanshiakhali Forest Range Chokoria, Cox's Bazar	N-24º42'807" E-92º23'379"
05.			N-24º42'932" E-92º05'110"
06.			N-24º42'791" E-92º04'948"
07.		Goneshpara, Thanchi Bandarban Hill District	N-22º08'261" E-92º11'369"
08.			N-22º08'358" E-92º11'489"
09.			N-22º08'318" E-92º11'349"
10.		Kaptai National Park Rangamati Hill District	N-22º28'293" E-92º13'827"
11.			N-22º28'266" E-92º13'826"
12.			N-22º28'220" E-92º13'759"
13.		Wasu, Matiranga Khagrachari Hill District	N-23º02'315" E-91º50'973"
14.			N-23º02'295" E-91º50'955"
15.			N-23º02'410" E-91º50'966"
16.	Sylhet Hill Forest	Satchari National Park Chunarughat, Habigonj	N-24º07'334" E-91º26'739"
17.			N-24º07'432" E-91º26'733"
18.			N-24º07'626" E-91º26'540"
19.		Lawachara National Park Srimongal, Moulovibazar	N-24º19'671" E-91º47'029"
20.			N-24º19'777" E-91º46'818"
21.			N-24º19'824" E-91º46'793"
22.		Tilagarh Eco Park, Sylhet	N-24º54'948" E-91º54'542"
23.			N-24º54'852" E-91º54'509"
24.			N-24º54'884" E-91º54'580"
25.	Sundarban Mangrove Forest	Munshigonj Forest Beat Burigoalini Forest Range Shamnagar, Satkhira	N-22º15'494" E-89º11'660"
26.			N-22º15'544" E-89º11'675"
27.			N-22º15'484" E-89º11'622"

28.		Dhangmari Forest Beat Chandpai Forest Range Dakop, Khulna	N-22º25'937" E-89º34'870"
29.			N-22º26'922" E-89º34'825"
30.			N-22º26'584" E-89º34'948"
31.		Bogi Forest Beat Sharankhola Forest Range Sharankhola, Bagerhat	N-22º12'516" E-89º49'778"
32.			N-22º12'571" E-89º49'843"
33.			N-22º12'491" E-89º49'725"
34.	Coastal Afforestation	Sonarchar, Rangabali Patuakhali	N-21º49'699" E-90º30'163"
35.			N-21º49'804" E-90º30'694"
36.			N-21º49'895" E-90º30'100"
37.		Kukri-Mukri, Charfashion Bhola	N-21º57'448" E-90º38'383"
38.			N-21º57'472" E-90º38'393"
39.			N-21º57'496" E-90º38'418"
40.		Nijhumdwip National Park Hatiya, Noakhali	N-22º02'627" E-90º58'886"
41.			N-22º02'320" E-91º00'748"
42.			N-22º07'096" E-91º00'599"
43.		Dumkhali, Mirersarai Chittagong	N-22º40'838" E-91º33'503"
44.			N-22º39'954" E-91º34'242"
45.			N-22º37'573" E-91º35'900"
46.	Sal Forest	Kotbari, Cumilla Sadar Cumilla	N-23º25'321" E-91º08'223"
47.			N-23º25'338" E-91º08'165"
48.			N-23º25'378" E-91º08'078"
49.		Dokhola Forest Range Madhupur, Tangail	N-24º38'543" E-90º04'935"
50.			N-24º38'541" E-90º04'983"
51.			N-24º38'575" E-90º04'038"
52.		Bhawal National Park Salna, Gazipur	N-24º03'894" E-90º23'399"
53.			N-24º03'846" E-90º23'366"
54.			N-24º03'807" E-90º23'380"

A-2. Analysis of soil particle size at different locations of different forest areas under different soil depth

Sl. No.	Location	Depth (cm)	Sand	Silt	Clay	Textural Class
			%			
Chittagong hill forest						
01.	Baraiyadhala National Park Sitakunda, Chittagong	0–15	55.25	24.25	20.50	SCL
			54.00	25.50	20.50	SCL
			52.75	28.00	19.25	SCL
		15–30	57.75	18.00	24.25	SCL
			56.50	19.25	24.25	SCL
			57.75	18.00	24.25	SCL
		30–50	59.00	20.50	20.50	SCL
			59.00	20.50	20.50	SCL
			59.00	20.50	20.50	SCL
		50–100	57.75	21.75	20.50	SCL
			57.75	21.75	20.50	SCL
			57.75	23.00	19.25	SCL
02.	Dulahazra Forest Beat Fanshiakhali Forest Range Chokoria, Cox's Bazar	0–15	69.25	15.00	15.75	SL
			69.25	15.00	15.75	SL
			69.25	15.00	15.75	SL
		15–30	60.50	16.25	23.25	SCL
			60.50	16.25	23.25	SCL
			60.50	17.50	22.00	SCL
		30–50	59.25	16.25	24.50	SCL
			58.00	17.50	24.50	SCL
			56.75	18.75	24.50	SCL
		50–100	56.75	17.50	25.75	SCL
			55.50	18.75	25.75	SCL
			55.50	18.75	25.75	SCL
03.	Goneshpara, Thanchi Bandarban Hill Forest	0–15	68.75	18.75	12.50	SL
			68.75	17.50	13.75	SL
			67.50	18.75	13.75	SL
		15–30	65.00	20.00	15.00	SL
			65.00	20.00	15.00	SL
			65.00	20.00	15.00	SL
		30–50	81.25	6.25	12.50	LS
			81.25	6.25	12.50	LS
			81.25	7.50	11.25	LS
		50–100	88.75	1.25	10.00	Sand
			88.75	2.50	8.75	Sand
			88.75	2.50	8.75	Sand

Sl. No.	Location	Depth (cm)	Sand	Silt	Clay	Textural Class
			%			
04.	Kaptai National Park Kaptai, Rangamati Hill District	0–15	48.25	26.00	25.75	SCL
			45.75	29.75	24.50	SCL
			48.25	28.50	23.25	SCL
		15–30	44.50	26.00	29.50	SCL
			43.25	26.00	30.75	SCL
			44.50	24.75	30.75	SCL
		30–50	43.25	24.75	32.00	CL
			44.50	23.50	32.00	CL
			43.25	24.75	32.00	CL
		50–100	43.25	24.75	32.00	CL
			43.25	23.50	33.25	CL
			43.25	23.50	33.25	CL
05.	Wasu, Matiramga Khagrachari Hill District	0–15	82.25	6.75	11.00	LS
			82.25	6.75	11.00	LS
			81.00	8.00	11.00	LS
		15–30	77.25	9.25	13.50	SL
			77.25	9.25	13.50	SL
			78.50	8.00	13.50	SL
		30–50	74.75	9.25	16.00	SL
			74.75	9.25	16.00	SL
			76.00	8.00	16.00	SL
		50–100	74.75	8.00	17.25	SL
			74.75	8.00	17.25	SL
			76.00	6.75	17.25	SL
Sylhet Hill Forest						
06.	Satchari National Park Chunarughat, Habigonj	0–15	80.75	5.00	14.25	SL
			79.50	5.00	15.50	SL
			80.75	5.00	14.25	SL
		15–30	80.75	3.75	15.50	SL
			80.75	3.75	15.50	SL
			82.00	2.50	15.50	SL
		30–50	80.75	3.75	15.50	SL
			82.00	2.50	15.50	SL
			82.00	1.25	16.75	SL
		50–100	84.50	1.25	14.25	SL
			84.50	1.25	14.25	SL
			84.50	1.25	14.25	SL

Sl. No.	Location	Depth (cm)	Sand	Silt	Clay	Textural Class
			%			
07.	Lawachara National Park Srimongal, Moulovibazar	0–15	72.13	14.13	13.75	SL
			72.13	14.13	13.75	SL
			72.13	14.13	13.75	SL
		15–30	72.13	12.88	15.00	SL
			74.63	10.38	15.00	SL
			73.38	11.63	15.00	SL
		30–50	73.38	10.38	16.25	SL
			72.13	11.63	16.25	SL
			72.13	11.63	16.25	SL
		50–100	70.88	11.63	17.50	SL
			72.13	10.38	17.50	SL
			73.38	7.88	18.75	SL
08.	Tilagarh Eco Park, Sylhet	0–15	81.25	3.25	15.50	SL
			82.50	2.00	15.50	SL
			81.25	3.25	15.50	SL
		15–30	83.75	2.00	14.25	SL
			83.75	2.00	14.25	SL
			83.75	2.00	14.25	SL
		30–50	85.00	4.50	10.50	LS
			85.00	4.50	10.50	LS
			85.00	4.50	10.50	LS
		50–100	87.50	1.25	11.25	LS
			87.50	1.25	11.25	LS
			87.50	1.25	11.25	LS
Sundarban Mangrove Forest						
09.	Munshigonj Forest Beat Burigoalini Forest Range Shamnagar, Satkhira	0–15	35.25	40.00	24.75	Loam
			35.25	40.00	24.75	Loam
			34.00	41.25	24.75	Loam
		15–30	36.50	36.25	27.25	Loam
			37.75	35.00	27.25	Loam
			39.00	35.00	26.00	Loam
		30–50	37.75	33.75	28.50	Loam
			37.75	33.75	28.50	Loam
			37.75	33.75	28.50	Loam
		50–100	39.00	31.25	29.75	Loam
			39.00	31.25	29.75	Loam
			39.00	31.25	29.75	Loam

Sl. No.	Location	Depth (cm)	Sand	Silt	Clay	Textural Class
			%			
10.	Dhangmari Forest Beat Chandpai Forest Range Dakop, Khulna	0–15	41.00	41.25	17.75	Loam
			39.75	42.50	17.75	Loam
			39.75	42.50	17.75	Loam
		15–30	42.25	40.00	17.75	Loam
			41.00	41.25	17.75	Loam
			41.00	41.25	17.75	Loam
		30–50	37.25	43.75	19.00	Loam
			38.50	42.50	19.00	Loam
			37.25	43.75	19.00	Loam
		50–100	39.75	40.00	20.25	Loam
			39.75	41.25	19.00	Loam
			39.75	42.50	17.75	Loam
11.	Bogi Forest Beat Sharankhola Forest Range Sharankhola, Bagerhat	0–15	39.75	48.75	11.50	Loam
			39.75	48.75	11.50	Loam
			38.50	50.00	11.50	Loam
		15–30	37.25	46.25	16.50	Loam
			38.50	45.00	16.50	Loam
			37.25	46.25	16.50	Loam
		30–50	37.25	47.50	15.25	Loam
			37.25	47.50	15.25	Loam
			37.25	47.50	15.25	Loam
		50–100	39.75	42.50	17.75	Loam
			38.50	43.75	17.75	Loam
			37.25	45.00	17.75	Loam
Coastal Afforestation						
12.	Sonarchar, Rangabali Patuakhali	0–15	44.75	45.00	10.25	Loam
			43.50	45.00	11.50	Loam
			43.50	45.00	11.50	Loam
		15–30	43.50	43.75	12.75	Loam
			44.75	42.50	12.75	Loam
			44.75	42.50	12.75	Loam
		30–50	42.25	42.50	15.25	Loam
			42.25	42.50	15.25	Loam
			43.50	41.25	15.25	Loam
		50–100	44.75	40.00	15.25	Loam
			44.75	40.00	15.25	Loam
			44.75	40.00	15.25	Loam

Sl. No.	Location	Depth (cm)	Sand	Silt	Clay	Textural Class
			%			
13.	Kukri-Mukri, Charfashion Bhola	0–15	42.50	42.13	15.38	Loam
			42.50	42.13	15.38	Loam
			41.25	42.13	16.63	Loam
		15–30	40.00	40.88	19.13	Loam
			40.00	40.88	19.13	Loam
			38.75	42.13	19.13	Loam
		30–50	37.50	44.63	17.88	Loam
			37.50	44.63	17.88	Loam
			36.25	44.63	19.13	Loam
		50–100	37.50	47.13	15.38	Loam
			38.75	45.88	15.38	Loam
			40.00	44.63	15.38	Loam
14.	Nijhumdwip National Park Hatiya Noakhali	0–15	38.25	46.25	15.50	Loam
			38.25	47.50	14.25	Loam
			37.00	47.50	15.50	Loam
		15–30	35.75	47.50	16.75	Loam
			35.75	47.50	16.75	Loam
			35.75	47.50	16.75	Loam
		30–50	35.75	48.75	15.50	Loam
			38.25	46.25	15.50	Loam
			37.00	46.25	16.75	Loam
		50–100	35.75	47.50	16.75	Loam
			38.25	45.00	16.75	Loam
			35.75	47.50	16.75	Loam
15.	Dumkhali, Mirersarai Chittagong	0–15	39.50	36.75	23.75	Loam
			39.50	36.75	23.75	Loam
			39.50	36.75	23.75	Loam
		15–30	38.25	34.25	27.50	Loam
			38.25	34.25	27.50	Loam
			39.50	33.00	27.50	Loam
		30–50	37.00	34.25	28.75	Loam
			37.00	34.25	28.75	Loam
			37.00	34.25	28.75	Loam
		50–100	37.00	34.25	28.75	Loam
			37.00	34.25	28.75	Loam
			37.00	34.25	28.75	Loam

Sl. No.	Location	Depth (cm)	Sand	Silt	Clay	Textural Class
			%			
Sal Forest						
16.	Kotbari, Cumilla Sadar Cumilla	0–15	55.25	28.00	16.75	SL
			54.00	28.00	18.00	SL
			54.00	26.75	19.25	SL
		15–30	60.25	20.50	19.25	SL
			59.00	21.75	19.25	SL
			57.75	23.00	19.25	SL
		30–50	67.75	9.25	23.00	SCL
			66.50	10.50	23.00	SCL
			66.50	11.75	21.75	SCL
		50–100	55.25	29.25	15.50	SL
			54.00	29.25	16.75	SL
			55.25	29.25	15.50	SL
17.	Dokhola Forest Range Madhupur, Tangail	0–15	52.75	30.50	16.75	SL
			54.00	28.00	18.00	SL
			55.25	25.50	19.25	SL
		15–30	52.75	25.50	21.75	SCL
			52.75	24.25	23.00	SCL
			51.50	26.75	21.75	SCL
		30–50	52.75	25.50	21.75	SCL
			54.00	23.00	23.00	SCL
			52.75	23.00	24.25	SCL
		50–100	77.75	3.00	19.25	SL
			76.50	5.50	18.00	SL
			75.25	6.75	18.00	SL
18.	Bhawal National Park Salna, Gazipur	0–15	51.75	29.75	18.50	SL
			50.50	29.75	19.75	SL
			49.25	31.00	19.75	SL
		15–30	39.25	27.25	33.50	CL
			40.50	27.25	32.25	CL
			39.25	27.25	33.50	CL
		30–50	39.25	27.25	33.50	CL
			40.50	27.25	32.25	CL
			39.25	27.25	33.50	CL
		50–100	39.25	27.25	33.50	CL
			40.50	27.25	32.25	CL
			39.25	27.25	33.50	CL

A-3. Soil moisture content (%) at different locations of different forest areas under different soil depth

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
01.	Baraiyadha National Park Sitakunda, Chittagong	16.84	18.25	17.87	12.40	7.26	8.60	5.96	3.04
		16.94	17.63	20.03	10.76	6.97	10.07	5.68	3.74
		18.53	18.25	15.49	14.08	6.39	12.44	5.52	5.33
02.	Dulahazra Forest Beat, Fanshiakhali Forest Range Chokoria, Cox's Bazar	15.62	19.66	23.15	24.76	8.08	13.15	14.60	18.04
		16.09	20.98	23.77	24.80	9.69	12.79	15.70	19.06
		17.23	22.16	24.22	25.14	10.97	9.80	16.25	19.05
03.	Goneshpara, Thanchi, Bandarban Hill District	12.88	13.67	14.19	15.26	10.95	10.76	12.19	13.45
		13.38	13.02	14.50	13.70	11.14	13.32	12.82	13.54
		13.12	13.17	13.99	13.63	10.88	10.31	10.36	12.18
04.	Kaptai National Park, Rangamati Hill District	19.62	22.79	22.88	23.02	19.21	20.01	19.92	23.47
		20.93	24.00	22.12	22.52	20.68	20.54	20.35	25.56
		22.63	22.89	22.75	22.47	19.74	22.16	19.07	23.16
05.	Wasu, Matiranga, Khagrachari Hill District	16.89	19.20	18.94	17.94	15.22	17.87	19.41	19.79
		15.21	15.35	19.06	18.79	16.20	19.19	18.96	20.77
		16.91	18.51	16.13	18.13	18.15	19.14	19.64	18.39
06.	Satchari National Park Chunarughat, Habigonj	12.77	13.22	14.21	13.37	12.10	13.22	15.50	11.90
		12.10	11.74	12.86	13.01	12.94	13.37	15.75	11.82
		14.29	14.88	12.94	13.22	12.86	13.01	15.06	11.74
07.	Lawachara National Park Srimongal, Moulovibazar	19.39	19.61	18.11	21.45	17.58	16.23	15.66	12.64
		20.65	19.71	19.13	20.79	17.21	16.30	15.98	11.97
		18.64	18.02	18.66	20.33	17.35	16.12	15.37	12.34

