Assessment of Soil Quality, Carbon Stock and Sequestration Potential Across Diverse Land Cover and Land Use Types in the Himalayan Region

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Declaration

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors

Author contribution

Bishnu Prasad Sahoo and Abhinetri Sharma performed the field visit, sampling, analysis and wrote the manuscript. Bishnu Prasad Sahoo and Suvarna Sahoo reviewed, edited the article and all authors have approved the final manuscript.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

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ABSTRACT

In this study, samples of soil, litter, sediment, and deadwood were systematically collected from different sites. The collected soil samples were analysed to assess a range of physical (Moisture content, bulk density, Soil aggregates), chemical (pH, EC, organic carbon, organic matter, nutrients, heavy metals), and biological (microbial biomass) parameters using standard analytical methods. Above-ground and below-ground biomass carbon were estimated using standard allometric equations, while carbon content was measured across five key pools—vegetation, litter, deadwood, soil, and sediment. Soil quality was statistically evaluated through Principal Component Analysis (PCA), Correlation Matrix, and Cluster Analysis to derive the Minimum Data Set (MDS) and calculate SQI to evaluate variations across different sites. The results found marked differences in biomass and carbon accumulation across forest types, with *Cedrus deodara* forests in Mussoorie and the Selaqui region of Dehradun exhibiting the highest total biomass, indicating their strong potential for carbon retention. Conversely, sites such as Premnagar, Asan Wetland, and pine forests in Mussoorie showed lower biomass values. Selaqui recorded elevated microbial biomass and soil organic carbon, while Panditwari exhibited higher levels of available nutrients. Mussoorie's forest soils, particularly under deodar cover, showed greater organic matter and moisture content, signifying enhanced carbon storage. In terms of soil properties, soil pH ranged widely, with significant relationships observed between pH, electrical conductivity, and microbial indicators. Principal Component Analysis (PCA) revealed that 75% to 100% of the total variance in soil properties could be explained through three to five components, depending on site complexity. Premnagar had the highest SQI value (1.03), indicating excellent soil functionality, whereas Shishambara scored the lowest (0.54), reflecting poor organic content and compaction issues. The study concludes that carbon sequestration potential and soil quality vary greatly across landscapes and are closely tied to vegetation type, land use, and ecological conditions.

Keyword: Carbon stock, Carbon sequestration, above ground biomass, below ground biomass, Bulk density, Soil Quality Index (SQI)

INTRODUCTION

The Earth's surface, composed of intricate geological and biological systems, maintains a dynamic relationship with the atmosphere, supporting vital processes such as agriculture, livestock grazing, and human habitation. Historically dominated by natural ecosystems, much of the terrestrial landscape has undergone significant transformation due to human intervention, leading to widespread deforestation, land-use changes, and environmental degradation. These activities have substantially increased atmospheric concentrations of greenhouse gases (GHGs), primarily carbon dioxide (CO_2), thereby intensifying global warming and accelerating climate change.

To mitigate these adverse effects, strategies that reduce emissions and enhance carbon capture in vegetation and soils are essential. One such approach is **carbon sequestration**, a cost-effective and promising method of transferring atmospheric carbon into long-term storage reservoirs, including the biosphere, geosphere, pedosphere, and oceans (Lal, 2008; Sharma et al., 2016). Recognizing the potential of sustainable land management, the **Kyoto Protocol** introduced the concept of **Land Use, Land Use Change, and Forestry (LULUCF)** to promote afforestation, reforestation, and improved land use practices as means of enhancing terrestrial carbon sinks (Nair et al., 2010). Agroforestry, in particular, has shown considerable potential for carbon sequestration, especially in developing regions (Basu, 2014).

Among terrestrial ecosystems, **forests act as major carbon reservoirs**, storing significantly more carbon than other land types, with an estimated 350,000 Tg of carbon distributed across biomass and soil pools. The global distribution of forest carbon stocks highlights the importance of tropical, temperate, and boreal zones, which collectively store the majority of terrestrial carbon (Malhi et al., 2002; Sohngen et al., 2006). According to the Food and Agriculture Organization (FAO), forest carbon is stored in multiple components: aboveground biomass (234 Pg), belowground biomass (62 Pg), deadwood (41 Pg), litter (23 Pg), and soils (398 Pg) (Kindermann et al., 2008). These pools are vital in mitigating climate change, particularly through the process of **carbon assimilation by trees and soil** (Zhang et al., 2019; Liu et al., 2014).

Soil, in particular, is a crucial carbon sink, holding approximately **75% of terrestrial organic carbon**, which is more than twice the carbon content of the atmosphere (Prentice, 2001). Forest soils play a key role in carbon cycling and ecosystem health by supporting plant growth, regulating climate, and recycling nutrients. The **physical, chemical, and biological properties** of soil—such as texture, pH, organic matter content, and microbial activity—affect its quality and capacity to store carbon (Paudel and Sah, 2003; Kumar et al., 2004). The decomposition of litter, root biomass, and detritus trophic chains also contribute significantly to nutrient cycling and carbon sequestration, particularly in tropical forests (Ola-Adams and Egunjobi, 1992; Oliveira and Lacerola, 1993).

To evaluate the role of soil in environmental health, the concept of **Soil Quality (SQ)** has been developed, defined as the soil's ability to function within natural or managed ecosystems to sustain productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994; Acton and Gregorich, 1995). The **Soil Quality Index (SQI)** is a quantitative tool that integrates key soil indicators to assess soil functionality and its response to management practices (Karlen and Stott, 1994; Vasu et al., 2016). Various methodologies—including simple additive, weighted additive, and statistical models—have been proposed to calculate SQI (Amacher et al., 2007; Mukherjee & Lal, 2014).