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**
08.	Tilagarh Eco Park, Sylhet	7.75	6.67	4.86	3.97	5.41	5.42	4.41	3.27
		7.39	6.95	6.26	3.92	5.88	5.67	4.86	3.48
		8.05	6.52	5.11	3.75	5.92	5.36	4.52	3.83
09.	Munshigonj Forest Beat, Burigoalini Forest Range Shamnagar, Satkhira	39.06	41.47	39.68	41.18	15.75	17.01	18.43	19.98
		36.69	40.47	40.85	41.05	15.05	17.47	18.57	20.18
		37.57	39.01	41.41	43.92	15.43	17.18	18.69	20.57
10.	Dhangmari Forest Beat, Chandpai Forest Range Dakop, Khulna	42.56	43.22	45.04	43.77	21.77	23.22	24.56	26.48
		40.83	40.68	37.96	43.86	21.86	23.68	24.87	26.97
		39.48	40.87	43.27	47.44	21.56	23.33	24.27	27.22
11.	Bogi Forest Beat, Sharankhola Forest Range Sharankhola, Bagerhat	22.85	18.63	24.86	28.18	13.38	18.36	20.49	23.09
		22.38	19.61	24.67	24.46	13.61	18.67	20.98	23.27
		21.60	20.41	25.54	26.49	14.07	18.54	20.85	23.52
12.	Sonarchar, Rangabali, Patuakhali	28.63	28.21	31.70	31.61	26.28	24.26	26.89	27.48
		26.21	27.41	29.76	30.79	26.25	25.11	25.15	25.74
		26.41	29.36	30.36	31.88	26.03	26.02	25.53	28.48
13.	Kukri-Mukri, Charfashion, Bhola	31.50	32.25	32.10	34.74	25.85	29.21	28.77	33.13
		31.21	30.56	32.95	33.75	26.08	29.96	29.69	31.59
		31.61	30.74	34.56	34.77	26.24	28.91	30.42	33.15
14.	Nijhumdwip National Park, Hatiya, Noakhali	31.04	34.15	32.31	32.32	15.91	22.43	25.52	28.56
		31.43	33.93	33.45	35.06	17.96	22.11	25.97	28.38
		31.91	33.97	33.71	34.47	16.51	23.05	26.34	28.94
15.	Dumkhali, Mirersarai, Chittagong	34.18	29.52	31.20	31.52	27.73	29.93	30.95	32.95
		34.54	29.48	31.83	31.71	27.70	29.32	30.47	32.47
		34.01	30.30	30.48	32.28	27.33	30.09	31.09	33.09

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
16.	Kotbari, Cumilla Sadar, Cumilla	22.62	21.21	24.26	24.09	22.77	23.23	22.52	19.00
		22.58	21.93	25.05	25.51	23.74	24.48	25.04	18.70
		21.33	22.01	25.23	25.12	23.32	23.78	22.22	16.58
17.	Dokhola Forest Range, Madhupur, Tangail	21.24	24.96	27.51	24.37	16.18	18.36	17.26	19.80
		21.03	23.93	28.00	24.31	15.91	16.34	18.63	19.59
		21.65	25.43	27.42	24.95	16.38	17.28	17.12	19.69
18.	Bhawal National Park, Salna, Gazipur	19.92	22.37	24.29	24.93	16.29	18.44	19.44	21.29
		19.04	22.63	23.27	24.84	15.45	17.74	19.00	21.30
		19.14	20.96	23.42	24.96	17.15	17.47	19.28	21.01

A-4. Soil bulk density (g cm^{-3}) at different locations of different forest areas under different soil depth

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
01.	Baraiyadha National Park Sitakunda, Chittagong	1.34	1.35	1.38	1.38	1.41	1.55	1.58	1.63
		1.37	1.37	1.30	1.38	1.40	1.49	1.53	1.54
		1.27	1.33	1.42	1.39	1.36	1.52	1.57	1.52
02.	Dulahazra Forest Beat, Fanshiakhali Forest Range Chokoria, Cox's Bazar	1.42	1.47	1.60	1.63	1.53	1.62	1.51	1.59
		1.44	1.42	1.54	1.52	1.60	1.53	1.66	1.68
		1.37	1.49	1.52	1.63	1.53	1.58	1.68	1.62
03.	Goneshpara, Thanchi, Bandarban Hill District	1.36	1.34	1.49	1.47	1.53	1.58	1.62	1.61
		1.39	1.45	1.45	1.49	1.59	1.56	1.56	1.54
		1.27	1.46	1.44	1.44	1.54	1.53	1.55	1.58
04.	Kaptai National Park, Rangamati Hill District	1.44	1.48	1.51	1.56	1.54	1.53	1.54	1.53
		1.44	1.46	1.52	1.54	1.48	1.51	1.58	1.53
		1.46	1.50	1.53	1.56	1.48	1.49	1.63	1.55

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
05.	Wasu, Matiranga, Khagrachari Hill District	1.44	1.48	1.51	1.56	1.54	1.53	1.53	1.54
		1.44	1.46	1.52	1.54	1.48	1.51	1.53	1.58
		1.46	1.50	1.53	1.56	1.48	1.49	1.55	1.63
06.	Satchari National Park Chunarughat, Habigonj	1.54	1.64	1.64	1.66	1.68	1.71	1.73	1.77
		1.58	1.56	1.59	1.64	1.69	1.72	1.70	1.70
		1.68	1.73	1.71	1.70	1.66	1.69	1.72	1.74
07.	Lawachara National Park Srimongal, Moulovibazar	1.53	1.59	1.57	1.67	1.45	1.49	1.62	1.72
		1.53	1.56	1.72	1.73	1.50	1.48	1.58	1.67
		1.45	1.62	1.67	1.59	1.47	1.52	1.60	1.70
08.	Tilagarh Eco Park, Sylhet	1.54	1.60	1.57	1.63	1.53	1.68	1.67	1.70
		1.54	1.55	1.63	1.62	1.55	1.65	1.67	1.76
		1.53	1.68	1.67	1.70	1.59	1.63	1.65	1.72
09.	Munshigonj Forest Beat, Burigoalini Forest Range Shamnagar, Satkhira	1.20	1.20	1.26	1.29	1.20	1.25	1.27	1.32
		1.21	1.26	1.25	1.35	1.21	1.28	1.27	1.35
		1.22	1.32	1.27	1.28	1.23	1.30	1.29	1.36
10.	Dhangmari Forest Beat, Chandpai Forest Range Dakop, Khulna	1.19	1.24	1.25	1.27	1.17	1.24	1.26	1.31
		1.13	1.30	1.31	1.29	1.24	1.28	1.28	1.35
		1.17	1.26	1.24	1.31	1.22	1.26	1.34	1.38
11.	Bogi Forest Beat, Sharankhola Forest Range Sharankhola, Bagerhat	1.30	1.48	1.40	1.38	1.32	1.35	1.40	1.48
		1.46	1.39	1.43	1.44	1.36	1.40	1.37	1.43
		1.35	1.32	1.40	1.48	1.34	1.38	1.39	1.45
12.	Sonarchar, Rangabali, Patuakhali	1.37	1.34	1.38	1.37	1.36	1.38	1.35	1.40
		1.34	1.38	1.41	1.41	1.38	1.42	1.42	1.48
		1.41	1.38	1.37	1.43	1.41	1.41	1.44	1.45
13.	Kukri-Mukri, Charfashion, Bhola	1.17	1.25	1.37	1.36	1.36	1.38	1.41	1.44
		1.25	1.37	1.34	1.32	1.44	1.43	1.42	1.43
		1.23	1.34	1.35	1.40	1.38	1.40	1.44	1.42

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
14.	Nijhumdwip National Park, Hatiya, Noakhali	1.34	1.34	1.36	1.43	1.37	1.34	1.42	1.49
		1.34	1.36	1.33	1.43	1.36	1.39	1.44	1.47
		1.35	1.35	1.38	1.45	1.44	1.43	1.45	1.49
15.	Dumkhali, Mirersarai, Chittagong	1.32	1.35	1.43	1.48	1.41	1.43	1.35	1.56
		1.39	1.41	1.38	1.45	1.40	1.47	1.44	1.55
		1.36	1.38	1.45	1.43	1.40	1.43	1.54	1.43
16.	Kotbari, Cumilla Sadar, Cumilla	1.52	1.44	1.50	1.54	1.49	1.50	1.51	1.72
		1.48	1.47	1.56	1.57	1.55	1.57	1.64	1.53
		1.39	1.50	1.53	1.60	1.49	1.54	1.62	1.54
17.	Dokhola Forest Range, Madhupur, Tangail	1.41	1.44	1.42	1.51	1.38	1.43	1.49	1.55
		1.40	1.41	1.45	1.49	1.43	1.44	1.46	1.52
		1.37	1.44	1.45	1.46	1.42	1.45	1.47	1.42
18.	Bhawal National Park, Salna, Gazipur	1.43	1.49	1.49	1.49	1.41	1.48	1.52	1.56
		1.42	1.44	1.51	1.58	1.44	1.42	1.46	1.59
		1.43	1.44	1.48	1.58	1.41	1.47	1.46	1.56

A-5. Soil pH at different locations of different forest areas under different soil depth

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
01.	Baraiyadha National Park Sitakunda, Chittagong	5.51	5.52	5.69	5.65	5.31	5.46	5.48	5.65
		5.55	5.64	5.57	5.84	5.29	5.45	5.58	5.72
		5.44	5.62	5.57	5.77	5.27	5.44	5.52	5.75
02.	Dulahazra Forest Beat, Fanshiakhali Forest Range Chokoria, Cox’s Bazar	4.95	4.78	5.15	5.26	5.05	5.10	5.12	5.34
		4.99	4.77	5.20	5.22	5.06	5.13	5.15	5.32
		5.00	4.76	5.14	5.26	4.98	5.09	5.13	5.38

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**
03.	Goneshpara, Thanchi, Bandarban Hill District	5.17	5.12	5.33	5.31	5.02	5.09	5.06	5.07
		5.12	5.14	5.32	5.38	5.04	5.09	5.06	5.09
		5.19	5.16	5.30	5.37	5.00	5.12	5.07	5.09
04.	Kaptai National Park, Rangamati Hill District	5.50	5.61	5.85	6.25	6.24	6.36	7.17	6.22
		5.48	5.66	5.82	6.27	6.23	6.32	6.22	6.11
		5.46	5.59	5.81	6.25	6.28	6.38	6.13	6.20
05.	Wasu, Matiranga, Khagrachari Hill District	4.81	4.94	5.21	4.78	4.91	4.70	4.96	4.68
		4.79	4.88	5.28	4.88	4.86	4.71	4.99	4.74
		4.84	4.75	5.22	4.85	4.98	4.70	4.98	4.75
06.	Satchari National Park Chunarughat, Habigonj	4.68	5.57	4.78	4.87	5.07	5.11	4.83	4.79
		4.62	4.55	4.70	4.85	5.12	5.09	4.87	4.78
		4.59	4.51	4.75	4.78	5.16	5.04	4.81	4.71
07.	Lawachara National Park Srimongal, Moulovibazar	4.75	4.61	4.76	5.02	5.42	5.48	5.28	5.32
		4.79	4.62	4.78	5.02	5.43	5.45	5.26	5.34
		4.77	4.64	4.74	5.02	5.36	5.40	5.26	5.39
08.	Tilagarh Eco Park, Sylhet	4.70	4.72	4.94	5.24	4.60	4.67	4.47	4.57
		4.68	4.71	4.96	5.24	4.67	4.62	4.46	4.57
		4.67	4.75	4.95	5.23	4.68	4.62	4.46	4.59
09.	Munshigonj Forest Beat, Burigoalini Forest Range Shamnagar, Satkhira	8.16	8.03	8.09	7.98	7.86	7.88	7.81	7.86
		8.19	8.03	8.06	7.97	7.85	7.88	7.87	7.85
		8.18	8.02	8.06	7.98	7.85	7.88	7.85	7.82
10.	Dhangmari Forest Beat, Chandpai Forest Range Dakop, Khulna	7.96	7.99	8.04	7.99	7.89	7.93	7.98	7.98
		7.96	8.00	8.04	8.01	7.89	7.93	7.94	7.99
		7.98	8.02	8.09	7.99	7.91	7.91	7.97	7.99
11.	Bogi Forest Beat, Sharankhola Forest Range Sharankhola, Bagerhat	7.75	7.88	7.97	8.10	6.63	7.55	7.72	7.93
		7.75	7.89	7.95	8.14	6.64	7.54	7.77	7.90
		7.72	7.86	7.96	8.12	6.68	7.56	7.75	7.96

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**
12.	Sonarchar, Rangabali, Patuakhali	7.96	8.28	8.36	8.40	7.86	8.03	8.07	8.16
		7.80	8.30	8.28	8.35	7.75	7.82	7.89	7.96
		8.11	8.19	8.26	7.96	7.79	7.88	7.91	7.88
13.	Kukri-Mukri, Charfashion, Bhola	7.70	7.97	7.86	8.05	7.53	7.94	7.83	7.58
		7.81	8.04	7.85	8.29	7.47	8.03	7.91	7.79
		7.91	8.00	7.99	8.04	7.53	7.86	7.91	7.71
14.	Nijhumdwip National Park, Hatiya, Noakhali	7.95	8.06	8.13	8.17	7.88	8.03	8.06	8.13
		7.95	8.09	8.14	8.17	7.91	8.05	8.09	8.12
		7.97	8.08	8.16	8.16	7.95	8.04	8.08	8.16
15.	Dumkhali, Mirersarai, Chittagong	7.75	7.81	7.99	8.05	7.62	7.76	7.91	8.00
		7.72	7.84	7.94	8.05	7.60	7.81	7.93	8.00
		7.78	7.85	7.99	8.08	7.68	7.84	7.92	7.99
16.	Kotbari, Cumilla Sadar, Cumilla	4.28	4.42	4.53	4.65	4.51	4.59	4.72	4.71
		4.26	4.41	4.56	4.63	4.50	4.63	4.67	4.77
		4.23	4.42	4.61	4.64	4.48	4.60	4.69	4.82
17.	Dokhola Forest Range, Madhupur, Tangail	4.90	4.95	5.17	5.40	5.36	5.42	5.65	5.73
		4.90	4.96	5.09	5.38	5.43	5.50	5.58	5.70
		4.81	4.92	5.14	5.30	5.35	5.40	5.51	5.70
18.	Bhawal National Park, Salna, Gazipur	4.70	4.75	4.88	5.36	4.74	4.99	5.31	5.53
		4.70	4.71	4.92	5.45	4.76	5.00	5.32	5.46
		4.65	4.65	4.91	5.38	4.75	4.96	5.32	5.49

A-6. Soil organic carbon (%) at different locations of different forest areas under different soil depth

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
01.	Baraiyadha National Park Sitakunda, Chittagong	1.08	0.79	0.43	0.14	0.69	0.74	0.56	0.11
		1.08	0.65	0.36	0.43	0.70	0.61	0.47	0.34
		1.01	0.65	0.36	0.22	0.63	0.62	0.51	0.15
02.	Dulahazra Forest Beat, Fanshiakhali Forest Range Chokoria, Cox's Bazar	0.79	0.36	0.29	0.43	0.31	0.18	0.14	0.20
		0.87	0.58	0.36	0.36	0.33	0.27	0.17	0.15
		0.87	0.36	0.43	0.29	0.33	0.17	0.20	0.12
03.	Goneshpara, Thanchi, Bandarban Hill District	1.12	1.16	1.05	1.05	1.13	1.06	0.79	0.76
		1.34	1.23	1.19	1.08	1.34	1.11	0.91	0.75
		1.30	1.16	1.26	1.12	1.30	1.06	0.94	0.81
04.	Kaptai National Park, Rangamati Hill District	0.87	0.47	0.51	0.40	0.82	0.51	0.59	0.30
		0.94	0.61	0.40	0.43	0.89	0.67	0.47	0.35
		0.87	0.43	0.36	0.40	0.82	0.47	0.43	0.32
05.	Wasu, Matiranga, Khagrachari Hill District	1.27	0.89	0.73	0.69	0.94	0.89	0.67	0.52
		1.27	0.88	0.74	0.69	0.96	0.88	0.68	0.50
		1.25	0.92	0.74	0.72	0.93	0.87	0.70	0.56
06.	Satchari National Park Chunarughat, Habigonj	0.59	0.56	0.37	0.37	0.44	0.48	0.29	0.36
		0.59	0.52	0.45	0.45	0.43	0.43	0.37	0.46
		0.67	0.45	0.41	0.33	0.50	0.38	0.35	0.29

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
07.	Lawachara National Park Srimongal, Moulovibazar	0.85	0.74	0.45	0.30	0.63	0.60	0.45	0.38
		0.89	0.78	0.56	0.37	0.66	0.64	0.59	0.46
		0.85	0.71	0.56	0.37	0.62	0.56	0.58	0.43
08.	Tilagarh Eco Park, Sylhet	0.40	0.25	0.14	0.06	1.10	0.64	0.62	0.46
		0.29	0.21	0.14	0.06	0.80	0.59	0.59	0.45
		0.36	0.17	0.10	0.10	0.98	0.49	0.45	0.78
09.	Munshigonj Forest Beat, Burigoalini Forest Range Shamnagar, Satkhira	0.77	0.77	0.69	0.69	0.58	0.31	0.26	0.21
		0.77	0.69	0.73	0.73	0.57	0.27	0.28	0.23
		0.81	0.77	0.69	0.66	0.60	0.29	0.27	0.20
10.	Dhangmari Forest Beat, Chandpai Forest Range Dakop, Khulna	0.78	0.71	0.63	0.63	0.53	0.44	0.44	0.27
		0.71	0.74	0.67	0.71	0.46	0.47	0.46	0.30
		0.78	0.71	0.67	0.63	0.51	0.44	0.48	0.28
11.	Bogi Forest Beat, Sharankhola Forest Range Sharankhola, Bagerhat	1.09	1.17	0.79	0.94	0.83	0.58	0.33	0.40
		1.17	1.17	0.94	0.87	0.88	0.56	0.41	0.38
		1.24	1.02	0.87	0.72	0.94	0.50	0.36	0.30
12.	Sonarchar, Rangabali, Patuakhali	1.10	0.89	0.54	0.61	0.46	0.67	0.37	0.51
		1.10	0.75	0.61	0.47	0.71	0.54	0.55	0.50
		1.17	0.68	0.75	0.61	0.69	0.49	0.61	0.55
13.	Kukri-Mukri, Charfashion, Bhola	0.93	0.37	0.33	0.26	0.61	0.41	0.35	0.29
		0.85	0.45	0.41	0.22	0.54	0.52	0.43	0.26
		1.00	0.37	0.26	0.22	0.70	0.29	0.30	0.26

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**
14.	Nijhumdwip National Park, Hatiya, Noakhali	0.61	0.58	0.40	0.32	0.42	0.41	0.33	0.26
		0.51	0.54	0.40	0.32	0.36	0.38	0.33	0.26
		0.65	0.47	0.43	0.36	0.45	0.34	0.35	0.27
15.	Dumkhali, Mirersarai, Chittagong	0.72	0.61	0.54	0.43	0.72	0.54	0.48	0.39
		0.72	0.61	0.58	0.47	0.74	0.53	0.50	0.41
		0.76	0.61	0.58	0.43	0.75	0.51	0.52	0.39
16.	Kotbari, Cumilla Sadar, Cumilla	0.59	0.33	0.33	0.26	0.71	0.41	0.38	0.36
		0.59	0.41	0.26	0.37	0.72	0.50	0.29	0.51
		0.67	0.33	0.37	0.30	0.81	0.40	0.41	0.42
17.	Dokhola Forest Range, Madhupur, Tangail	0.73	0.65	0.51	0.45	0.66	0.58	0.46	0.39
		0.74	0.65	0.36	0.42	0.65	0.60	0.31	0.38
		0.75	0.58	0.51	0.43	0.64	0.47	0.46	0.33
18.	Bhawal National Park, Salna, Gazipur	0.65	0.36	0.22	0.25	0.78	0.42	0.20	0.23
		0.43	0.43	0.36	0.29	0.51	0.52	0.34	0.25
		0.58	0.40	0.29	0.22	0.66	0.48	0.25	0.19

A-7. Total nitrogen (%) in both forest and homestead site at different locations of different forest areas under different soil depth

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
01.	Baraiyadha National Park Sitakunda, Chittagong	0.17	0.11	0.11	0.19	0.11	0.11	0.11	0.11
		0.19	0.06	0.15	0.17	0.08	0.08	0.08	0.08
		0.19	0.24	0.06	0.19	0.09	0.09	0.09	0.09
02.	Dulahazra Forest Beat, Fanshiakhali Forest Range Chokoria, Cox's Bazar	0.15	0.24	0.19	0.24	0.09	0.06	0.02	0.06
		0.19	0.28	0.15	0.19	0.08	0.09	0.09	0.09
		0.15	0.19	0.19	0.19	0.09	0.06	0.09	0.06
03.	Goneshpara, Thanchi, Bandarban Hill District	0.15	0.24	0.19	0.24	0.24	0.19	0.15	0.09
		0.19	0.28	0.15	0.19	0.27	0.22	0.14	0.13
		0.15	0.19	0.19	0.19	0.21	0.23	0.12	0.09
04.	Kaptai National Park, Rangamati Hill District	0.15	0.11	0.09	0.08	0.13	0.11	0.09	0.08
		0.15	0.11	0.11	0.06	0.15	0.11	0.11	0.06
		0.11	0.11	0.09	0.06	0.12	0.11	0.09	0.06
05.	Wasu, Matiranga, Khagrachari Hill District	0.19	0.19	0.15	0.15	0.17	0.17	0.17	0.13
		0.19	0.24	0.19	0.11	0.17	0.17	0.13	0.11
		0.19	0.24	0.19	0.06	0.20	0.15	0.15	0.09
06.	Satchari National Park Chunarughat, Habigonj	0.17	0.13	0.17	0.09	0.08	0.09	0.09	0.09
		0.13	0.20	0.24	0.09	0.11	0.09	0.06	0.06
		0.13	0.13	0.17	0.06	0.09	0.09	0.09	0.06

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
07.	Lawachara National Park Srimongal, Moulovibazar	0.20	0.09	0.06	0.17	0.15	0.12	0.09	0.06
		0.39	0.09	0.09	0.20	0.15	0.10	0.09	0.09
		0.24	0.09	0.06	0.17	0.11	0.13	0.09	0.06
08.	Tilagarh Eco Park, Sylhet	0.24	0.13	0.09	0.02	0.24	0.19	0.24	0.11
		0.31	0.24	0.13	0.09	0.32	0.28	0.19	0.15
		0.13	0.24	0.09	0.20	0.28	0.24	0.19	0.24
09.	Munshigonj Forest Beat, Burigoalini Forest Range Shamnagar, Satkhira	0.09	0.06	0.02	0.06	0.13	0.09	0.09	0.09
		0.06	0.09	0.09	0.09	0.06	0.09	0.06	0.06
		0.09	0.06	0.09	0.06	0.09	0.06	0.09	0.06
10.	Dhangmari Forest Beat, Chandpai Forest Range Dakop, Khulna	0.09	0.09	0.09	0.13	0.09	0.09	0.06	0.09
		0.06	0.09	0.06	0.06	0.06	0.09	0.09	0.09
		0.06	0.06	0.09	0.09	0.09	0.09	0.09	0.09
11.	Bogi Forest Beat, Sharankhola Forest Range Sharankhola, Bagerhat	0.08	0.09	0.09	0.09	0.06	0.11	0.06	0.11
		0.11	0.09	0.06	0.06	0.11	0.11	0.11	0.06
		0.09	0.09	0.09	0.06	0.11	0.11	0.11	0.11
12.	Sonarchar, Rangabali, Patuakhali	0.10	0.09	0.09	0.09	0.11	0.10	0.09	0.09
		0.13	0.17	0.09	0.13	0.09	0.08	0.09	0.09
		0.09	0.09	0.06	0.06	0.09	0.08	0.06	0.06
13.	Kukri-Mukri, Charfashion, Bhola	0.13	0.09	0.06	0.09	0.11	0.09	0.09	0.06
		0.13	0.09	0.09	0.09	0.10	0.09	0.09	0.09
		0.09	0.09	0.09	0.09	0.11	0.09	0.09	0.09

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**
14.	Nijhumdwip National Park, Hatiya, Noakhali	0.17	0.17	0.17	0.17	0.09	0.09	0.09	0.06
		0.13	0.17	0.17	0.20	0.09	0.09	0.06	0.09
		0.17	0.20	0.20	0.13	0.09	0.06	0.09	0.06
15.	Dumkhali, Mirersarai, Chittagong	0.17	0.17	0.17	0.13	0.17	0.13	0.17	0.09
		0.17	0.17	0.20	0.17	0.19	0.20	0.13	0.09
		0.20	0.17	0.17	0.17	0.17	0.13	0.13	0.06
16.	Kotbari, Cumilla Sadar, Cumilla	0.09	0.06	0.09	0.09	0.17	0.17	0.17	0.13
		0.09	0.09	0.09	0.06	0.17	0.17	0.20	0.17
		0.09	0.06	0.06	0.09	0.20	0.17	0.17	0.17
17.	Dokhola Forest Range, Madhupur, Tangail	0.06	0.11	0.06	0.11	0.12	0.10	0.08	0.09
		0.11	0.11	0.11	0.06	0.12	0.08	0.06	0.07
		0.11	0.11	0.11	0.11	0.09	0.11	0.10	0.05
18.	Bhawal National Park, Salna, Gazipur	0.09	0.09	0.06	0.09	0.13	0.11	0.11	0.08
		0.06	0.09	0.09	0.09	0.12	0.11	0.09	0.07
		0.09	0.09	0.09	0.09	0.10	0.08	0.08	0.06

A-8. Carbon and nitrogen ratio (C/N) in both forest and homestead site at different locations of different forest areas under different soil depth

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
01.	Baraiyadha National Park Sitakunda, Chittagong	6.37	7.37	4.02	0.74	4.13	4.37	5.16	1.02
		5.58	10.05	2.39	2.55	3.45	4.04	3.14	4.20
		5.21	2.74	5.58	1.12	4.88	4.79	3.93	1.67
02.	Dulahazra Forest Beat, Fanshiakhali Forest Range Chokoria, Cox's Bazar	5.26	1.52	1.49	1.83	3.34	3.21	7.70	3.56
		4.47	2.06	2.39	1.86	4.16	2.94	1.87	1.59
		5.74	1.86	2.23	1.49	3.52	3.08	2.16	2.21
03.	Goneshpara, Thanchi, Bandarban Hill District	5.89	4.81	9.52	4.36	4.69	5.57	5.28	8.17
		4.77	3.84	7.94	5.70	4.96	5.07	6.48	5.77
		5.42	4.13	5.27	5.89	6.19	4.62	7.80	8.75
04.	Kaptai National Park, Rangamati Hill District	5.74	4.35	5.62	4.97	6.29	4.77	6.60	3.78
		6.22	5.69	3.68	6.70	5.95	6.22	4.37	5.35
		8.04	4.02	4.01	6.14	6.86	4.32	4.79	4.90
05.	Wasu, Matiranga, Khagrachari Hill District	6.52	4.58	4.82	4.55	5.64	5.33	4.00	4.01
		6.52	3.72	3.82	6.36	5.76	5.29	5.25	4.64
		6.42	3.86	3.82	11.17	4.58	5.79	4.67	6.18
06.	Satchari National Park Chunarughat, Habigonj	3.54	4.32	2.22	4.00	5.48	5.21	3.10	3.85
		4.55	2.55	1.87	4.86	3.90	4.61	6.61	8.29
		5.17	3.47	2.46	5.94	5.43	4.07	3.73	5.26

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
07.	Lawachara National Park Srimongal, Moulovibazar	4.19	8.02	8.02	1.78	4.16	4.98	4.85	6.91
		2.29	8.42	6.01	1.82	4.39	6.39	6.33	5.01
		3.55	7.62	10.02	2.23	5.72	4.29	6.24	7.79
08.	Tilagarh Eco Park, Sylhet	1.65	1.92	1.48	3.41	4.59	3.39	2.58	4.19
		0.91	0.88	1.06	0.68	2.51	2.12	3.09	3.03
		2.78	0.72	1.08	0.49	3.51	2.06	2.35	3.25
09.	Munshigonj Forest Beat, Burigoalini Forest Range Shamnagar, Satkhira	8.30	13.83	37.49	12.50	4.44	3.35	2.78	2.22
		13.83	7.50	7.90	7.90	10.20	2.90	5.06	4.12
		8.70	13.83	7.50	11.83	6.43	5.23	2.89	3.58
10.	Dhangmari Forest Beat, Chandpai Forest Range Dakop, Khulna	8.42	7.62	6.82	4.87	5.71	4.73	7.89	2.91
		12.70	8.02	12.03	12.70	8.30	5.07	4.99	3.23
		14.03	12.70	7.22	6.82	5.48	4.73	5.15	3.01
11.	Bogi Forest Beat, Sharankhola Forest Range Sharankhola, Bagerhat	13.65	12.59	8.58	10.18	12.89	5.36	5.03	3.67
		10.60	12.59	16.97	15.64	8.18	5.21	3.82	5.82
		13.39	10.99	9.38	12.96	8.75	4.67	3.33	2.80
12.	Sonarchar, Rangabali, Patuakhali	10.99	9.60	5.82	6.58	4.22	6.70	4.04	5.51
		8.48	4.49	6.58	3.62	7.93	6.81	5.90	5.54
		12.62	7.33	13.48	10.96	7.42	6.13	10.95	9.86
13.	Kukri-Mukri, Charfashion, Bhola	7.16	4.01	6.01	2.81	5.56	4.41	3.79	5.27
		6.59	4.81	4.41	2.41	5.40	5.57	4.63	2.76
		10.83	4.01	2.81	2.41	6.41	3.08	3.21	2.80

Sl. No.	Location	Forested Site				Homestead Site			
		0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**
14.	Nijhumdwip National Park, Hatiya, Noakhali	3.68	3.47	2.38	1.95	4.53	4.45	3.56	4.69
		3.90	3.25	2.38	1.60	3.89	4.07	5.85	2.84
		3.90	2.30	2.13	2.79	4.86	6.17	3.78	4.88
15.	Dumkhali, Mirersarai, Chittagong	4.33	3.68	3.25	3.34	4.33	4.14	2.88	4.21
		4.33	3.68	2.84	2.82	3.87	2.59	3.88	4.45
		3.72	3.68	3.47	2.60	4.49	3.95	4.04	6.94
16.	Kotbari, Cumilla Sadar, Cumilla	6.37	5.94	3.56	2.81	4.26	2.48	2.25	2.80
		6.37	4.43	2.81	6.66	4.34	3.01	1.42	3.08
		7.23	5.94	6.66	3.24	3.98	2.42	2.45	2.50
17.	Dokhola Forest Range, Madhupur, Tangail	11.36	6.05	7.88	4.17	5.50	5.82	5.71	4.36
		6.88	6.03	3.34	6.49	5.38	7.50	5.18	5.46
		7.00	5.38	4.73	3.99	7.10	4.26	4.58	6.53
18.	Bhawal National Park, Salna, Gazipur	7.02	3.90	3.90	2.73	6.01	3.81	1.82	2.92
		7.80	4.68	3.90	3.12	4.22	4.77	3.80	3.53
		6.24	4.29	3.12	2.34	6.60	5.97	3.07	3.17

A-9. Electrical conductivity (dS m^{-1}) in forest and homestead area at different locations of Sundarban Mangrove Forest and Coastal Afforestation area under different soil depth

Sl. No.	Location	Forested Area				Homestead Area			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
01.	Munshigonj Forest Beat,	11.45	11.55	11.30	14.20	4.15	7.95	3.50	2.65
	Burigoalini Forest Range	11.35	11.75	11.25	14.10	3.90	6.35	3.55	2.60
	Shamnagar, Satkhira	11.15	11.85	11.10	14.25	3.90	6.10	3.60	2.60
02.	Dhangmari Forest Beat, Chandpai	8.60	7.50	6.70	7.25	9.90	7.85	6.50	5.60
	Forest Range Dakop, Khulna	8.35	7.25	6.75	7.20	9.90	7.65	6.75	5.65
		8.00	7.40	6.55	7.20	9.70	6.90	6.80	5.75
03.	Bogi Forest Beat, Sharankhola	2.70	3.30	2.85	2.95	2.40	1.70	1.75	1.75
	Forest Range Sharankhola, Bagerhat	2.75	3.25	2.90	2.90	2.60	1.75	1.75	1.75
		2.75	3.10	2.95	2.95	2.40	1.70	1.85	1.75
04.	Sonarchar, Rangabali, Patuakhali	11.35	9.30	9.10	10.00	7.95	9.30	9.30	8.60
		11.20	9.20	9.10	9.95	7.95	9.20	9.50	8.70
		11.35	9.20	9.15	10.00	7.90	9.25	9.45	8.70
05.	Kukri-Mukri, Charfashion, Bhola	12.30	8.45	9.20	8.40	10.05	7.75	8.45	8.60
		12.45	8.70	9.10	8.40	10.10	7.60	8.45	8.70
		12.50	8.60	9.20	8.45	10.20	7.80	8.30	8.85
06.	Nijhumdwip National Park, Hatiya,	12.20	9.90	9.30	8.65	9.15	7.45	7.35	7.65
	Noakhali	12.35	9.90	9.30	8.60	9.05	7.50	7.40	7.50
		12.30	9.90	9.35	8.60	9.00	7.50	7.35	7.65
07.	Dumkhali, Mirersarai, Chittagong	8.60	6.10	5.70	5.90	10.00	6.60	6.65	6.70
		8.60	6.25	5.60	5.90	9.65	6.60	6.60	6.60
		8.75	6.65	6.10	5.90	9.55	6.80	6.75	6.80

A-10. Soil organic carbon stocks (t ha^{-1}) in forest and homestead area at different locations of different forest areas under different soil depth