The **Himalayan region**, recognized as one of the most ecologically diverse and geologically young landscapes in the world, spans eight countries and hosts a wide array of vegetation types, ranging from tropical forests to alpine meadows. In **India**, the **Western Himalayas**—encompassing parts of Himachal Pradesh, Jammu & Kashmir, and Uttarakhand—represent a biodiversity hotspot, covering just 18% of the country's land but contributing to over 50% of its forest cover and 40% of its endemic plant species (Maikhuri et al., 2000; Singh and Hajra, 1996). However, this region has experienced substantial forest loss over the past few decades, primarily due to land use change (Khan et al., 2012).

The region's **low temperatures and complex topography** enhance soil organic carbon (SOC) storage due to slower decomposition rates, making it a critical contributor to national carbon sequestration efforts (Singh, 2007). The diverse land cover types—such as grasslands, agricultural land, horticulture, and natural forests—exhibit varying capacities for biomass accumulation and carbon storage (Singh et al., 2018).

the present study, titled **"Assessment of Soil Quality, Carbon Stock, and Sequestration Potential Across Diverse Land Cover and Land Use Types in the Northern Himalayan Region"**, aims to address the following objectives:

- To **quantify and compare the biomass** present across various land cover and land use types in the Indian Himalayan region.

- To **assess the carbon stock and sequestration potential** in these land use systems.
- To **evaluate the physical, chemical, and trace metal characteristics** of soils and develop a **Soil Quality Index (SQI)** for the region's diverse land types.

REVIEW OF LITERATURE

The present literature was reviewed considering the study objective to provide an insight into work done in the past and provide the basis for interpretation and discussion of the research findings. The literature about the present investigation entitled " **Assessment of Soil Quality, Carbon Stock and Sequestration Potential Across Diverse Land Cover and Land Use Types in the Northern Himalayan Region**

Biomass in different Land Cover and Land Use Types in the Northern Himalayan Region

The quantity and spatial distribution of carbon stocks, particularly soil organic carbon (SOC) and above-ground biomass, are impacted by land use and land cover (LULC). The crucial role that forests and other vegetative systems play in sequestering carbon is highlighted by several regional and international studies. According to Vagen et al. (2016), Tanzanian woods and croplands had the highest concentrations of topsoil SOC (17.3 and 13.3 g C kg^{1}, respectively), and SOC stocks could be precisely mapped using remote sensing using MODIS photography ($R^2 = 0.77–0.81$). There was a net loss of nearly 11 MtC in soil organic carbon in India between 1994 and 2014, mainly as a result of agricultural expansion, which caused a 23.14% decrease in forest cover (Sharma et al., 2019). Forests sequester the most carbon (124.17 Mg/ha), followed by agriculture (13.54 Mg/ha) (Bera et al., 2024). Species richness and soil moisture had a significant impact on overall carbon levels, and in the Eastern Himalaya, soils stored 43–75% of ecosystem carbon while plant biomass made up 24–55%. (Gogoi et al., 2022). The significance of forest areas in carbon dynamics is highlighted by research from multiple regions. Meena et al. (2022) found that forest areas had the highest above-ground biomass, at 49.76 Mg/ha. A total standing biomass of 38.11 t/ha was recorded by Mishra et al. (2020) in central Indian *Delonix regia* plantings. Chir pine biomass in Nepal varied in depending on site quality, with values ranging from 7.53 to 35.15 t/ha. According to (Mohns et al., 1988). Significant carbon flows have been caused by changes in land cover in Asia and Europe, although afforestation efforts enabled partial restoration. Rojas et al. (2012) and Deng et al. (2016) reported significant losses of soil organic carbon following deforestation. Using the InVEST model, Liang et al. (2021) predicted that ecological conservation scenarios on China's

Loess Plateau could result in an 11.36 Pg increase in carbon storage. Zhang et al. (2020) found that Shanghai's growing urbanization causes an annual carbon loss of 0.48%, demonstrating the ongoing threat that urbanization poses to the environment. Rajput et al. (2017) found that agro-horticulture systems had the highest annual sequestration rate (2.17 Mg/ha) and forest systems at higher elevations (2000–2300 m) had the highest carbon density (393.29 Mg C ha^{-1}) in the Himalayan region. Active carbon pools predominate in managed areas, with the highest total soil organic carbon (SOC) concentration (2.75%) found in northeast Indian wild forests and the lowest in grasslands (1.31%), according to Sahoo et al. (2019). These results were supported by Mahato et al. (2016), who estimated that the soil organic carbon stock in a Himalayan community forest was 218.57 t/ha, with the highest values found in the surface soil. The necessity of protecting forest ecosystems and using combined field and remote sensing techniques for effective carbon monitoring and management is emphasized by these studies taken together.

Assessment of Carbon stock and carbon sequestration potential of different Land Cover and Land Use Types in the Northern Himalayan Region

Multiple studies have assessed the capacity of different land uses and forest ecosystems to store carbon in both biomass and soil across various geographic and ecological contexts. Terakunpisut et al. (2007) indicated that tropical rainforests possess the greatest carbon sequestration capacity (137.73 ± 48.09 C/ha), followed by dry evergreen and mixed deciduous forests, underscoring the impact of forest type on carbon reserves. Dabi et al. (2021) employed GIS and satellite-derived vegetation indices to assess above-ground biomass (AGB) in plantations of *Citrus sinensis*, Hevea brasiliensis, and Areca catechu in Arunachal Pradesh, India, with H. brasiliensis exhibiting the greatest AGB at 60.74 t/ha. Sarangle et al. (2018) similarly reported the largest total carbon stocks in pure eucalyptus plantations (654.91 t/ha), followed by mixed regimes, whilst monoculture wheat exhibited the lowest (6.78 t/ha). Kafle (2024) underscored the significance of altitude, forest type, and sustainable management in affecting SOC levels in Nepal, promoting the incorporation of remote sensing and machine learning for enhanced evaluation. In Iran, Alidoust et al. (2018) discovered that forest soils exhibited the highest soil organic carbon (SOC) levels; nevertheless, alterations in land use diminished SOC by 100 Gg, notwithstanding the sequestration potential affected by soil texture and aggregate stability. Modelling methodologies like CO2 FIX have been utilized to evaluate long-term carbon sequestration; Groen et al. (2006) confirmed its efficacy in afforestation and reduced-impact logging initiatives, whereas Pandey et al. (2015) employed the model on