Sl. No.	Location	Forested Area				Homestead Area			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
01.	Baraiyadha National Park Sitakunda, Chittagong	21.77	16.09	11.96	9.97	14.57	17.25	17.58	8.93
		22.26	13.36	9.39	29.90	14.76	13.55	14.41	25.89
		19.26	12.97	10.26	15.06	12.89	14.20	16.04	11.42
02.	Dulahazra Forest Beat, Fanshiakhali Forest Range Chokoria, Cox's Bazar	16.92	7.96	9.24	35.32	7.09	4.34	4.31	15.74
		18.72	12.31	11.12	27.44	7.99	6.25	5.75	12.37
		17.81	8.07	13.17	23.54	7.48	4.06	6.73	9.96
03.	Goneshpara, Thanchi, Bandarban Hill District	22.84	23.23	31.21	76.97	26.75	24.27	25.67	60.92
		27.86	26.70	34.56	80.71	31.36	26.58	28.32	57.59
		24.76	25.31	36.40	80.60	29.84	24.53	29.03	63.98
04.	Kaptai National Park, Rangamati Hill District	18.72	10.42	15.27	30.98	18.89	11.79	18.30	23.13
		20.28	13.44	12.08	33.37	19.82	15.18	14.87	26.46
		18.98	9.75	11.05	30.98	18.27	10.40	14.05	24.57
05.	Wasu, Matiranga, Khagrachari Hill District	27.33	19.74	21.98	53.52	21.70	20.40	20.42	40.15
		27.33	19.32	22.53	52.83	21.31	19.98	20.83	39.55
		27.27	20.61	22.68	56.33	20.71	19.42	21.73	45.32
06.	Satchari National Park Chunarughat, Habigonj	13.63	13.78	12.14	30.71	11.04	12.38	9.93	31.54
		13.98	12.17	14.31	36.90	10.86	11.01	12.48	39.13
		16.88	11.68	14.02	28.05	12.51	9.55	11.88	25.41

Sl. No.	Location	Forested Area				Homestead Area			
		0–15 cm	**15–30 cm**	**30–50 cm**	**50–100 cm**	**0–15 cm**	**15–30 cm**	**30–50 cm**	**50–100 cm**
07.	Lawachara National Park Srimongal, Moulovibazar	19.60	17.71	13.99	24.80	13.67	13.37	14.55	33.02
		20.45	18.25	19.16	32.12	14.90	14.19	18.54	38.77
		18.57	17.14	18.60	29.52	13.60	12.73	18.51	36.81
08.	Tilagarh Eco Park, Sylhet	9.18	5.97	4.31	5.14	25.29	16.22	20.64	39.15
		6.60	4.92	4.48	5.11	18.66	14.66	19.58	40.02
		8.27	4.40	3.35	8.52	23.47	12.08	14.73	67.09
09.	Munshigonj Forest Beat, Burigoalini Forest Range Shamnagar, Satkhira	13.83	13.83	17.50	44.78	10.37	5.81	6.53	13.57
		13.95	13.12	18.29	49.37	10.29	5.16	7.15	15.47
		14.74	15.22	17.64	42.06	10.99	5.66	6.89	13.52
10.	Dhangmari Forest Beat, Chandpai Forest Range Dakop, Khulna	13.92	13.12	15.78	40.08	9.27	8.15	11.05	17.63
		11.96	14.48	17.51	45.50	8.58	9.01	11.83	20.20
		13.68	13.33	16.57	41.34	9.29	8.29	12.78	19.26
11.	Bogi Forest Beat, Sharankhola Forest Range Sharankhola, Bagerhat	21.29	25.88	22.25	65.07	16.51	11.69	9.11	29.31
		25.53	24.31	26.97	62.56	18.00	11.79	11.28	26.93
		25.11	20.14	24.33	53.30	18.95	10.43	9.97	21.85
12.	Sonarchar, Rangabali, Patuakhali	22.58	17.87	14.88	41.72	9.48	13.87	10.11	35.73
		22.09	15.50	17.17	33.06	14.77	11.60	15.53	36.91
		24.72	14.06	20.52	43.54	14.53	10.37	17.52	39.73

Sl. No.	Location	Forested Area				Homestead Area			
		0–15 cm	15–30 cm	30–50 cm	50–100 cm	0–15 cm	15–30 cm	30–50 cm	50–100 cm
13.	Kukri-Mukri, Charfashion, Bhola	16.29	6.96	9.16	17.67	12.47	8.46	9.90	21.09
		16.01	9.16	10.95	14.70	11.67	11.06	12.19	18.28
		18.50	7.46	7.02	15.59	14.59	5.99	8.57	18.42
14.	Nijhumdwip National Park, Hatiya, Noakhali	12.34	11.61	10.80	23.24	8.63	8.27	9.37	19.41
		10.16	11.05	10.57	23.24	7.35	7.85	9.36	19.33
		13.16	9.51	11.96	26.18	9.73	7.35	10.15	20.19
15.	Dumkhali, Mirersarai, Chittagong	14.30	12.43	15.49	32.07	15.27	11.52	12.94	30.38
		15.06	12.98	15.95	34.03	15.45	11.65	14.48	31.91
		15.47	12.71	16.76	30.98	15.71	10.98	16.12	27.57
16.	Kotbari, Cumilla Sadar, Cumilla	13.45	7.13	9.90	20.02	15.88	9.30	11.33	31.22
		13.10	9.04	8.11	29.05	16.84	11.81	9.51	39.24
		13.97	7.43	11.32	24.00	18.14	9.33	13.21	32.12
17.	Dokhola Forest Range, Madhupur, Tangail	15.53	14.10	14.48	33.98	13.65	12.49	13.61	30.44
		15.57	13.75	10.44	31.29	13.85	12.97	9.07	29.04
		15.51	12.53	14.79	31.39	13.61	10.20	13.45	23.18
18.	Bhawal National Park, Salna, Gazipur	13.94	8.07	6.46	18.83	16.53	9.30	6.08	18.24
		9.23	9.36	10.91	22.82	10.94	11.17	9.98	19.62
		12.39	8.58	8.55	17.12	13.95	10.54	7.17	14.84

A-11. Pearson correlation matrix of different soil properties in different forest areas under the study

Soil parameter	Sand (%)	Silt (%)	Clay (%)	MC (%)	BD (g cm^{-3})	pH	Total-N (%)	C/N Ratio	EC (dS m^{-1})	SOC (%)	SOC stock (t ha^{-1})
Chittagong hill forest											
Sand (%)	-								-		
Silt (%)	-0.941***	-							-		
Clay (%)	-0.930***	0.750***	-						-		
MC (%)	-0.612**	0.390**	0.771***	-					-		
BD ((g cm^{-3})	-0.037ns	-0.212ns	0.303*	-0.564***	-				-		
pH	-0.656***	0.594***	0.636***	0.206ns	-0.039ns	-			-		
Total-N (%)	0.449***	-0.344**	-0.503***	-0.299*	-0.129ns	-0.559***	-		-		
C/N Ratio	0.199ns	-0.176ns	-0.197ns	-0.212ns	-0.123ns	0.053ns	-0.500***	-	-		
SOC (%)	0.601***	-0.406**	-0.731***	-0.604***	-0.380**	-0.399**	0.319*	0.5188**	-	-	
SOC stocks (t ha^{-1})	0.583***	-0.614***	-0.471***	-0.320*	0.212ns	-0.104ns	0.075ns	0.329*	-	0.398**	-
Sylhet Hill Forest											
Sand (%)	-								-		
Silt (%)	-0.936***	-							-		
Clay (%)	-0.609***	0.290ns	-						-		
MC (%)	-0.9098**	0.796***	0.674***	-					-		
BD ((g cm^{-3})	0.185ns	-0.258ns	0.077ns	-0.005ns	-				-		
pH	0.247ns	-0.167ns	-0.294ns	-0.253ns	0.246ns	-			-		
Total-N (%)	-0.140ns	0.096ns	0.164ns	0.055ns	-0.378*	-0.161ns	-		-		
C/N Ratio	-0.523**	0.498**	0.299ns	0.589***	0.034ns	-0.302ns	-0.538**	-	-		
SOC (%)	-0.724***	0.699***	0.393*	0.767***	-0.363*	-0.448**	0.199ns	0.602***	-	-	

Soil parameter	Sand (%)	Silt (%)	Clay (%)	MC (%)	BD (g cm^{-3})	pH	Total-N (%)	C/N Ratio	EC (dS m^{-1})	SOC (%)	SOC stock (t ha^{-1})
SOC stocks (t ha^{-1})	-0.496**	0.364*	0.525**	0.734***	0.191ns	-0.028ns	-0.073ns	0.402*	-	0.449**	-
Sal Forest											
Sand (%)	-								-		
Silt (%)	-0.815***	-							-		
Clay (%)	-0.708***	0.169ns	-						-		
MC (%)	0.145ns	-0.317ns	0.139ns	-					-		
BD ((g cm^{-3})	0.032ns	-0.167ns	0.150ns	0.414*	-				-		
pH	-0.029ns	-0.246ns	0.349*	0.491**	0.091ns	-			-		
Total-N (%)	0.003ns	-0.051ns	0.058ns	0.169ns	-0.181ns	0.231ns	-		-		
C/N Ratio	0.179ns	0.189ns	-0.535**	-0.413*	-0.587***	-0.252ns	-0.372*	-	-		
SOC (%)	0.135ns	0.201ns	-0.474**	-0.362*	-0.731***	-0.157ns	0.311ns	0.749***	-	-	
SOC stocks (t ha^{-1})	0.467**	-0.373*	-0.340*	0.306ns	0.303ns	0.531**	0.135ns	-0.030ns	-	0.022ns	-
Sundarban Mangrove Forest											
Sand (%)	-										
Silt (%)	-0.021ns	-									
Clay (%)	-0.294ns	-0.950***	-								
MC (%)	0.195ns	-0.687***	0.596***	-							
BD (g cm^{-3})	-0.025ns	0.434**	-0.407*	-0.736***	-						
pH	-0.405*	-0.448**	0.555***	0.483**	-0.308ns	-					
Total-N (%)	0.069ns	0.275ns	-0.284ns	-0.120ns	0.138ns	-0.295ns	-				
C/N Ratio	-0.086ns	-0.076ns	0.100ns	-0.183ns	0.071ns	0.026ns	-0.781***	-			

Soil parameter	Sand (%)	Silt (%)	Clay (%)	MC (%)	BD (g cm^{-3})	pH	Total-N (%)	C/N Ratio	EC (dS m^{-1})	SOC (%)	SOC stock (t ha^{-1})
EC (dS m^{-1})	-0.121ns	-0.920***	0.918***	0.759***	-0.630***	0.443**	-0.255ns	0.015ns	-		
SOC (%)	-0.056ns	0.627***	-0.582***	-0.874***	0.536**	-0.668***	0.234ns	0.129ns	-0.627***	-	
SOC stocks (t ha^{-1})	0.153ns	-0.036ns	-0.013ns	-0.184ns	0.549**	0.070ns	0.001ns	-0.009ns	-0.193ns	0.037ns	-
Coastal Afforestation											
Sand (%)	-										
Silt (%)	-0.072ns	-									
Clay (%)	-0.491***	-0.834***	-								
MC (%)	-0.602***	0.192ns	0.165ns	-							
BD ((g cm^{-3})	-0.188ns	-0.268ns	0.338*	-0.024ns	-						
pH	0.209ns	0.301*	-0.378**	-0.066ns	0.352*	-					
Total-N (%)	-0.511***	-0.201ns	0.458**	0.223ns	0.168ns	-0.209ns	-				
C/N Ratio	0.746***	0.027ns	-0.437**	-0.591***	-0.212ns	0.009ns	-0.606***	-			
EC (dS m^{-1})	0.385**	0.680***	-0.808***	-0.114ns	-0.578***	-0.036ns	-0.269ns	0.449**	-		
SOC (%)	0.613***	-0.121ns	-0.234ns	-0.658***	-0.297*	-0.263ns	-0.046ns	0.752***	0.443**	-	
SOC stocks (t ha^{-1})	0.372**	-0.262ns	0.022ns	-0.143ns	0.454**	0.297*	-0.137ns	0.288*	-0.081ns	0.154ns	-

Values in Table are Pearson correlation coefficient (r) values. * = p<0.05, ** = p<0.01, *** = p<0.001 and ns = not significant

A-12. Changes of soil organic carbon (SOC) concentration during 2019 and 2022 at different locations under different soil depth

Sl. No.	Location	Soil organic carbon (SOC) concentration								Percentage of changes of soil organic carbon (SOC)			
		2019				2022							
		0−15	15−30	30−50	50−100	0−15	15−30	30−50	50−100	0−15	15−30	30−50	50−100
01.	Baraiyadha National Park Sitakunda, Chittagong	1.08	0.79	0.43	0.14	1.12	0.83	0.42	0.15	3.45	0.83	-2.33	4.98
		1.08	0.65	0.36	0.43	1.13	0.69	0.40	0.45	4.91	0.69	11.11	4.65
		1.01	0.65	0.36	0.22	1.04	0.66	0.37	0.23	2.97	0.66	2.78	3.01
02.	Dulahazra Forest Beat, Fanshiakhali Forest Range Chokoria, Cox's Bazar	0.79	0.36	0.29	0.43	0.78	0.38	0.32	0.39	-1.27	0.38	10.34	-9.60
		0.87	0.58	0.36	0.36	0.89	0.53	0.40	0.37	2.30	0.53	11.11	2.78
		0.87	0.36	0.43	0.29	0.90	0.39	0.40	0.33	3.45	0.39	-6.98	13.79
03.	Goneshpara, Thanchi, Bandarban Hill District	1.12	1.16	1.05	1.05	1.15	1.21	1.08	1.07	2.68	1.21	2.86	1.90
		1.34	1.23	1.19	1.08	1.40	1.27	1.22	1.10	4.48	1.27	2.52	1.85
		1.30	1.16	1.26	1.12	1.40	1.23	1.42	1.16	7.69	1.23	12.60	3.57
04.	Kaptai National Park, Rangamati Hill District	0.87	0.47	0.51	0.4	0.90	0.49	0.53	0.39	3.86	0.49	3.92	-1.93
		0.94	0.61	0.40	0.43	0.98	0.64	0.43	0.44	4.21	0.64	7.50	2.18
		0.87	0.43	0.36	0.4	0.92	0.45	0.38	0.39	5.57	0.45	5.56	-2.60
05.	Wasu, Matiranga, Khagrachari Hill District	1.27	0.89	0.73	0.69	1.32	0.92	0.75	0.67	3.94	0.92	2.74	-2.90
		1.27	0.88	0.74	0.69	1.30	0.95	0.76	0.65	2.36	0.95	2.70	-5.80
		1.25	0.92	0.74	0.72	1.29	0.93	0.77	0.70	3.20	0.93	4.05	-2.78
06.	Satchari National Park Chunarughat, Habigonj	0.59	0.56	0.37	0.37	0.62	0.57	0.37	0.39	5.19	2.21	-0.84	4.61
		0.59	0.52	0.45	0.45	0.60	0.54	0.48	0.50	1.20	3.85	6.65	11.77
		0.67	0.45	0.41	0.33	0.71	0.46	0.43	0.32	5.96	2.60	4.25	-1.77

Sl. No.	Location	Soil organic carbon (SOC) concentration								Percentage of changes of soil organic carbon (SOC)			
		2019				2022							
		0−15	**15−30**	**30−50**	**50−100**	**0−15**	**15−30**	**30−50**	**50−100**	**0−15**	**15−30**	**30−50**	**50−100**
07.	Lawachara National Park Srimongal, Moulovibazar	0.85	0.74	0.45	0.30	0.87	0.77	0.48	0.32	2.35	4.05	6.67	6.67
		0.89	0.78	0.56	0.37	0.91	0.81	0.60	0.36	2.78	3.85	7.14	-2.70
		0.85	0.71	0.56	0.37	0.86	0.72	0.58	0.39	0.88	1.61	3.57	4.94
08.	Tilagarh Eco Park, Sylhet	0.40	0.25	0.14	0.06	0.42	0.24	0.13	0.07	5.00	-4.14	-9.65	16.67
		0.29	0.21	0.14	0.06	0.32	0.23	0.15	0.06	10.34	8.82	7.14	0.00
		0.36	0.17	0.10	0.10	0.35	0.18	0.12	0.09	-2.78	5.88	20.00	-10.00
09.	Munshigonj Forest Beat, Burigoalini Forest Range Shamnagar, Satkhira	0.77	0.77	0.69	0.69	0.80	0.79	0.71	0.72	3.90	2.60	2.90	4.35
		0.77	0.69	0.73	0.73	0.82	0.72	0.77	0.85	7.12	4.35	5.48	16.02
		0.81	0.77	0.69	0.66	0.85	0.80	0.72	0.58	4.94	3.90	4.35	-12.12
10.	Dhangmari Forest Beat, Chandpai Forest Range Dakop, Khulna	0.78	0.71	0.63	0.63	0.80	0.74	0.64	0.63	2.22	4.03	2.12	-0.22
		0.71	0.74	0.67	0.71	0.75	0.78	0.72	0.66	5.37	5.41	7.23	-7.12
		0.78	0.71	0.67	0.63	0.75	0.71	0.64	0.67	-3.29	0.60	-3.98	5.61
11.	Bogi Forest Beat, Sharankhola Forest Range Sharankhola, Bagerhat	1.09	1.17	0.79	0.94	1.18	1.23	0.74	1.02	8.26	5.13	-6.33	8.34
		1.17	1.17	0.94	0.87	1.25	1.22	1.04	0.93	6.84	4.27	11.10	6.90
		1.24	1.02	0.87	0.72	1.34	1.09	0.95	0.70	8.06	6.86	8.97	-2.78
12.	Sonarchar, Rangabali, Patuakhali	1.10	0.89	0.54	0.61	1.17	0.94	0.55	0.63	6.36	5.06	1.85	3.28
		1.10	0.75	0.61	0.47	1.14	0.78	0.63	0.52	3.67	4.47	3.28	10.64
		1.17	0.68	0.75	0.61	1.21	0.70	0.79	0.60	3.42	3.34	5.33	-1.64

Sl. No.	Location	Soil organic carbon (SOC) concentration								Percentage of changes of soil organic carbon (SOC)			
		2019				2022							
		0−15	15−30	30−50	50−100	0−15	15−30	30−50	50−100	0−15	15−30	30−50	50−100
13.	Kukri-Mukri, Charfashion, Bhola	0.93	0.37	0.33	0.26	0.99	0.40	0.34	0.27	6.88	9.08	2.74	5.21
		0.85	0.45	0.41	0.22	0.88	0.46	0.42	0.24	3.53	2.55	2.75	7.36
		1.00	0.37	0.26	0.22	1.03	0.40	0.26	0.22	3.00	8.88	0.32	-1.34
14.	Nijhumdwip National Park, Hatiya, Noakhali	0.61	0.58	0.40	0.32	0.65	0.62	0.43	0.34	6.56	6.90	7.50	6.70
		0.51	0.54	0.40	0.32	0.56	0.57	0.45	0.33	9.80	5.56	12.50	3.45
		0.65	0.47	0.43	0.36	0.69	0.49	0.40	0.35	6.15	4.26	-6.98	-3.31
15.	Dumkhali, Mirersarai, Chittagong	0.72	0.61	0.54	0.43	0.70	0.64	0.61	0.46	-2.78	4.92	12.96	6.98
		0.72	0.61	0.58	0.47	0.75	0.66	0.56	0.45	4.17	8.20	-3.45	-4.26
		0.76	0.61	0.58	0.43	0.82	0.65	0.62	0.47	7.89	6.56	6.90	9.30
16.	Kotbari, Cumilla Sadar, Cumilla	0.59	0.33	0.33	0.26	0.62	0.34	0.34	0.28	4.36	3.51	3.03	7.69
		0.59	0.41	0.26	0.37	0.60	0.42	0.28	0.35	1.69	2.07	7.69	-5.41
		0.67	0.33	0.37	0.30	0.69	0.34	0.35	0.32	3.29	4.24	-6.28	6.67
17.	Dokhola Forest Range, Madhupur, Tangail	0.73	0.65	0.51	0.45	0.75	0.69	0.53	0.47	2.74	5.65	3.92	4.44
		0.74	0.65	0.36	0.42	0.77	0.70	0.34	0.43	4.05	7.93	-5.56	2.38
		0.75	0.58	0.51	0.43	0.73	0.52	0.54	0.42	-2.93	-9.71	5.88	-1.78
18.	Bhawal National Park, Salna, Gazipur	0.65	0.36	0.22	0.25	0.65	0.35	0.21	0.26	0.18	-2.78	-4.55	4.00
		0.43	0.43	0.36	0.29	0.44	0.44	0.37	0.28	1.40	2.33	2.78	-3.45
		0.58	0.40	0.29	0.22	0.58	0.42	0.30	0.22	-0.27	5.00	3.45	0.00

A-13: Wood density (WD) of different collected trees and saplings species under the study areas (* = oven dry basis)

Sl. No.	Local Name	Scientific Name	WD* (g cm^{-3})	References
01.	Aam	*Mangifera indica*	0.54	Sattar et al., 1999
02.	Achargola	*Grewia* spp.	0.50	Chave et al., 2005
03.	Agar	*Aquilaria malaccensis*	0.32	Zanne et al., 2009
04.	Akashmoni	*Acacia auriculiformis*	0.70	Sattar et al., 1999
05.	Amloki	*Phyllanthus emblica*	0.68	Zanne et al., 2009
06.	Arjun	*Terminalia arjuna*	0.52	Hossain et al., 2019
07.	Awal	*Vitex pubescens*	0.54	Zanne et al., 2009
08.	Babla	*Acacia nilotica*	0.73	Sattar et al., 1999
09.	Baen	*Avicennia officinalis*	0.58	Sattar et al., 1999
10.	Bajna	*Zanthoxylum rhetsa*	0.44	Zanne et al., 2009
11.	Bandarhola	*Duabanga grandiflora*	0.46	Sattar et al., 1999
12.	Bankau	*Garcinia cowa*	0.56	Sattar et al., 1999
13.	Banshpata	*Podocarpus nerrifolius*	0.52	Sattar et al., 1999
14.	Batna	*Castanopsis tribuloides*	0.93	Sattar et al., 1999
15.	Barela	*Holigarna caustica*	0.43	Sattar et al., 1999
16.	Belpoi	*Elaeocarpus robustus*	0.52	Zanne et al., 2009
17.	Bhadi	*Lanea coromandilica*	0.65	Sattar et al., 1999
18.	Bohera	*Termanalia bellerica*	0.78	Sattar et al., 1999
19.	Bonshimul	*Bombax insigne*	0.36	Sattar et al., 1999
20.	Chakua koroi	*Albizia chinensis*	0.45	Sattar et al., 1999
21.	Chalta	*Dillenia indica*	0.58	Sattar et al., 1999
22.	Champa	*Michelia champaca*	0.59	Sattar et al., 1999
23.	Chapalish	*Artocarpus chama*	0.49	Sattar et al., 1999
24.	Chatian	*Alstonia scholaris*	0.44	Zanne et al., 2009
25.	Chikrashi	*Chukrassia velutina*	0.58	Sattar et al., 1999
26.	Civit	*Swintonia floribunda*	0.61	Sattar et al., 1999
27.	Dakroom	*Fernandoa adenophylla*	0.68	Sattar et al., 1999
28.	Dhakijam	*Syzygium grande*	0.79	Sattar et al., 1999
29.	Dharmara	*Stereospermum personatum*	0.72	Sattar et al., 1999
30.	Dumur	*Ficus hispida*	0.34	Sattar et al., 1999
31.	Eucalyptus	*Eucalyptus camaldulensis*	0.68	Sattar et al., 1999

Sl. No.	Local Name	Scientific Name	WD* (g cm^{-3})	References
32.	Gab	*Diospyros peregrina*	0.63	Sattar et al., 1999
33.	Gamar	*Gmelia arborea*	0.44	Sattar et al., 1999
34.	Garjan	*Dipterocarpus turbinatus*	0.78	Sattar et al., 1999
35.	Gewa	*Excoecaria agallocha*	0.48	Sattar et al., 1999
36.	Ghoraneem	*Melia azadarach*	0.46	Sattar et al., 1999
37.	Goda	*Vitex peduncularis*	0.94	Sattar et al., 1999
38.	Goran	*Ceriops decandra*	0.77	Zanne et al., 2009
39.	Gutguttya	*Protium serratum*	0.88	Sattar et al., 1999
40.	Hargaza	*Dillenia pentagyna*	0.64	Sattar et al., 1999
41.	Hybrid acacia	*A. auriculiformis* x *A. mangium*	0.58	Rokeya et al., 2010
42.	Itchri	*Anogeissus acuminata*	0.92	Sattar et al., 1999
43.	Jalpai	*Elaeocarpus floribundas*	0.62	Sattar et al., 1999
44.	Jarul	*Lagerstroemia speciosa*	0.61	Sattar et al., 1999
45.	Jharugach	*Dichapetalum gelonioides*	0.76	Zanne et al., 2009
46.	Kadam	*Neolamarckia cadamba*	0.47	Sattar et al., 1999
47.	Kalojam	*Syzygium cumini*	0.67	Sattar et al., 1999
48.	Kanaidingga	*Oroxylum indicum*	0.48	Zanne et al., 2009
49.	Kanak	*Schima wallichii*	0.72	Sattar et al., 1999
50.	Kankra	*Bruguiera gymnorrhiza*	0.81	Sattar et al., 1999
51.	Kanthal	*Artocarpus heterophyllus*	0.49	Sattar et al., 1999
52.	Karanja	*Pongamia pinnata*	0.62	Sattar et al. 1999
53.	Katbadam	*Terminalia catappa*	0.52	Zanne et al., 2009
54.	Keora	*Sonneratia apetala*	0.56	Sattar et al., 1999
55.	Khalshi	*Aegiceras corniculatum*	0.51	Zanne et al., 2009
56.	Khudijam	*Syzygium balsameum*	0.69	Zanne et al., 2009
57.	Kurchi	*Holarrhena antidysenterica*	0.64	Zanne et al., 2009
58.	Lichu	*Litchi chinensis*	0.88	Zanne et al., 2009
59.	Lohakat	*Xylia xylocarpa*	0.68	Zanne et al., 2009
60.	Lotkon	*Baccaurea ramiflora*	0.64	Zanne et al., 2009
61.	Mahogany	*Swietenia macrophylla*	0.55	Rokeya et al., 2014
62.	Mandar	*Erythrina orientalis*	0.24	Sattar et al., 1999
63.	Mangium	*Acacia mangium*	0.56	Sattar et al., 1999
64.	Melastoma	*Melastoma malabathricum*	0.44	Zanne et al., 2009

Sl. No.	Local Name	Scientific Name	WD* (g cm^{-3})	References
65.	Minjiri	*Senna siamea*	0.75	Sattar et al., 1999
66.	Nageashwar	*Mesua ferrea*	1.03	Sattar et al., 1999
67.	Narikel	*Cocos nucifera*	0.50	Zanne et al., 2009
68.	Narikeli	*Pterygota alata*	0.66	Sattar et al., 1999
69.	Pannya Dumur	*Ficus glomerata*	0.38	Sattar et al., 1999
70.	Parul	*Stereospermum chelonoides*	0.72	Sattar et al., 1999
71.	Passur	*Xylocarpus mekongensis*	0.73	Sattar et al., 1999
72.	Peyara	*Psidium guajava*	0.80	Zanne et al. 2009
73.	Pine	*Pinus caribaea*	0.48	Sattar et al., 1999
74.	Pitali	*Trewia nudiflora*	0.44	Sattar et al., 1999
75.	Pitraj	*Aphananmixis polystachya*	0.54	Sattar et al., 1999
76.	Putijam	*Syzygium fruticosum*	0.71	Sattar et al., 1999
77.	Raintree	*Samanea saman*	0.59	Sattar et al., 1999
78.	Rajkoroi	*Albizia richardiana*	0.75	Rahman et al., 2013
79.	Raktan	*Lophopetalum fimbriatum*	0.42	Sattar et al., 1999
80.	Rong	*Morinda angustifolia*	0.72	Zanne et al., 2009
81.	Royna/Rata	*Aphananmixis polystachya*	0.62	Sattar et al., 1999
82.	Rubber	*Havea brasiliensis*	0.56	Sattar et al., 1999
83.	Sal	*Shorea robusta*	0.82	Sattar et al., 1999
84.	Segun	*Tectona grandis*	0.61	Sattar et al., 1999
85.	Silkoroi	*Albizzia procera*	0.73	Sattar et al., 1999
86.	Sindur	*Mallotus philippensis*	0.65	Zanne et al., 2009
87.	Singra	*Cynometra ramiflora*	0.75	Zanne et al., 2009
88.	Sissoo	*Dalbergia sissoo*	0.74	Sattar et al., 1999
89.	Sundari	*Heritiera fomes*	1.01	Sattar et al., 1999
90.	Supari	*Areca catechu*	0.50	Zanne et al., 2009
91.	Telsur	*Hopea odorata*	0.64	Sattar et al., 1999
92.	Tentul	*Terminalia indica*	0.79	Sattar et al., 1999
93.	Toon	*Toona ciliata*	0.48	Sattar et al., 1999
94.	Tetuyakoroi	*Albizia odoratissima*	0.67	Zanne et al., 2009
95.	Udal	*Sterculia villosa*	0.33	Sattar et al., 1999
96.	Uriam	*Mangifera sylvatica*	0.54	Sattar et al., 1999
97.	Zigni/Nalita	*Trema orientalis*	0.34	Zanne et al., 2009

A-14. Total biomass of collected different trees and saplings under the study areas

Sl. No.	Species	Scientific Name	DBH (cm)	Height (m)	AGB		BGB		Total Biomass	
					(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})
Trees										
01.	Aam	*Mangifera indica*	9.78 (8-14)	5.25 (5-6)	32.43 (21-59)	1.30 (0.85-2.36)	7.43 (5-11)	0.30 (0.21-0.51)	39.85 (26-72)	1.59 (1.05-2.87)
02.	Achergola	*Grewia nervosa*	6.56 (5-11)	6.09 (3-13)	19.24 (7-73)	0.77 (0.26-2.93)	4.64 (2-15)	0.19 (0.07-0.62)	23.88 (8-89)	0.96 (0.34-3.55)
03.	Agar	*Aquilaria malaccensis*	9.04 (6-11)	9.60 (6-13)	32.64 (11-53)	1.31 (0.46-2.12)	7.42 (3-12)	0.30 (0.12-0.46)	40.06 (14-65)	1.60 (0.58-2.59)
04.	Akashmoni	*Acacia auriculiformis*	10.97 (5-24)	10.96 (6-19)	55.88 (6-271)	2.24 (0.24-10.86)	11.50 (2-49)	0.46 (0.07-1.96)	67.38 (8-321)	2.70 (0.31-12.82)
05.	Amloki	*Phyllanthus emblica*	5.73	3.00	10.63	0.43	2.80	0.11	13.43	0.54
06.	Arjun	*Terminalia arjuna*	17.45 (14-22)	9.43 (7-14)	127.27 (70-233)	5.09 (2.79-9.32)	24.90 (15-43)	1.00 (0.59-1.71)	152.16 (85-276)	6.09 (3.39-11.03)
07.	Awal	*Vitex pubescens*	48.21 (38-57)	22.00 (18-25)	1334.97 (746-1883)	53.40 (29.83-75.32)	199.40 (120-272)	7.98 (4.79-10.86)	1534.36 (865-2155)	61.37 (34.62-86.18)
08.	Baen	*Avicennia officinalis*	14.60 (5-58)	9.63 (3-30)	152.87 (6-2036)	6.11 (0.22-81.42)	26.15 (2-291)	1.05 (0.06-11.64)	179.02 (7-2326)	7.16 (0.28-93.06)
09.	Bankau	*Garcinia cowa*	7.24 (5-11)	5.75 (3-9)	23.83 (8-55)	0.95 (0.31-2.20)	5.58 (2-12)	0.22 (0.08-0.48)	29.41 (10-67)	1.18 (0.39-2.68)
10.	Batna	*Castanopsis tribuloides*	10.08 (8-12)	9.83 (7-12)	89.46 (46-138)	3.58 (1.86-5.53)	18.19 (10-27)	0.73 (0.41-1.08)	107.64 (57-165)	4.31 (2.27-6.62)
11.	Bohera	*Termanalia bellerica*	5.09	4.50	11.93	0.48	3.10	0.12	15.03	0.60
12.	Boloch	*Sapium baccatum*	18.56 (15-23)	10.33 (8-12)	171.88 (95-251)	6.88 (3.80-10.02)	32.52 (19-46)	1.30 (0.78-1.83)	204.40 (114-296)	8.18 (4.58-11.85)