Cedrus deodara in Uttarakhand, documenting biomass and soil carbon accumulation of 179.27 and 139.67 t/ha, respectively, over a century. In Pakistan, Chen et al. (2017) employed the InVEST and DLS models to evaluate land use and land cover (LULC)-induced carbon alterations under prospective scenarios, revealing that ecological conservation produced the greatest storage enhancements. Gupta et al. (2017) predicted that agroforestry in India may reduce CO_2 emissions by 109.34 Mt yearly, accounting for one-third of agricultural emissions. Xingliang et al. (2004) demonstrated that root-derived organic matter can persist for decades, with nitrogen deposition facilitating carbon stability in alpine meadows, hence promoting long-term carbon sequestration. Schulze et al. (2002) characterized net sequestration as the equilibrium between net primary production (NPP) and carbon losses through respiration, combustion, and harvesting. Mulat et al. (2018) observed that in Ethiopia, soil organic carbon stocks were greatest in grazing pastures, positively correlated with clay content and plant cover. Akpa et al. (2016) assessed Nigeria's soil organic carbon storage at 6.5 Pg, identifying humid zones as possessing the greatest potential. Tree species and afforestation methods in affect initial carbon accumulation; Rytter & Rytter (2020) noted comparable total carbon across species, with willow exhibiting superior performance due to its greater density, while soil carbon was predominantly affected by previous land use. Sahoo et al. (2021) discovered that temperate forests in Northeast India contained the most vegetation carbon (122.09 Mg C/ha), but tropical forests exhibited the highest soil organic carbon (72.54 Mg C/ha), and biomass carbon exhibited a strong correlation with tree basal area. Melo and Durigan (2006) documented elevated carbon storage in mature riparian forests on clay-rich soils (79.7 t/ha) in contrast to cerrado soils (50 t/ha). Jina et al. (2008) documented carbon sequestration rates in the central Himalaya varying from 1.47 to 6.66 t ha^{1} yr^{1} in both degraded and non-degraded oak and pine forests. Dimri et al. (2016) observed significant diversity in biomass along elevation gradients in the Garhwal Himalaya, with *Cedrus deodara* and *Abies pindrow* forests exhibiting the highest values (>600 Mg/ha). Kumar et al. (2021d) evaluated *Quercus leucotrichophora* and discovered that Silvi-pasture systems at lower elevations sequestered more carbon than those at higher elevations, whereas Agri-silviculture systems at elevated altitudes exhibited superior performance. Ordonez et al. (2008) identified the highest soil carbon content in oak forest and the lowest in degraded forest, with surface disturbances diminishing soil organic carbon (Zheng et al., 2007). In the Kumaun Himalaya, Gosain et al. (2015) noted that oak forest sequestered double the soil carbon of pine forests (173.7 vs. 85.9 Mg/ha), exhibiting more above-ground biomass in the oak forest. Elevation gradients influenced carbon dynamics in *Cedrus deodara* forests in the Central Himalaya, as noted by

Sheikh et al. (2020), who observed a decrease in biomass and soil organic carbon with increasing altitude. Sheikh and Kumar (2010) previously determined that *Pinus roxburghii* and *Anogeissus latifolia* exhibited the highest biomass in the Tehri Garhwal forests. Chauhan et al. (2004) observed that mixed pine communities in Dehradun had superior carbon stocks relative to pure pine forests or *Cinnamomum camphora*, highlighting the significance of species composition in ecosystem carbon dynamics.

To assess the Physical Properties, Chemical Properties, Biological properties, and Trace Metal Contents of Soils and evaluate the Soil Quality Index of different Land Cover and Land Use Types in the Northern Himalayan Region

The physical, chemical, and biological characteristics of soil are essential markers of its health and productivity, directly affecting its ability to deliver ecosystem services. Mahajan et al. (2007) noted that the particle size distribution in Northwest Himalayan soils rises with depth, influencing water retention, infiltration, and soil structure. The position on a slope further affects these physical attributes, resulting in diminished moisture, organic matter, and nutrient retention on steeper inclines (Mandal et al., 2010). Bulk density (BD), a critical measure of soil compaction and porosity, is affected by land use and elevation; Valentine et al. (2018) discovered that natural forests possess the lowest BD, whilst agricultural and grazing fields demonstrate the greatest. Kalu et al. (2015) reported analogous findings, indicating sandy loam textures across various land uses, with pastures exhibiting the largest bulk density attributed to moisture loss induced by evaporation. The texture of sub-humid soils in Kashmir varied from silty clay loam to loamy loam, exhibiting diverse sand, silt, and clay compositions (Mahapatra et al., 2000), whereas Sharma and Kanwar (2010) reported variations in silt and clay in Himachal Pradesh. Alterations in land use affect particle size and structure; Ali et al. (2014) demonstrated that the transformation of rangelands to irrigated or dry land agriculture elevated silt, clay, and sand content. Soil aggregate stability, influenced by organic matter, tillage, and biological activity, is crucial for structural resilience (Arshad et al., 1996). Wei et al. (2015) emphasized that soil compaction and particle arrangement markedly affect shear strength and erosion vulnerability.