Sl. No.	Species	Scientific Name	DBH (cm)	Height (m)	AGB		BGB		Total Biomass	
					(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})
13.	Chakua koroi	*Albizia chinensis*	15.27	12.00	106.67	4.27	21.49	0.86	128.16	5.13
14.	Chapalish	*Artocarpus chama*	56.86 (11-92)	25.93 (8-45)	2185.93 (77-5776)	87.44 (3.06-231.04)	299.96 (16-731)	12.00 (0.64-29.24)	2485.90 (93-6507)	99.44 (3.70-260.28)
15.	Chikrashi	*Chukrassia velutina*	35.52 (28-49)	19.50 (16-25)	813.39 (471-1580)	32.54 (18.86-63.22)	127.54 (80-233)	5.10 (3.20-9.31)	940.93 (551-1813)	37.64 (22.05-72.53)
16.	Civit	*Swintonia floribunda*	30.12 (24-39)	15.67 (13-19)	529.32 (293-907)	21.17 (11.74-36.28)	87.84 (53-142)	3.51 (2.10-5.70)	617.16 (346-1049)	24.69 (13.83-41.98)
17.	Dhakijam	*Syzygium grande*	31.20 (6-62)	20.56 (2-38)	1175.74 (8-4094)	47.03 (0.32-163.78)	170.74 (2-539)	6.83 (0.09-21.58)	1346.38 (10-4634)	53.86 (0.41-185.35)
18.	Dharmara	*Stereospermum personatum*	37.65 (24-62)	25.67 (12-50)	1857.53 (328-4782)	74.30 (13.13-191.29)	251.76 (58-619)	10.07 (2.32-24.75)	2109.29 (386-5401)	84.37 (15.45-216.04)
19.	Dumur	*Ficus hispida*	33.19 (5-111)	18.84 (7-42)	734.09 (14-5832)	29.36 (0.55-233.26)	108.42 (4-737)	4.34 (0.14-29.49)	842.51 (17-6569)	33.70 (0.69-262.75)
20.	Eucalyptus	*Eucalyptus camaldulensis*	19.99 (16-24)	22.17 (15-27)	396.08 (184-617)	15.84 (7.38-24.67)	67.90 (35-101)	2.72 (1.39-4.05)	463.98 (219-718)	18.56 (8.77-28.72)
21.	Gamar	*Gmelia arborea*	21.85 (17-31)	15.00 (12-20)	236.84 (127-449)	9.47 (5.09-17.96)	42.65 (25-77)	1.71 (1.00-3.06)	279.50 (152-525)	11.18 (6.09-21.02)
22.	Garjan	*Dipterocarpus turbinatus*	19.58 (5-92)	15.69 (4-45)	798.32 (14-8905)	31.93 (0.55-356.19)	111.15 (4-1072)	4.45 (0.14-42.87)	909.47 (17-9976)	36.38 (0.70-399.06)
23.	Gewa	*Excoecaria agallocha*	9.05 (5-24)	8.92 (3-18)	20.44 (5-153)	0.82 (0.20-6.13)	4.69 (0.58-30)	0.19 (0.02-1.18)	25.13 (6-183)	1.01 (0.22-7.31)
24.	Goran	*Ceriops decandra*	6.76 (5-9)	6.50 (4-8)	15.53 (7-30)	0.62 (0.28-1.20)	3.89 (2-70	0.16 (0.08-0.28)	19.42 (9-37)	0.78 (0.36-1.47)
25.	Hental	*Phoenix paludosa*	5.80 (5-7)	5.76 (3-8)	8.82 (6-15)	0.35 (0.23-0.59)	2.37 (2-4)	0.09 (0.06-0.15)	11.19 (7.34-18.53)	0.45 (0.29-0.74)
26.	Hybrid acacia	*A. auriculimormis* x *A. mangium*	22.63 (16-33)	17.38 (13.27)	362.51 (164-896)	14.50 (6.56-35.83)	62.29 (31-141)	2.74 (1.26-8.95)	424.28 (57-165)	17.24 (7.82-99.60)

Sl. No.	Species	Scientific Name	DBH (cm)	Height (m)	AGB (kg tree^{-1})	AGB (t ha^{-1})	BGB (kg tree^{-1})	BGB (t ha^{-1})	Total Biomass (kg tree^{-1})	Total Biomass (t ha^{-1})
27.	Jalpai	*Elaeocarpus floribundas*	10.08 (9-11)	7.00 (6-8)	45.92 (38-54)	1.84 (1.51-2.16)	10.19 (9-12)	0.41 (0.34-0.47)	56.11 (46-66)	2.24 (1.85-2.64)
28.	Jarul	*Lagerstroemia speciosa*	23.03 (6-113)	16.96 (4-60)	515.09 (11-12719)	20.60 (0.46-508.75)	78.35 (3-1469)	3.13 (0.12-58.74)	593.45 (14-14187)	23.74 (0.58-567.50)
29.	Jharugach	*Dichapetalum gelonioides*	18.38 (8-27)	9.75 (5-13)	185.18 (25-360)	7.41 (1.00-14.40)	34.09 (6-63)	1.36 (0.24-2.52)	219.27 (31-423)	8.77 (1.23-16.92)
30.	Kadam	*Neolamarckia cadamba*	38.95 (36-40)	28.60 (20-38)	1015.41 (756-1321)	40.62 (30.22-52.84)	156.96 (121-199)	6.28 (4.85-7.94)	1172.37 (877-1519)	46.89 (35.07-60.78)
31.	Kalojam	*Syzygium cumini*	22.44 (10-38)	20.69 (9-30)	487.25 (53-1304)	19.49 (2.18-52.16)	80.49 (12-196)	3.22 (0.48-7.85)	567.74 (66-1500)	22.71 (2.66-60.01)
32.	Kanaidinga	*Oroxylum indicum*	8.91	9.00	26.82	1.07	6.34	0.25	33.16	1.33
33.	Kanak	*Schima wallichii*	25.14 (17-35)	13.11 (11-16)	374.79 (219-548)	14.99 (8.78-21.93)	64.92 (41-91)	2.60 (1.63-3.65)	439.71 (260-639)	17.59 (10.40-25.58)
34.	Kankra	*Bruguiera gymnorrhiza*	17.14 (7-23)	13.42 (6-17)	167.61 (31-298)	6.70 (1.26-11.93)	31.65 (7-53)	1.27 (0.29-2.13)	199.25 (39-352)	7.97 (1.55-14.06)
35.	Kanthal	*Artocarpus heterophyllus*	14.89 (6-25)	8.50 (6-11)	86.79 (19-181)	3.47 (0.74-7.22)	17.63 (5-34)	0.71 (0.18-1.37)	104.43 (23-215)	4.18 (0.92-8.59)
36.	Katbadam	*Terminalia catappa*	7.00 (6-9)	6.00 (5-7)	20.25 (14-32)	0.81 (0.56-1.30)	4.91 (4-8)	0.20 (0.14-0.30)	25.15 (18-40)	1.01 (0.70-1.60)
37.	Keora	*Sonneratia apetala*	21.92 (5-59)	17.06 (5-35)	245.41 (9-1485)	9.82 (0.36-59.40)	42.75 (2-220)	1.71 (0.10-8.81)	288.17 (12-1705)	11.53 (0.46-68.21)
38.	Khalshi	*Aegiceras corniculatum*	6.43 (5-10)	6.04 (4-9)	10.67 (5-33)	0.43 (0.20-1.34)	2.77 (1-8)	0.11 (0.06-0.31)	13.44 (7-41)	0.54 (0.26-1.64)
39.	Khudijam	*Syzygium balsameum*	34.68 (28-52)	21.80 (16-36)	1050.68 (498-2624)	42.03 (19.92-104.96)	158.29 (84-364)	6.33 (3.35-14.56)	1208.97 (582-2988)	48.36 (23.27-119.53)
40.	Lichu	*Litchi chinensis*	9.23	5.20	41.60	1.66	9.33	0.37	50.92	2.04

Sl. No.	Species	Scientific Name	DBH (cm)	Height (m)	AGB		BGB		Total Biomass	
					(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})
			(8-11)	(5-6)	(31-57)	(1.26-2.27)	(7-12)	(0.29-0.49)	(39-69)	(1.55-2.76)
41.	Lohakat	*Xylia xylocarpa*	71.27 (62-80)	45.67 (35-65)	5889.57 (5272-6504)	235.58 (210.89-260.17)	743.52 (674-812)	29.74 (26.98-32.48)	6633 (5947-7316)	265.32 (237.87-292.65)
42.	Lotkon	*Baccaurea ramiflora*	5.09	5.00	11.36	0.45	2.97	0.12	14.33	0.57
43.	Mahogany	*Swietenia macrophylla*	13.28 (5-61)	8.89 (5-28)	196.71 (10-2327)	7.87 (0.42-93.06)	31.38 (3-327)	1.26 (0.11-13.10)	228.08 (13-2654)	9.12 (0.53-106.16)
44.	Mandar	*Erythrina orientalis*	18.88 (16-21)	10.33 (8-12)	78.75 (71-88)	3.15 (2.83-3.52)	16.43 (15-18)	0.66 (0.260-0.73)	95.17 (85-106)	3.81 (3.43-4.25)
45.	Mangium	*Acacia mangium*	20.47 (11-28)	16.00 (15-17)	184.39 (33-327)	7.38 (1.30-13.06)	33.91 (8-58)	1.36 (0.30-2.31)	218.30 (40-384)	8.73 (1.60-15.37)
46.	Minjiri	*Senna siamea*	15.75 (15-16)	12.50 (12-13)	175.52 (161-190)	7.02 (6.45-7.59)	33.35 (31-36)	1.33 (1.24-1.43)	208.88 (192-226)	8.36 (7.69-9.02)
47.	Passur	*Xylocarpus mekongensis*	12.36 (5-45)	8.64 (4-15)	82.46 (6-1091)	3.30 (0.26-43.63)	16.03 (2-168)	0.64 (0.07-6.71)	98.49 (8-1258)	3.94 (0.33-50.34)
48.	Peyara	*Psidium guajava*	7.64 (6-9)	6.50 (6-7)	32.17 (22-41)	1.29 (0.88-1.63)	7.43 (5-9)	0.30 (0.21-0.37)	39.60 (27-50)	1.58 (1.10-1.99)
49.	Pine	*Pinus caribaea*	52.44 (39-69)	46.80 (45-48)	2558.30 (1540-3962)	102.33 (61.60-158.49)	353.29 (227-524)	14.13 (9.09-20.96)	2911.58 (1767-4486)	116.46 (70.69-179.45)
50.	Putijam	*Syzygium fruticosum*	9.70 (9-11)	7.50 (7-8)	51.46 (39-64)	2.06 (1.57-2.54)	11.25 (9-14)	0.45 (0.36-0.54)	62.72 (48-72)	2.51 (1.93-3.09)
51.	Raintree	*Samanea saman*	43.99 (27-59)	26.75 (22-32)	1510.73 (536-2583)	60.43 (21.45-103.31)	220.66 (80-359)	8.83 (3.58-14.36)	1731.39 (626-2942)	69.26 (25.03-117.67)
52.	Raktan	*Lophopetalum fimbriatum*	8.72 (5-14)	7.23 (3-12)	30.14 (6-84)	1.21 (0.22-3.38)	6.89 (2-17)	0.28 (0.06-0.70)	37.04 (7-102)	1.48 (0.29-4.08)
53.	Rubber	*Havea brasiliensis*	19.52 (16-22)	12.00 (11-13)	193.02 (127-244)	7.72 (5.07-9.77)	36.16 (25-41)	1.45 (1.00-1.70)	229.18 (152-289)	9.17 (6.07-11.56)

Sl. No.	Species	Scientific Name	DBH (cm)	Height (m)	AGB		BGB		Total Biomass	
					(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})
54.	Sal	*Shorea robusta*	22.55 (8-48)	15.19 (5-31)	247.25 (5-1652)	9.89 (0.19-66.09)	43.61 (2-242)	1.74 (0.05-9.68)	290.86 (6-1894)	11.63 (0.24-75.77)
55.	Segun	*Tectona grandis*	23.16 (5-90)	18.14 (2-55)	629.71 (9-7640)	25.19 (0.34-305.60)	94.47 (2-936)	3.78 (0.09-37.44)	224.18 (11-8576)	28.97 (0.43-343.04)
56.	Silkoroi	*Albizzia procera*	31.50	30.00	1068.22	42.73	164.57	6.58	1232.79	49.31
57.	Singra	*Cynometra ramiflora*	8.2	6.5	22.20	0.89	5.37	0.21	27.57	1.10
58.	Sundari	*Heritiera fomes*	11.07 (5-51)	10.64 (3-28)	87.80 (7-2205)	3.51 (0.30-88.20)	16.41 (2-312)	0.66 (0.08-12.49)	104.22 (9-2517)	4.17 (0.38-100.69)
59.	Telsur	*Hopea odorata*	17.71 (14-24)	18.67 (14-24)	283.23 (134-512)	11.33 (5.38-20.46)	50.09 (26-86)	2.00 (1.05-3.43)	333.32 (161-597)	13.33 (6.43-23.90)
60.	Zigni	*Trema orientalis*	7.32	8.00	17.29	0.69	4.30	0.17	21.59	0.86
Saplings										
61.	Amur	*Amoora cuculata*	2.57 (1.27-3.82)	2.45 (1.30-4)	1.26 (0.19-3.07)	0.13 (0.02-0.31)	0.41 (0.08-0.93)	0.04 (0.01-0.09)	1.67 (0.27-4.01)	0.17 (0.03-0.40)
62.	Bhadi	*Lanea coromandilica*	4.30 (4.14-4.45)	5.50 (5.50-6)	9.82 (9.23-10.41)	0.98 (0.92-1.04)	2.61 (2.47-2.75)	0.26 (0.25-0.27)	12.43 (11.70-13.16)	1.24 (0.17-1.32)
63.	Goran	*Ceriops decandra*	1.50 (1.27-2.23)	1.96 (1.80-2.40)	0.42 (0.27-0.99)	0.04 (0.03-0.10)	0.16 (0.11-0.34)	0.02 (0.01-0.03)	0.58 (0.37-1.34)	0.06 (0.04-0.13)
64.	Kurchi	*Holarrhena antidysenterica*	3.82 (3.50-4.14)	3.25 (3-3.50)	5.06 (4.10-6.08)	0.51 (0.41-0.61)	1.45 (1.21-1.71)	0.15 (0.12-0.17)	6.51 (5.30-7.79)	0.65 (0.53-0.78)
65.	Rong	*Morinda angustifolia*	3.80 (2.55-4.79)	4.53 (3-7)	8.15 (2.73-14.66)	0.81 (0.27-1.47)	2.19 (0.84-3.72)	0.22 (0.08-0.37)	10.34 (3.57-18.38)	1.03 (0.36-1.84)
66.	Singra	*Cynometra ramiflora*	2.29 (1.27-3.18)	2.55 (1.80-3.20)	0.96 (0.23-1.90)	0.10 (0.02-0.19)	0.33 (0.09-0.61)	0.03 (0.01-0.06)	1.29 (0.32-2.52)	0.13 (0.03-0.25)

Values are mean value. Values in parentheses are from minimum to maximum value. AGB = above ground biomass and BGB = below ground biomass

A-15. Total biomass carbon of collected different trees and saplings under the study areas

Sl. No.	Species	Scientific Name	DBH (cm)	Height (m)	CAGB		CBGB		Total Biomass Carbon	
					(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})
Trees										
01.	Aam	*Mangifera indica*	9.78 (8-14)	5.25 (5-6)	14.67 (9-27)	0.59 (0.38-1.08)	3.71 (3-6)	0.15 (0.10-0.25)	18.38 (12-33)	0.74 (0.48-1.34)
02.	Achergola	*Grewia nervosa*	6.56 (5-11)	6.09 (3-13)	8.62 (3-34)	0.34 (0.12-1.35)	2.32 (1-8)	0.09 (0.04-0.31)	10.94 (4-41)	0.44 (0.15-1.65)
03.	Agar	*Aquilaria malaccensis*	9.04 (6-11)	9.60 (6-13)	14.79 (5-24)	0.59 (0.20-0.97)	3.71 (2-6)	0.15 (0.06-0.23)	18.50 (7-30)	0.74 (0.26-1.20)
04.	Akashmoni	*Acacia auriculiformis*	10.97 (5-24)	10.96 (6-19)	27.37 (3-133)	1.09 (0.12-5.32)	5.75 (1-25)	0.23 (0.03-0.98)	33.12 (4-157)	1.32 (0.15-6.30)
05.	Amloki	*Phyllanthus emblica*	5.73	3.00	4.68	0.19	1.40	0.06	6.08	0.24
06.	Arjun	*Terminalia arjuna*	17.45 (14-22)	9.43 (7-14)	59.32 (32-110)	2.37 (1.28-4.39)	12.45 (7-21)	0.50 (0.30-0.86)	71.77 (39-131)	2.87 (1.58-5.25)
07.	Awal	*Vitex pubescens*	48.21 (38-57)	22.00 (18-25)	654.69 (361-929)	26.19 (14.43-37.18)	99.70 (60-136)	3.99 (2.40-5.43)	754.38 (421-1065)	30.18 (16.82-42.61)
08.	Baen	*Avicennia officinalis*	14.60 (5-58)	9.63 (3-30)	74.77 (3-1000)	2.99 (0.11-40.00)	13.08 (1-145)	0.52 (0.03-5.82)	87.84 (3-1145)	3.51 (0.14-45.81)
09.	Bankau	*Garcinia cowa*	7.24 (5-11)	5.75 (3-9)	10.74 (3-25)	0.43 (0.14-1.01)	2.79 (1-6)	0.11 (0.04-0.24)	13.53 (4-31)	0.54 (0.18-1.24)
10.	Batna	*Castanopsis tribuloides*	10.08 (8-12)	9.83 (7-12)	41.39 (21-64)	1.66 (0.84-2.58)	9.09 (5-14)	0.36 (0.21-0.54)	50.49 (26-78)	2.02 (1.05-3.12)
11.	Bohera	*Termanalia bellerica*	5.09	4.50	5.27	0.21	1.55	0.06	6.82	0.27
12.	Boloch	*Sapium baccatum*	18.56 (15-23)	10.33 (8-12)	80.62 (44-118)	3.22 (1.76-4.73)	16.26 (10-23)	0.65 (0.39-0.91)	96.88 (54-141)	3.88 (2.14-5.65)

Sl. No.	Species	Scientific Name	DBH (cm)	Height (m)	CAGB		CBGB		Total Biomass Carbon	
					(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})
13.	Chakua koroi	*Albizia chinensis*	15.27	12.00	49.43	1.98	10.74	0.43	60.18	2.41
14.	Chapalish	*Artocarpus chama*	56.86 (11-92)	25.93 (8-45)	1089.87 (32-2922)	43.59 (1.41-116.89)	149.98 (8-366)	6.00 (0.32-14.62)	1239.85 (43-3288)	49.59 (13.90-131.51)
15.	Chikrashi	*Chukrassia velutina*	35.52 (28-49)	19.50 (16-25)	395.37 (226-777)	15.81 (9.03-31.09)	63.77 (40-116)	2.55 (1.60-4.65)	459.14 (266-893)	18.37 (10.63-35.74)
16.	Civit	*Swintonia floribunda*	30.12 (24-39)	15.67 (13-19)	254.49 (139-441)	10.18 (5.56-17.62)	43.92 (26-71)	1.76 (1.05-2.85)	298.41 (165-512)	11.94 (6.61-20.47)
17.	Dhakijam	*Syzygium grande*	31.20 (6-62)	20.56 (2-38)	580.09 (4-2056)	23.20 (0.14-82.24)	85.32 (1-270)	3.41 (0.04-10.79)	665.41 (5-2326)	26.62 (0.19-93.02)
18.	Dharmara	*Stereospermum personatum*	37.65 (24-62)	25.67 (12-50)	928.85 (165-2409)	37.15 (6.24-96.38)	125.88 (29-309)	5.04 (1.16-12.38)	1054.73 (185-2719)	42.19 (7.40-108.75)
19.	Dumur	*Ficus hispida*	33.19 (5-111)	18.84 (7-42)	361.41 (6-2951)	14.46 (0.24-118.04)	54.21 (2-369)	2.17 (0.07-14.75)	415.62 (8-3320)	16.62 (0.31-132.79)
20.	Eucalyptus	*Eucalyptus camaldulensis*	19.99 (16-24)	22.17 (15-27)	189.27 (87-297)	7.57 (3.46-11.88)	33.95 (17-51)	1.36 (0.70-2.03)	223.22 (104-348)	8.93 (4.16-13.91)
21.	Gamar	*Gmelia arborea*	21.85 (17-31)	15.00 (12-20)	120.92 (59-241)	4.84 (2.37-9.64)	21.33 (13-38)	0.85 (0.50-1.53)	124.23 (64-244)	5.69 (2.87-11.17)
22.	Garjan	*Dipterocarpus turbinatus*	19.58 (5-92)	15.69 (4-45)	397.41 (6-4548)	15.90 (0.25-181.93)	55.57 (2-536)	2.22 (0.07-21.44)	452.98 (8-5084)	18.12 (0.32-203.37)
23.	Gewa	*Excoecaria agallocha*	9.05 (5-24)	8.92 (3-18)	13.33 (2-113)	0.53 (0.08-4.53)	2.34 (0.29-14.80)	0.09 (0.01-0.59)	15.67 (3-128)	0.63 (0.11-5.12)
24.	Goran	*Ceriops decandra*	6.76 (5-9)	6.50 (4-8)	7.58 (3-15)	0.30 (0.14-0.58)	1.94 (0.97-3.49)	0.08 (0.04-0.14)	9.52 (4-18)	0.38 (0.18-0.72)
25.	Hental	*Phoenix paludosa*	5.80 (5-7)	5.76 (3-8)	4.29 (3-7)	0.17 (0.11-0.29)	1.18 (0.81-1.87)	0.05 (0.03-0.07)	5.47 (4-9)	0.22 (0.14-0.36)
26.	Hybrid acacia	*A. auriculimormis* x *A. mangium*	22.63 (16-33)	17.38 (13.27)	173.20 (77-435)	6.93 (3.07-17.40)	34.37 (16-70)	1.37 (0.63-2.82)	207.57 (92-505)	8.30 (3.70-20.22)

Sl. No.	Species	Scientific Name	DBH (cm)	Height (m)	CAGB		CBGB		Total Biomass Carbon	
					(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})
27.	Jalpai	*Elaeocarpus floribundas*	10.08 (9-11)	7.00 (6-8)	20.90 (17-25)	0.84 (0.68-0.99)	5.09 (4-6)	0.20 (0.17-0.24)	25.99 (21-31)	1.04 (0.85-1.22)
28.	Jarul	*Lagerstroemia speciosa*	23.03 (6-113)	16.96 (4-60)	253.69 (6-6548)	10.15 (0.22-261.91)	39.18 (1-734)	1.57 (0.06-29.37)	292.87 (7-7282)	11.71 (0.28-291.28)
29.	Jharugach	*Dichapetalum gelonioides*	18.38 (8-27)	9.75 (5-13)	87.33 (11-171)	3.49 (0.45-6.85)	17.04 (3-31)	0.68 (0.12-1.26)	104.37 (14-203)	4.17 (0.57-8.11)
30.	Kadam	*Neolamarckia cadamba*	38.95 (36-40)	28.60 (20-38)	494.73 (366-647)	19.79 (14.62-25.88)	78.48 (61-99)	3.14 (2.42-3.97)	573.20 (426-746)	22.93 (17.05-29.85)
31.	Kalojam	*Syzygium cumini*	22.44 (10-38)	20.69 (9-30)	354.53 (25-639)	9.38 (1-25.54)	40.24 (6-98)	1.61 (0.24-3.93)	274.78 (31-737)	10.99 (1.23-29.47)
32.	Kanaidinga	*Oroxylum indicum*	8.91	9.00	12.06	0.48	3.17	0.13	15.23	0.24
33.	Kanak	*Schima wallichii*	25.14 (17-35)	13.11 (11-16)	178.72 (103-263)	7.15 (4.13-10.53)	32.46 (20-46)	1.30 (0.81-1.83)	211.18 (124-309)	8.45 (4.94-12.36)
34.	Kankra	*Bruguiera gymnorrhiza*	17.14 (7-23)	13.42 (6-17)	82.17 (14-146)	3.29 (0.57-5.86)	15.82 (3.65-26.66)	0.63 (0.15-1.07)	98.00 (18-173)	3.92 (0.71-6.92)
35.	Kanthal	*Artocarpus heterophyllus*	14.89 (6-25)	8.50 (6-11)	40.17 (8-85)	1.61 (0.33-3.39)	8.82 (2-17)	0.35 (0.09-0.68)	48.99 (11-102)	1.96 (0.42-4.07)
36.	Katbadam	*Terminalia catappa*	7.00 (6-9)	6.00 (5-7)	9.06 (6-15)	0.36 (0.25-0.59)	2.45 (2-4)	0.10 (0.07-0.15)	11.52 (8-18)	0.46 (0.32-0.74)
37.	Keora	*Sonneratia apetala*	21.92 (5-59)	17.06 (5-35)	121.94 (4-741)	4.88 (0.18-29.65)	21.38 (1-110)	0.86 (0.05-4.40)	143.32 (6-851)	5.73 (0.23-34.05)
38.	Khalshi	*Aegiceras corniculatum*	6.43 (5-10)	6.04 (4-9)	5.18 (2-16)	0.21 (0.10-0.65)	1.38 (0.73-3.85)	0.06 (0.03-0.15)	6.57 (3-20)	0.26 (0.13-0.81)
39.	Khudijam	*Syzygium balsameum*	34.68 (28-52)	21.80 (16-36)	514.75 (239-1305)	20.59 (9.55-52.19)	79.14 (42-182)	3.17 (1.68-7.28)	593.89 (281-1487)	23.76 (11.23-59.47)
40.	Lichu	*Litchi chinensis*	9.23	5.20	18.89	0.76	4.66	0.19	23.55	0.94

Sl. No.	Species	Scientific Name	DBH (cm)	Height (m)	CAGB		CBGB		Total Biomass Carbon	
					(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})	(kg tree^{-1})	(t ha^{-1})
			(8-11)	(5-6)	(14-26)	(0.57-1.04)	(4-6)	(0.15-0.25)	(18-32)	(0.71-1.28)
41.	Lohakat	*Xylia xylocarpa*	71.27 (62-80)	45.67 (35-65)	2981.26 (2662-3299)	119.25 (106.48-131.97)	371.76 (337-406)	14.87 (13.49-16.24)	3353.02 (2999-3705)	134.12 (119.97-148.21)
42.	Lotkon	*Baccaurea ramiflora*	5.09	5.00	5.01	0.20	1.48	0.06	6.50	0.26
43.	Mahogany	*Swietenia macrophylla*	13.28 (5-61)	8.89 (5-28)	95.59 (5-1154)	3.82 (0.18-46.15)	15.69 (1-164)	0.63 (0.06-6.55)	111.28 (6-1317)	4.45 (0.24-52.70)
44.	Mandar	*Erythrina orientalis*	18.88 (16-21)	10.33 (8-12)	36.25 (32-41)	1.45 (1.30-1.63)	8.21 (7-9)	0.33 (0.30-0.36)	44.46 (40-50)	1.78 (1.60-1.99)
45.	Mangium	*Acacia mangium*	20.47 (11-28)	16.00 (15-17)	91.47 (16-162)	3.66 (0.64-6.48)	16.96 (4-29)	0.68 (0.15-1.15)	108.43 (20-191)	4.34 (0.79-7.64)
46.	Minjiri	*Senna siamea*	15.75 (15-16)	12.50 (12-13)	82.24 (75-89)	3.29 (3.02-3.56)	16.68 (15-18)	0.67 (0.62-0.72)	98.92 (91-107)	3.96 (3.64-4.28)
47.	Passur	*Xylocarpus mekongensis*	12.36 (5-45)	8.64 (4-15)	40.90 (3-536)	1.64 (0.13-21.35)	8.01 (1-84)	0.32 (0.04-3.35)	48.91 (4-618)	1.96 (0.16-24.70)
48.	Peyara	*Psidium guajava*	7.64 (6-9)	6.50 (6-7)	14.53 (10-18)	0.58 (0.40-0.74)	3.71 (3-5)	0.15 (0.11-0.18)	18.24 (13-23)	0.73 (0.50-0.92)
49.	Pine	*Pinus caribaea*	52.44 (39-69)	46.80 (45-48)	1273.48 (757-1988)	50.94 (30.27-79.52)	176.64 (114-262)	7.07 (4.55-10.48)	1450.12 (870-2250)	58.00 (34.82-90.00)
50.	Putijam	*Syzygium fruticosum*	9.70 (9-11)	7.50 (7-8)	23.48 (18-29)	0.94 (0.71-1.17)	5.63 (4-7)	0.23 (0.18-0.27)	29.11 (22-36)	1.16 (0.89-1.44)
51.	Raintree	*Samanea saman*	43.99 (27-59)	26.75 (22-32)	744.17 (253-1284)	29.77 (10.30-51.35)	110.33 (45-180)	4.41 (1.79-7.18)	854.49 (302-1463)	34.18 (12.09-58.53)
52.	Raktan	*Lophopetalum fimbriatum*	8.72 (5-14)	7.23 (3-12)	13.64 (2-39)	0.55 (0.10-1.56)	3.45 (0.79-8.74)	0.14 (0.03-0.35)	17.09 (3-48)	0.68 (0.13-1.91)
53.	Rubber	*Havea brasiliensis*	19.52 (16-22)	12.00 (11-13)	90.69 (57-115)	3.63 (2.36-4.61)	18.08 (13-22)	0.72 (0.50-0.89)	108.77 (71-138)	4.35 (2.86-5.51)
54.	Sal	*Shorea robusta*	22.55	15.19	133.0	5.32	21.81	0.87	154.81	6.19

Sl. No.	Species	Scientific Name	DBH (cm)	Height (m)	CAGB (kg tree^{-1})	CAGB (t ha^{-1})	CBGB (kg tree^{-1})	CBGB (t ha^{-1})	Total Biomass Carbon (kg tree^{-1})	Total Biomass Carbon (t ha^{-1})
			(8-48)	(5-31)	(3-890)	(0.10-35.59)	(1-121)	(0.03-4.84)	(3-1011)	(0.13-40.42)
55.	Segun	*Tectona grandis*	23.16 (5-90)	18.14 (2-55)	309.16 (4-3889)	12.37 (0.15-155.57)	47.23 (1-468)	0.98 (0.05-18.72)	356.40 (5-4357)	14.26 (0.20-174.29)
56.	Silkoroi	*Albizzia procera*	31.50	30.00	520.75	20.83	82.28	3.29	603.03	24.12
57.	Singra	*Cynometra ramiflora*	8.20	6.50	11.63	0.46	2.68	0.11	14.31	0.57
58.	Sundari	*Heritiera fomes*	11.07 (5-51)	10.64 (3-28)	41.69 (4-1062)	1.43 (0.05-42.46)	8.21 (1-156)	0.56 (0.04-6.24)	49.90 (5-1218)	2.00 (0.18-48.71)
59.	Telsur	*Hopea odorata*	17.71 (14-24)	18.67 (14-24)	134.58 (63-245)	5.38 (2.51-9.82)	25.05 (13-43)	1.00 (0.53-1.72)	159.62 (76-288)	6.38 (3.03-11.53)
60.	Zigni	*Trema orientalis*	7.32	8.00	7.70	0.31	2.15	0.09	9.85	0.39
Saplings										
61.	Amur	*Amoora cuculata*	2.57 (1.27-3.82)	2.45 (1.30-4)	0.61 (0.09-1.49)	0.06 (0.01-0.15)	0.21 (0.04-0.470	0.02 (0.01-0.05)	0.81 (0.13-1.96)	0.08 (0.01-0.20)
62.	Bhadi	*Lanea coromandilica*	4.30 (4.14-4.45)	5.50 (5.50-6)	4.32 (4.05-4.58)	0.43 (0.41-0.46)	1.31 (1.24-1.37)	0.13 (0.12-0.14)	5.62 (5.29-5.96)	0.56 (0.53-0.60)
63.	Goran	*Ceriops decandra*	1.50 (1.27-2.23)	1.96 (1.80-2.40)	0.20 (0.13-0.48)	0.02 (0.01-0.05)	0.08 (0.05-0.17)	0.01 (0.01-0.02)	0.28 (0.18-0.65)	0.03 (0.02-0.07)
64.	Kurchi	*Holarrhena antidysenterica*	3.82 (3.50-4.14)	3.25 (3-3.50)	2.19 (1.77-2.65)	0.22 (0.18-0.26)	0.73 (0.60-0.86)	0.07 (0.06-0.09)	2.92 (2.37-3.50)	0.29 (0.24-0.35)
65.	Rong	*Morinda angustifolia*	3.80 (2.55-4.79)	4.53 (3-7)	8.50 (2.88-15.01)	0.85 (0.29-1.50)	1.09 (0.42-1.86)	0.11 (0.04-0.19)	9.59 (3.31-16.87)	0.96 (0.33-1.69)
66.	Singra	*Cynometra ramiflora*	2.29 (1.27-3.18)	2.55 (1.80-3.20)	0.46 (0.11-0.92)	0.05 (0.01-0.09)	0.16 (0.05-0.31)	0.02 (0.01-0.03)	0.63 (0.16-1.23)	0.06 (0.02-0.12)

Values are mean value. Values in parentheses are from minimum to maximum value. CAGB = Carbon in above ground biomass and CBGB = Carbon in below ground biomass

A-16. Analysis of Variance (ANOVA) table for SOC stocks in forested site of different forest areas under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Forest area	4	18754	4688.4	5.95	0.001
Error	49	38593	787.6		
Total	53	57346			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Forest Area	N	Mean	Grouping
Chittagong hill forest	15	98.8	A
Sylhet Hill Forest	9	59.82	B
Sunadarban Mangrove Forest	9	103.15	A
Coastal Afforestation	12	69.94	A B
Sal Forest	9	59.57	B

Means that do not share a letter are significantly different

A-17. Analysis of Variance (ANOVA) table for SOC stocks in homestead site of different forest areas under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Forest area	4	8712	2178.0	3.62	0.012
Error	49	29455	601.1		
Total	53	38167			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Forest Area	N	Mean	Grouping
Chittagong hill forest	15	82	A
Sylhet Hill Forest	9	83.55	A
Sunadarban Mangrove Forest	9	50.29	B
Coastal Afforestation	12	61.15	A B
Sal Forest	9	62.43	A B

Means that do not share a letter are significantly different

A-18. Analysis of Variance (ANOVA) table for soil CO_2 mitigation density in forested site of different forest areas under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Forest area	4	252589	63147	5.95	0.001
Error	49	519801	10608		
Total	53	772391			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Forest Area	N	Mean	Grouping
Chittagong hill forest	15	362.5	A
Sylhet Hill Forest	9	219.6	B
Sunadarban Mangrove Forest	9	378.6	A
Coastal Afforestation	12	256.7	A B
Sal Forest	9	218.6	B

Means that do not share a letter are significantly different

A-19. Analysis of Variance (ANOVA) table for soil CO_2 mitigation density in homestead site of different forest areas under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Forest area	4	117340	29335	3.62	0.012
Error	49	396731	8097		
Total	53	514071			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Forest Area	N	Mean	Grouping
Chittagong hill forest	15	300.9	A
Sylhet Hill Forest	9	306.6	A
Sunadarban Mangrove Forest	9	184.6	B
Coastal Afforestation	12	224.4	A B
Sal Forest	9	229.1	A B