Chemically, soil characteristics including pH, electrical conductivity (EC), and nutrient composition are essential for carbon sequestration and fertility. Soil pH, affected by temperature and land utilization, governs microbial activity and the decomposition of organic matter (Zhao et al., 2017). Auwal and David (2015) documented variability in soil pore space among forest, orchard, and agricultural fields, affecting nitrogen dispersion and aeration. Kumar et al. (2014) discovered that pH (6.9–8.5), electrical conductivity, and nutrient availability in Chhattisgarh's Vertisols exhibited significant variability, influencing soil organic carbon and micronutrient dynamics. The decomposition of organic matter, influenced by precipitation and litter quality, also differs according to land use. Swarnalatha and Reddy (2011) identified the highest decomposition rates in forests (k=3.050 yr^{-1}), succeeded by Acacia and Eucalyptus plantations, with nutrient dynamics exhibiting spatial and species-specific heterogeneity. Joffre and Agren (2001) highlighted that root biomass in temperate grasslands is predominantly located within the upper 30 cm, which is essential for soil organic matter synthesis. Kumari and Bhardwaj (2017) established that bamboo plants enhance soil fertility, with *Dendrocalamus* as per exhibiting the highest soil organic carbon (SOC) at 16.20 g kg^{-1}, nutrient availability, and SOC stock of 36.41 Mg ha^{-1}, especially in the topsoil (0–20 cm).

Biological characteristics, frequently the most sensitive indicators of soil health, signify microbial activity, biomass, and respiration. Lin et al. (2004) observed reduced microbial biomass carbon and bacterial diversity in greenhouse cultivation relative to open-field agriculture. Biological indicators are essential for evaluating nitrogen cycling and soil composition (Elliott, 1997; Gregorich et al., 1994). Dhaliwal et al. (2009) demonstrated that forests and undisturbed soils had in greater microbial biomass carbon and nitrogen, along with enhanced soil respiration, compared to cultivated and grazed areas in Punjab’s sub-montane zone.

Soil quality indicators (SQIs) have been devised to incorporate these features. Amacher et al. (2007) developed a Soil Quality Index (SQI) utilizing 19 physical and chemical parameters to evaluate forest soil conditions. Singh et al. (2014) highlighted the impact of soil organic carbon (SOC) and accessible phosphorus on soil quality index (SQI), indicating that exchangeable aluminium and DTPA-extractable manganese adversely influenced soil quality in acidic soils. Chandel et al. (2017) discovered that forest had the greatest Soil Quality Index (SQI) in submontane Punjab, with significant factors including soil organic carbon (SOC), potassium, electrical conductivity (EC), and clay content. Prasad et al. (2017) assessed soil quality index enhancements in *Hardwickia binata* agroforestry systems, demonstrating improved soil health with optimal tree density. Yadav et al. (2022) utilized geospatial methods to evaluate soil quality in Rajasthan, revealing spatial variations among tehsils. Larson and Pierce (1994) previously established a minimal data set (MDS) for soil health evaluation, encompassing metrics such as bulk density, water-holding capacity, nutrient availability, and labile carbon, which continue to be fundamental to contemporary soil quality frameworks.

MATERIAL AND METHODS

STUDY AREA: The study will be conducted in Dehradun (Forest, city, and agricultural fields), Mussoorie (Forest, city, and agricultural fields), and Asan wetland. Dehradun is the capital city of Uttarakhand, is situated in the Doon Valley in the Himalayan foothills. Dehradun lies at a latitude of approximately 30.3165° N and longitude of 78.0322° E, with an average elevation of 640 meters above sea level and average annual rainfall of 2,200 mm, with temperatures varying between 5˚-35˚C.

Mussoorie, located in the Indian state of Uttarakhand, is well-known for its abundant biodiversity and dense forest. Nevertheless, the consequences of climate change present substantial risks to this fragile forest ecosystem. Gaining a comprehensive understanding of these effects is essential for formulating efficient conservation policies and ensuring the sustained well-being of the forest ecosystem. The Mussoorie Forest Division covers a substantial area surrounding Mussoorie and comprises diverse forested areas, ranging from oak and deodar woods to mixed coniferous forest.

The Asan wetland was officially designated as the Asan Conservation Reserve in 1967 following the construction of a barrage at the meeting point of the Asan River and the Dhalipur power station's outlet channel. The barrage, which is 287.5 meters long and 3.2 square kilometers in size, is located in the Doon Valley in the middle Himalayas.

CLIMATE: The site Dehradun, Mussoorie and Asan wetland lies in a Sub-tropical climate. The district has a cool, dry climate, with three distinct seasons: the cold season, which lasts from October to February; the hot season, which lasts from March to June and has an annual temperature range of -1 to 38°C; and the rainy season, which lasts from July to September. The average annual rainfall of the site Dehradun and Mussoorie is 2051.4 mm and 2000-2500mm and the average annual rainfall of third site Asan wetland is 250cm annually.

Figure 1 to be inserted

COLLECTION, PREPARATION AND ANALYSIS OF SOIL SAMPLES: Based on the assessment of the area, Soil, sediment and litter samples will be collected from different locations and analysed in the laboratory as per the standard protocols.

Soil, Sediment, Litter, and Deadwood Sampling

Soil sampling: 60 soil samples were collected from 0–15 cm depth across three Dehradun sites. After shade-drying, samples were sieved (2 mm mesh) and stored for analysis.