Means that do not share a letter are significantly different

A-20. Analysis of Variance (ANOVA) table for SOC stocks in forested site of different locations under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Location	17	56403.1	3317.83	126.64	0.000
Error	36	943.2	26.20		
Total	53	57346.2			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Location	N	Mean	Grouping
Goneshpara, Thanchi, Bandarban Hill District	3	163.71	A
Bogi Forest Beat, Sharankhola, Bagerhat	3	132.25	B
Wasu, Matiranga, Khagrachari Hill District	3	123.82	B
Sonarchar, Rangabali, Patuakhali	3	95.91	C
Munshigonj Forest Beat, Shamnagar, Satkhira	3	91.45	C D
Dhangmari Forest Beat, Dakop, Khulna	3	85.76	C D E
Lawachara National Park, Sreemongal Moulovibazar	3	83.30	C D E
Dumkhali, Mirersarai, Chittagong	3	76.07	D E F
Kaptai National Park, Rangamati Hill District	3	75.11	E F

Dokhola Forest Range, Madhupur, Tangail	3	74.45	E F
Satchari National Park, Chunarughat, Habigonj	3	72.75	E F G
Dulahazra Forest Beat, Chokoria, Cox's Bazar	3	67.21	F G H
Baraiyadhala National Park, Sitakunda, Chittagong	3	64.08	F G H I
Nijhumdwip National Park, Hatiya, Noakhali	3	57.94	G H I
Kotbari, Cumilla Sadar, Cumilla	3	55.50	H I
Char Kukri-Mukri, Charfashion, Bhola	3	49.824	I
Bhawal National Park, Salna, Gazipur	3	48.75	I
Tilagarh Eco Park, Sylhet	3	23.42	J

Means that do not share a letter are significantly different

A-21. Analysis of Variance (ANOVA) table for SOC stocks in homestead site of different locations under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Location	17	37197.5	2188.09	81.23	0.000
Error	36	969.7	26.94		
Total	53	38167.3			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Location	N	Mean	Grouping
Goneshpara, Thanchi, Bandarban Hill District	3	142.98	A
Tilagarh Eco Park, Sylhet	3	103.86	B
Wasu, Matiranga, Khagrachari Hill District	3	103.84	B
Lawachara National Park, Sreemongal Moulovibazar	3	80.88	C
Sonarchar, Rangabali, Patuakhali	3	76.72	C
Kotbari, Cumilla Sadar, Cumilla	3	72.64	C D
Kaptai National Park, Rangamati Hill District	3	71.91	C D
Dumkhali, Mirersarai, Chittagong	3	71.33	C D
Satchari National Park, Chunarughat, Habigonj	3	65.91	C D E
Bogi Forest Beat, Sharankhola, Bagerhat	3	65.27	C D E F
Dokhola Forest Range, Madhupur, Tangail	3	65.19	C D E F
Baraiyadhala National Park, Sitakunda, Chittagong	3	60.50	D E F G
Char Kukri-Mukri, Charfashion, Bhola	3	50.90	E F G H
Bhawal National Park, Salna, Gazipur	3	49.45	F G H
Dhangmari Forest Beat, Dakop, Khulna	3	48.45	G H
Nijhumdwip National Park, Hatiya, Noakhali	3	45.67	G H I
Munshigonj Forest Beat, Shamnagar, Satkhira	3	37.143	H I
Dulahazra Forest Beat, Chokoria, Cox's Bazar	3	30.69	I

Means that do not share a letter are significantly different

A-22. Analysis of Variance (ANOVA) table for soil CO_2 mitigation density in forested site of different locations under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Location	17	759687	44687.5	126.64	0.000

Error	36	12703	352.9		
Total	53	772391			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Location	N	Mean	Grouping
Goneshpara, Thanchi, Bandarban Hill District	3	600.8	A
Bogi Forest Beat, Sharankhola, Bagerhat	3	485.4	B
Wasu, Matiranga, Khagrachari Hill District	3	454.43	B
Sonarchar, Rangabali, Patuakhali	3	352.0	C
Munshigonj Forest Beat, Shamnagar, Satkhira	3	335.61	C D
Dhangmari Forest Beat, Dakop, Khulna	3	314.75	C D E
Lawachara National Park, Sreemongal Moulovibazar	3	305.7	C D E
Dumkhali, Mirersarai, Chittagong	3	279.19	D E F
Kaptai National Park, Rangamati Hill District	3	275.64	E F
Dokhola Forest Range, Madhupur, Tangail	3	273.24	E F
Satchari National Park, Chunarughat, Habigonj	3	266.99	E F G
Dulahazra Forest Beat, Chokoria, Cox’s Bazar	3	246.66	F G H
Baraiyadhala National Park, Sitakunda, Chittagong	3	235.2	F G H I
Nijhumdwip National Park, Hatiya, Noakhali	3	212.63	G H I
Kotbari, Cumilla Sadar, Cumilla	3	203.70	H I
Char Kukri-Mukri, Charfashion, Bhola	3	182.85	I
Bhawal National Park, Salna, Gazipur	3	178.92	I
Tilagarh Eco Park, Sylhet	3	85.95	J

Means that do not share a letter are significantly different

A-23. Analysis of Variance (ANOVA) table for soil CO_2 mitigation density in homestead site of different locations under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Location	17	501010	29471.2	81.23	0.000
Error	36	13061	362.8		
Total	53	514071			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Location	N	Mean	Grouping
Goneshpara, Thanchi, Bandarban Hill District	3	524.7	A
Tilagarh Eco Park, Sylhet	3	381.2	B
Wasu, Matiranga, Khagrachari Hill District	3	381.09	B
Lawachara National Park, Sreemongal Moulovibazar	3	296.8	C
Sonarchar, Rangabali, Patuakhali	3	281.6	C
Kotbari, Cumilla Sadar, Cumilla	3	266.6	C D
Kaptai National Park, Rangamati Hill District	3	263.92	C D
Dumkhali, Mirersarai, Chittagong	3	261.77	C D
Satchari National Park, Chunarughat, Habigonj	3	241.9	C D E

Bogi Forest Beat, Sharankhola, Bagerhat	3	239.55	C D E F
Dokhola Forest Range, Madhupur, Tangail	3	239.2	C D E F
Baraiyadhala National Park, Sitakunda, Chittagong	3	222.0	D E F G
Char Kukri-Mukri, Charfashion, Bhola	3	186.79	E F G H
Bhawal National Park, Salna, Gazipur	3	181.48	F G H
Dhangmari Forest Beat, Dakop, Khulna	3	177.82	G H
Nijhumdwip National Park, Hatiya, Noakhali	3	167.59	G H I
Munshigonj Forest Beat, Shamnagar, Satkhira	3	136.32	H I
Dulahazra Forest Beat, Chokoria, Cox's Bazar	3	112.62	I

Means that do not share a letter are significantly different

A-24. Analysis of Variance (ANOVA) table for DBH of trees at different forest areas under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Forest area	4	779.4	194.84	5.04	0.002
Error	49	1895.8	38.69		
Total	53	2675.2			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Forest Area	N	Mean	Grouping
Sylhet Hill Forest	9	22.98	A
Sal Forest	9	22.63	A
Chittagong hill forest	15	18.46	A B
Coastal Afforestation	12	16.05	A B
Sunadarban Mangrove Forest	9	12.04	B

Means that do not share a letter are significantly different

A-25. Analysis of Variance (ANOVA) table for DBH of trees at different locations under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Location	17	1914.1	112.59	5.33	0.000
Error	36	761.1	21.14		
Total	53	2675.2			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Location	N	Mean	Grouping
Satchari National Park, Chunarughat, Habigonj	3	33.15	A
Kaptai National Park, Rangamati Hill District	3	26.41	A B
Kotbari, Cumilla Sadar, Cumilla	3	24.90	A B C
Tilagarh Eco Park, Sylhet	3	23.25	A B C D
Bhawal National Park, Salna, Gazipur	3	22.53	A B C D
Dokhola Forest Range, Madhupur, Tangail	3	20.45	A B C D

Goneshpara, Thanchi, Bandarban Hill District	3	20.27	A B C D
Nijhumdwip National Park, Hatiya, Noakhali	3	19.94	A B C D
Dulahazra Forest Beat, Chokoria, Cox's Bazar	3	18.04	B C D
Dumkhali, Mirersarai, Chittagong	3	17.72	B C D
Baraiyadhala National Park, Sitakunda, Chittagong	3	15.34	B C D
Dhangmari Forest Beat, Dakop, Khulna	3	13.90	B C D
Char Kukri-Mukri, Charfashion, Bhola	3	13.51	B C D
Sonarchar, Rangabali, Patuakhali	3	13.04	B C D
Lawachara National Park, Sreemongal Moulovibazar	3	12.52	B C D
Wasu, Matiranga, Khagrachari Hill District	3	12.24	C D
Bogi Forest Beat, Sharankhola, Bagerhat	3	12.05	C D
Munshigonj Forest Beat, Shamnagar, Satkhira	3	10.16	D

Means that do not share a letter are significantly different

A-26. Analysis of Variance (ANOVA) table for height of trees at different forest areas under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Forest area	4	202.5	50.63	2.58	0.049
Error	49	961.8	19.63		
Total	53	1164.4			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Forest Area	N	Mean	Grouping
Sal Forest	9	15.78	A
Chittagong hill forest	15	15.24	A
Coastal Afforestation	12	13.41	A
Sylhet Hill Forest	9	13.35	A
Sunadarban Mangrove Forest	9	9.96	A

Means that do not share a letter are significantly different

A-27. Analysis of Variance (ANOVA) table for height of trees at different locations under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Location	17	829.7	48.80	5.25	0.000
Error	36	334.7	9.297		
Total	53	1164.4			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Location	N	Mean	Grouping
Kaptai National Park, Rangamati Hill District	3	23.92	A
Kotbari, Cumilla Sadar, Cumilla	3	18.18	A B
Satchari National Park, Chunarughat, Habigonj	3	17.88	A B

Dokhola Forest Range, Madhupur, Tangail	3	17.28	A B C
Nijhumdwip National Park, Hatiya, Noakhali	3	15.58	A B C
Goneshpara, Thanchi, Bandarban Hill District	3	15.29	A B C
Dulahazra Forest Beat, Chokoria, Cox's Bazar	3	14.96	A B C
Baraiyadhala National Park, Sitakunda, Chittagong	3	13.95	B C
Tilagarh Eco Park, Sylhet	3	13.69	B C
Dumkhali, Mirersarai, Chittagong	3	13.66	B C
Char Kukri-Mukri, Charfashion, Bhola	3	12.67	B C
Bhawal National Park, Salna, Gazipur	3	11.87	B C
Sonarchar, Rangabali, Patuakhali	3	11.74	B C
Dhangmari Forest Beat, Dakop, Khulna	3	11.16	B C
Bogi Forest Beat, Sharankhola, Bagerhat	3	10.57	B C
Lawachara National Park, Sreemongal Moulovibazar	3	8.48	C
Munshigonj Forest Beat, Shamnagar, Satkhira	3	8.15	C
Wasu, Matiranga, Khagrachari Hill District	3	8.09	C

Means that do not share a letter are significantly different

A-28. Analysis of Variance (ANOVA) table for total biomass density of trees at different forest areas under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Forest area	4	650842	162710	1.86	0.132
Error	49	4286241	87474		
Total	53	4937083			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Forest Area	N	Mean	Grouping
Chittagong hill forest	15	555	A
Sylhet Hill Forest	9	537	A
Sal Forest	9	436.9	A
Sunadarban Mangrove Forest	9	347.9	A
Coastal Afforestation	12	284	A

Means that do not share a letter are significantly different

A-29. Analysis of Variance (ANOVA) table for total biomass density of trees at different locations under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Location	17	3064153	180244	3.39	0.001
Error	36	1916825	53245		
Total	53	4980978			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Location	N	Mean	Grouping

Satchari National Park, Chunarughat, Habigonj	3	1121	A
Kaptai National Park, Rangamati Hill District	3	861	A B
Dulahazra Forest Beat, Chokoria, Cox's Bazar	3	804	A B
Kotbari, Cumilla Sadar, Cumilla	3	555	A B
Goneshpara, Thanchi, Bandarban Hill District	3	548	A B
Dhangmari Forest Beat, Dakop, Khulna	3	482.9	A B
Dokhola Forest Range, Madhupur, Tangail	3	437.44	A B
Nijhumdwip National Park, Hatiya, Noakhali	3	415.8	A B
Baraiyadhala National Park, Sitakunda, Chittagong	3	415	A B
Bogi Forest Beat, Sharankhola, Bagerhat	3	407.2	B
Bhawal National Park, Salna, Gazipur	3	366.9	B
Lawachara National Park, Sreemongal Moulovibazar	3	337	B
Dumkhali, Mirersarai, Chittagong	3	331.6	B
Char Kukri-Mukri, Charfashion, Bhola	3	249.7	B
Sonarchar, Rangabali, Patuakhali	3	248.5	B
Wasu, Matiranga, Khagrachari Hill District	3	241.5	B
Tilagarh Eco Park, Sylhet	3	234.6	B
Munshigonj Forest Beat, Shamnagar, Satkhira	3	230.6	B

Means that do not share a letter are significantly different

A-30. Analysis of Variance (ANOVA) table for total carbon density at different forest areas under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Forest area	4	162951	40738	1.85	0.134
Error	49	1076886	21977		
Total	53	1239837			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Forest Area	N	Mean	Grouping
Chittagong hill forest	15	377.9	A
Sylhet Hill Forest	9	338.2	A
Sal Forest	9	299.9	A
Sunadarban Mangrove Forest	9	290.0	A
Coastal Afforestation	12	227.3	A

Means that do not share a letter are significantly different

A-31. Analysis of Variance (ANOVA) table for carbon density at different locations under the study

Source	DF	Adj SS	Adj MS	F-value	P-value
Location	17	762969	44881	3.39	0.001
Error	36	476868	13246		
Total	53	1239837			

Tukey Pairwise Comparisons: Grouping information using the Tukey method and 95% confidence

Location	N	Mean	Grouping
Satchari National Park, Chunarughat, Habigonj	3	620.3	A
Kaptai National Park, Rangamati Hill District	3	493.7	A B
Dulahazra Forest Beat, Chokoria, Cox’s Bazar	3	461	A B
Goneshpara, Thanchi, Bandarban Hill District	3	430	A B
Kotbari, Cumilla Sadar, Cumilla	3	349.8	A B
Bogi Forest Beat, Sharankhola, Bagerhat	3	337.2	A B
Dhangmari Forest Beat, Dakop, Khulna	3	326.7	A B
Dokhola Forest Range, Madhupur, Tangail	3	307.18	A B
Nijhumdwip National Park, Hatiya, Noakhali	3	266.7	B
Baraiyadhala National Park, Sitakunda, Chittagong	3	264	B
Lawachara National Park, Sreemongal Moulovibazar	3	247	B
Dumkhali, Mirersarai, Chittagong	3	242.8	B
Bhawal National Park, Salna, Gazipur	3	242.6	B
Wasu, Matiranga, Khagrachari Hill District	3	240.7	B
Sonarchar, Rangabali, Patuakhali	3	223	B
Munshigonj Forest Beat, Shamnagar, Satkhira	3	206	B
Char Kukri-Mukri, Charfashion, Bhola	3	176.8	B
Tilagarh Eco Park, Sylhet	3	147.4	B

Means that do not share a letter are significantly different

A-32. Data sheet of collected forest species (trees and saplings) data and soil sample

Location:	**Plot No:**	**Date:**
Latitude:	**Longitude:**	**Altitude:**

TAGB [>5 cm DBH−Measure within 8.92 m (250 m^2) radius circular plot]

Sl. No.	**Species**	**DBH (cm)**	**Height (m)**	**Sl. No.**	**Species**	**DBH (cm)**	**Height (m)**
01				07			
02				08			
03				09			
04				10			
05				11			
06				12			

SAGB [1–5 cm DBH −Measure within 5.64 m (100 m^2) radius circular plot]

Sl. No.	**Species**	**DBH (cm)**	**Height (m)**	**Sl. No.**	**Species**	**DBH (cm)**	**Height (m)**
01				07			
02				08			
03				09			
04				10			
05				11			
06				12			

Regeneration [<1 cm DBH−Measure within 1.0 m radius circular plot]

Sl. No.	**Species**	**Total count**	**Field weight**	**Sl. No.**	**Species**	**Total count**	**Field weight**
01				07			
02				08			
03				09			
04				10			
05				11			
06				12			

LHG and Soil sample collection [Measure within 0.56 m radius circular plot]

Sl. No.	**Field weight (fresh) of LHG (g/plot)**	**Soil Samples (Profile and Composite)**			
		0-15 cm	**15-30 cm**	**30-50 cm**	**50-100 cm**
01					
02					
03					

[Approximately 100 g of evenly mixed LHG samples will be taken for oven dry weight.
TAGB & SAGB = Trees & saplings above ground biomass and LHG = leaf litter, herb and grass]