- **Sediment Sampling:** Top 0–10 cm sediment was collected with stainless-steel scoops, cleaned of debris, air-dried, ground, and sieved for chemical testing.
- **Surface Litter:** Surface litter from four random 1×1 m^2 plots was collected, weighed, dried at 65 ±5°C, and assumed to contain **45% carbon**.
- **Deadwood Sampling:** Coarse woody debris (≥10 cm diameter) was collected from four random 1×1 m^2 plots, cleaned, and oven-dried at **105°C** for 24–48 hours to measure dry biomass.

Carbon Stock and CO_2 Sequestration Assessment

1. Forest Carbon Sequestration

- **Aboveground Biomass (AGB):** Estimated using tree volume × species-specific gravity × Biomass Expansion Factor (BEF).

Species-specific gravity data were obtained from the Forest Survey of India. The UNFCCC's (United Nations Framework Convention on Climate Change) database provided the biomass expansion factor for a species.

- **Belowground Biomass (BGB):** Estimated as **26% of AGB** (Hangarge et al., 2012).

Species-specific gravity data were obtained from the Forest Survey of India

The UNFCCC's (United Nations Framework Convention on Climate Change) database provided the biomass expansion factor for a species.

- **Total Biomass = AGB + BGB** (Sheikh et al., 2011).
- **Carbon Content = Biomass × 0.5**

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2. Soil Carbon Sequestration

- **Soil Organic Carbon (SOC):** Samples taken at various depths (e.g., 0–30 cm). SOC (%) is measured in the lab.
- **Carbon Stock Formula:** Carbon Stock = SOC (%) × Bulk Density (g/cm^3) × Depth (cm) × Area

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3. Grasslands or Agroecosystems

- Carbon in biomass, litter, deadwood, and soil is measured using standard methods similar to those used in forests.

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4. Wetland Carbon Sequestration

- **Soil and Sediment Carbon:** Organic carbon content measured from soil and sediment samples. Carbon Stock = SSOC (%) × Bulk Density × Soil Depth
- **Vegetation Carbon:**
    - AGB estimated using plant size measurements and allometric equations.
    - BGB estimated as 20–50% of AGB (often using 26%).
    - **Carbon = Biomass × 0.5**
- **Total Wetland Carbon Sequestration = Soil + Sediment + Vegetation Carbon**

LABORATORY STUDY: A variety of physical, chemical, and biological characteristics were examined in soil samples that were taken from the selected sites. The bulk density, moisture content, and soil aggregates are among the physical characteristics. On the other hand, pH, electrical conductivity, organic carbon, organic matter, available nitrogen, available phosphorus, exchangeable potassium, available sulphur and Acid Digestion & Spectroscopy Method (Mg, Pb, Cd and Mn) were the chemical parameters and Microbial biomass nitrogen (MBN) or Microbial biomass carbon (MBC) were the biological parameters that were determined during the current investigation.

Table 1 to be inserted

LITTER ANALYSIS: Litter samples were tested for carbon content using a standard combustion method. The process began with weighing clean, dry crucibles. Roughly 1 gram of oven-dried litter was added to each, and the combined weight was recorded. The samples were then combusted in a muffle furnace at **400°C for 2 hours** to burn off organic material, leaving only ash. After cooling, the crucibles were reweighed to determine ash content.

Calculation:

Carbon was calculated by using the following equation:

Carbon % = 100 – (Ash weight + molecular weight of O_2 (53.3) in $C_6H_{12}O_6$).

DEADWOOD ANALYSIS: Initially, each sample was labelled, cleaned to remove soil and bark. To lower the moisture content and produce dry biomass, the samples were oven dried for 24 to 48 hours at a constant temperature of 105°C. The dry weight of each sample was recorded using an analytical balance. It was thought that 50% of the carbon in the dried surface litter was carbon, and the carbon stock was calculated.

SOIL QUALITY ASSESSMENT: The basis of evaluating soil quality is based on the selection of suitable parameters. Evaluation of the physical, chemical and biological characteristics of the soil in the Forest, city and agriculture areas including bulk density, moisture content, soil aggregates, pH, EC, OC, OM, available N, P & S, exchangeable K as well as the total Pb, Cd, Mg, and Mn, MBN, MBC.

STATISTICAL ANALYSIS: The data were statistically analyzed using IBM SPSS Statistics 2019 for Correlation Analysis, PCA, and Hierarchical Cluster Analysis (HCA).

Soil quality index and interpretation: Soil quality index (Q) was classified into three categories as presented in Table 2:

Table 2 to be inserted

RESULTS AND DISCUSSION

Assessment of Biomass, carbon stock and carbon sequestration potential in different Land Cover and Land Use Types in the Northern Himalayan Region

The current study evaluated above-ground biomass (AGB), below-ground biomass (BGB), total biomass, and forest carbon stock across selected ecosystems in Dehradun, Asan Wetland, and the Mussoorie region of Uttarakhand the results are summarized in Table 3.

Table 3 to be inserted

In Dehradun, notable variation in AGB was observed among the four surveyed forest sites. The Selaqui site recorded the highest AGB at 44.07 t ha^{-1}, followed by Panditwari (26.53 t ha^{-1}), Shishambara (23.98 t ha^{-1}), and Prem Nagar (22.68 t ha^{-1}). These results support the findings of Meena et al. (2022), which indicated that forest areas generally hold higher biomass than agricultural or wetland regions. At the Asan Wetland site, AGB was measured at 23.51 t ha^{-1}, corroborating Meena et al.'s observation that wetlands store the least biomass among major land use types. Within the Mussoorie forests, variation in AGB across forest types was substantial. The Deodar Forest exhibited the greatest AGB (51.88 t ha^{-1}), followed by Oak (33.34 t ha^{-1}), Mixed (20.00 t ha^{-1}), and Pine forests (15.55 t ha^{-1}). This trend aligns with earlier studies by Singh and Singh (2013) and Gosain et al. (2015), which reported *Cedrus deodara* and *Quercus* species as dominant contributors to forest biomass relative to *Pinus*.

The analysis of below-ground biomass displayed a similar pattern. Among Dehradun sites, Selaqui again showed the highest BGB at 11.46 t ha^{-1}, while Panditwari, Shishambara, and Prem Nagar reported 6.90 t ha^{-1}, 6.23 t ha^{-1}, and 5.90 t ha^{-1}, respectively. In the Asan Wetland, BGB was recorded at 4.85 t ha^{-1}. Mussoorie's forest types followed a consistent order with Deodar Forest yielding the highest BGB (13.49 t ha^{-1}), followed by Oak (8.67 t ha^{-1}), Mixed (5.20 t ha^{-1}), and Pine (4.04 t ha^{-1}). These findings echo the conclusions of Singh and Singh (2013) and Pandey et al. (2013), emphasizing the superior biomass potential of *Cedrus deodara* and *Quercus* species. The pattern was further reflected in the total biomass estimates. Among the Dehradun sites, total biomass peaked in Selaqui (55.52 t ha^{-1}), followed by Panditwari (33.43 t ha^{-1}), Shishambara (30.21 t ha^{-1}), and Prem Nagar (28.58 t ha^{-1}). At Asan Wetland, the total biomass was 28.36 t ha^{-1}. In Mussoorie, Deodar forests had the highest total biomass (65.37 t ha^{-1}), followed by Oak (42.01 t ha^{-1}), Mixed (25.19 t ha^{-1}), and Pine forests (19.59 t ha^{-1}), consistent with Dimri et al. (2016), who emphasized the dominance of *Cedrus deodara* in biomass accumulation.

Carbon stock assessments revealed parallel trends. In Dehradun, the Selaqui site recorded the highest carbon stock at 26.10 t ha^{-1}, corresponding to a CO_2 sequestration potential of 95.77 t ha^{-1}. Panditwari followed with 16.72 t ha^{-1} of carbon and 57.66 t ha^{-1} of CO_2 sequestration, while Shishambara and Prem Nagar had carbon stocks of 14.20 t ha^{-1} and 13.43 t ha^{-1}, with CO_2 potentials of 52.11 and 49.30 t ha^{-1}, respectively. In the Asan Wetland, carbon stock and CO_2 sequestration were recorded at 11.76 t ha^{-1} and 40.55 t ha^{-1}, respectively. Among the Mussoorie forest types, Deodar Forest showed the greatest carbon stock (30.72 t ha^{-1}) and CO_2

sequestration capacity (112.76 t ha⁻¹), followed by Oak (19.74 t ha^{-1}; 72.46 t ha^{-1} CO_2), Mixed (11.84 t ha^{-1}; 43.46 t ha^{-1} CO_2), and Pine Forest (9.21 t ha^{-1}; 33.79 t ha^{-1} CO_2). These results reinforce the conclusions of Singh and Singh (2013), affirming that *Cedrus deodara* possesses the highest carbon sequestration potential, followed by *Quercus* species. Collectively, the study highlights the critical role of forest type and land use in regulating biomass accumulation and carbon dynamics in the central Himalayan ecosystem.

Figure 2 to be inserted

LITTER CARBON BIOMASS: The study assessed the carbon stock and CO_2 sequestration across different sites located in Dehradun, Asan wetland, Mussoorie region of Uttarakhand. The results are summarized in Table 4.

Table 4 to be inserted

The data presented in Table 4 indicate notable variation in carbon stock and CO_2 sequestration potential across different forest sites in Dehradun, the Asan Wetland, and Mussoorie. Among the four forest sites in Dehradun, the Selaqui site recorded the highest carbon stock at 7.58 t ha^{-1}, corresponding to a CO_2 sequestration potential of 27.81 t ha^{-1}. This was followed by the Panditwari site with a carbon stock of 7.30 t ha^{-1} and CO_2 sequestration of 26.78 t ha^{-1}. The Shishambara site had a moderate carbon stock of 5.52 t ha^{-1} and CO_2 sequestration of 20.27 t ha^{-1}. In contrast, the Prem Nagar site exhibited the lowest values, with a carbon stock of 2.85 t ha^{-1} and a CO_2 sequestration potential of 10.47 t ha^{-1}. In the Asan Wetland, a significantly higher carbon stock was recorded at 26.68 t ha^{-1}, resulting in a CO_2 sequestration potential of 97.93 t ha^{-1}. Similarly, in Mussoorie, carbon stock varied among different forest types. The deodar forest had the highest carbon stock of 7.54 t ha^{-1} and CO_2 sequestration of 27.67 t ha^{-1}, followed closely by the oak forest (6.61 t ha^{-1}, 24.27 t ha^{-1}), mixed forest (6.58 t ha^{-1}, 24.14 t ha^{-1}), and pine forest (6.53 t ha^{-1}, 23.97 t ha^{-1}). These results highlight the spatial variability in carbon storage capacity and underscore the importance of forest type and location in carbon sequestration dynamics.

Figure 3 to be inserted

DEADWOOD CARBON BIOMASS: The study of the carbon stock and CO_2 sequestration across different sites located in Dehradun, Asan wetland, Mussoorie region of Uttarakhand. The results are summarized in Table 5.

Table 5 to be inserted

The data present in Table 5 reveal that the variation in carbon stock and CO_2 sequestration potential across different forest sites in Dehradun, the Asan Wetland, and Mussoorie. In Dehradun, the highest carbon stock was recorded at the Selaqui site (0.015 t ha^{-1}), corresponding to a CO_2 sequestration potential of 0.054 t ha^{-1}. This was followed by the Prem Nagar site, which had a carbon stock of 0.014 t ha^{-1} and CO_2 sequestration of 0.053 t ha^{-1}. The Panditwari site reported slightly lower values, with a carbon stock of 0.012 t ha^{-1} and sequestration potential of 0.045 t ha^{-1}, while the Shishambara site had the lowest values, at 0.010 t ha^{-1} and 0.020 t ha^{-1} for carbon stock and CO_2 sequestration, respectively. In the Asan Wetland, carbon stock was observed to be 0.020 t ha^{-1} with a CO_2 sequestration potential of 0.090 t ha^{-1}. In Mussoorie, carbon stock also varied by forest type. The pine forest exhibited the highest carbon stock (0.022 t ha^{-1}) and CO_2 sequestration potential (0.080 t ha^{-1}), followed by deodar (0.020 t ha^{-1}, 0.073 t ha^{-1}), oak (0.019 t ha^{-1}, 0.071 t ha^{-1}), and mixed forest types, which recorded the lowest carbon stock and CO_2 sequestration values at 0.018 t ha^{-1} and 0.065 t ha^{-1}, respectively. These findings demonstrate spatial and compositional differences in carbon sequestration potential across the study sites.

Figure 4 to be inserted

SOIL CARBON BIOMASS: The study assessed the carbon stock and CO_2 sequestration across different sites located in Dehradun, Asan wetland, Mussoorie region of Uttarakhand. The results are summarized in Table 6.

Table 6 to be inserted

Table 6 presents the variation in carbon stock and CO_2 sequestration potential across different forest sites in Dehradun, the Asan Wetland, and Mussoorie. In Dehradun, the Selaqui site recorded the highest carbon stock at 22.57 t ha^{-1}, resulting in a CO_2 sequestration potential of 82.83 t ha^{-1}. This was followed by Prem Nagar (21.87 t ha^{-1}, 80.26 t ha^{-1}) and Panditwari (20.48 t ha^{-1}, 75.15 t ha^{-1}). The Shishambara site exhibited the lowest values, with a carbon stock of 4.72 t ha^{-1} and CO_2 sequestration of 17.32 t ha^{-1}. In the Asan Wetland, a notably higher carbon stock of 36.87 t ha^{-1} was recorded, corresponding to a CO_2 sequestration potential of 135.33 t ha^{-1}. In Mussoorie, carbon stock differed among forest types. The pine forest showed the highest carbon stock of 20.85 t ha^{-1} and CO_2 sequestration of 76.53 t ha^{-1}, followed by the oak forest (13.00 t ha^{-1}, 47.72 t ha^{-1}) and deodar forest (5.72 t ha^{-1}, 20.99 t ha^{-1}). The mixed forest had the lowest carbon stock and CO_2 sequestration values, recorded at 1.22 t ha^{-1} and 4.49 t ha^{-1}, respectively. These results underline the influence of site characteristics and forest type on carbon storage and sequestration potential.

Figure 5 to be inserted

SEDIMENT CARBON: The study assessed the carbon stock and CO_2 sequestration across different sites located in Dehradun, Asan wetland, and Mussoorie region of Uttarakhand. The results are summarized in Table 7.

Table 7 to be inserted

The data present in Table 7 reveal that the carbon stock was observed in the Asan wetland site. The carbon stock observed at the Asan wetland site is 36.87 t ha^{-1}, and CO_2 sequestration is 135.33 tons/ha.

Figure 6 to be inserted

To assess the Physical Properties, Chemical Properties, Biological properties, and Trace Metal Contents of Soils and evaluate the Soil Quality Index of different Land Cover and Land Use Types in the Northern Himalayan Region

The important physical, chemical, and biological properties, viz., pH, electrical conductivity, organic carbon, organic matter, available nitrogen, available phosphorus, exchangeable potassium, available sulphur and Acid Digestion & Spectroscopy Method (Mg, Pb, Cd and Mn) were the chemical parameters and Microbial biomass nitrogen (MBN) or Microbial biomass carbon (MBC) were the biological parameters etc., were taken into account according to their relative importance for the assessment of soil quality index. The point-wise results obtained are presented as under:

DESCRIPTIVE ANALYSIS:

IN DEHRADUN: Table 8 provides descriptive statistics for selected physical, chemical, and biological parameters of soils sampled from four study locations in the Dehradun region: Shishambara, Selaqui, Premnagar, and Panditwari.

Soil pH and Electrical Conductivity: The pH of soil samples varied between 5.60 and 8.70 across the study sites. Shishambara exhibited the highest average pH value of 8.32 (±0.48), indicating a strongly alkaline nature, whereas Premnagar recorded the lowest mean pH of 5.60 (±0.65), characterizing it as acidic. Overall, pH levels ranged from slightly acidic to neutral, potentially influenced by land management practices, precipitation, and the application of inorganic fertilizers, consistent with findings by Emiru and Gebrekidan (2013). Electrical conductivity (EC) ranged from 80 to 225 µS/cm. The highest EC was observed at Selaqui with a mean of 146.14 µS/cm (±67.66), while Premnagar recorded the lowest mean EC of 104.00 µS/cm (±23.03).

Soil Organic Carbon and Organic Matter: Soil organic carbon (SOC) content ranged from 0.08% to 2.53%. Selaqui had the highest mean SOC at 1.81% (±0.42), while Shishambara reported the lowest, at 0.28% (±0.19). These variations are likely due to differences in land use and management practices, particularly the application of organic and inorganic fertilizers. These results align with studies by Maqbool et al. (2017) and Weldesemayat & Nandita (2020), which reported higher SOC levels in forested areas due to the accumulation and decomposition of organic residues. Similarly, soil organic matter (SOM) ranged from 0.14% to 4.37%, with Selaqui again showing the highest mean value (3.12%, ±0.73) and Shishambara the lowest (0.48%, ±0.33).

Available Nitrogen: Available nitrogen content ranged from 250.88 to 489.22 kg/ha. Panditwari recorded the highest average nitrogen level at 421.48 kg/ha (±52.17), while Premnagar had the lowest (328.65 kg/ha, ±56.38). A decreasing trend in nitrogen with increasing soil depth was observed, attributed to the corresponding decrease in organic matter. These findings are consistent with studies by Kumari (2015), Chandel (2020), Shekhawat (2018), and Ahmad et al. (2021).

Available Phosphorus: Phosphorus availability ranged between 8.51 and 71.23 kg/ha. Panditwari recorded the highest mean phosphorus level (68.13 kg/ha, ±2.38), while Selaqui had the lowest (31.52 kg/ha, ±56.38). The observed variations could be linked to differing levels of phosphorus inputs and biomass turnover.

Exchangeable Potassium: Exchangeable potassium content ranged from 4.48 to 616 kg/ha. Panditwari had the highest mean potassium level (380.35 kg/ha, ±167.19), whereas Shishambara reported the lowest (69.89 kg/ha, ±46.49). The spatial variability is likely influenced by differential use of organic and inorganic fertilizers.

Available Sulphur: Available sulphur ranged from 124.26 to 844.85 kg/ha. Shishambara exhibited the highest mean value (697.79 kg/ha, ±200.29), while Premnagar recorded the lowest (237.50 kg/ha, ±164.88). Variations in sulphur content are likely tied to differences in SOM levels at various depths, as noted by Das et al. (2021), Singh (2014), and Singh et al. (2014).

Bulk Density: Bulk density values ranged from 1.38 to 2.28 g/cm³. Shishambara had the highest mean bulk density (2.18 g/cm³, ±0.54), while Selaqui recorded the lowest (1.65 g/cm³, ±0.34). A bulk density below 1.50 g/cm³ generally indicates low soil compaction. Agroforestry systems typically show medium BD values ranging between 1.39 and 1.49 g/cm³ (Briliawan et al., 2022; Weldesemayat & Nandita, 2020; Pandey et al., 2018).

Moisture Content: Moisture content ranged from 0.14% to 4.37%. Selaqui had the highest average moisture content (3.12%, ±0.73), while Shishambara recorded the lowest (0.48%, ±0.33).

Microbial Biomass Carbon: Microbial biomass carbon (MBC) ranged from 0 to 1184.21 mg C/kg. Selaqui showed the highest mean MBC (453.95 mg C/kg, ±427.88), while Premnagar and Panditwari reported the lowest average values (256.68 mg C/kg, ±112.52 and ±149.66, respectively). According to Maini et al. (2020), the input of organic matter via leaf litter and farmyard manure (FYM) supports microbial growth and contributes to higher MBC levels.

Microbial Biomass Nitrogen: Microbial biomass nitrogen (MBN) ranged from 0 to 4.97 mg N/kg. Selaqui recorded the highest mean MBN (2.42 mg N/kg, ±1.86), while Panditwari had the lowest (0.92 mg N/kg, ±0.77). The accumulation of organic materials, such as leaf litter and FYM, plays a crucial role in enhancing microbial nitrogen content (Maini et al., 2020).

Soil Aggregate Stability Mean weight diameter (MWD), indicating soil aggregate stability, varied from 0.18 to 1.89 mm. Panditwari recorded the highest mean MWD (1.22 mm, ±0.61), while Premnagar had the lowest (1.03 mm, ±0.43). Variations in MWD reflect differences in soil texture, organic matter content, and management practices.

Heavy metal concentration: The data in Table 8 revealed that the heavy metals, like Pb, Cd, Mn, and Mg, present in soil ranged from 0- 24.02 ppm. Cd was undetectable in all samples. The concentration of Pb was also negligible in all sites. Manganese (Mn) levels were generally low across all sites. The highest mean Mn concentration was recorded at Selaqui, 1.54 ppm, with std. deviation 0.49 ±. While Shishambara had the lowest mean value, 0 ppm with std. deviation ±0.52. Shishambara has the highest mean value of magnesium concentration is 22.93 ppm with std. deviation has the highest mean value of magnesium concentration is 22.93 ppm with std. deviation ±1.70. And Panditwari had the lowest mean value of Mg is 17.53 with std. deviation ±1.70. And Panditwari had the lowest mean value of Mg is 17.53 with std. deviation ±3.02. Variations in parent material and organic matter composition, along with site-specific nutrition management techniques, may be the cause of these variations. This indicates that lead contamination is modest and probably below ecological risk levels. The continuously low Pb level may be explained by the lack of industrial or vehicle activity close to these test locations. According to these findings, there is very little cadmium pollution, and neither crop safety nor soil health is immediately threatened. The extremely low concentration of Cd points to a possible absence of common sources of Cd, such as phosphate fertilizers, sewage sludge, and industrial effluents.

Table 8 to be inserted

IN ASAN WETLAND: The data shows the descriptive statistics of selected physical, chemical, and biological parameters of soils collected from Asan wetland.

pH and Electrical conductivity: The data in Table 9 revealed that the pH of the soil sample ranged from 6.62 to 8.36, with a mean value 7.51 and std. deviation 0.35. It indicates that the soil is mostly neutral to slightly alkaline in nature. The pH variation may be caused by ongoing management practices, precipitation, and the use of inorganic fertilizers (Emiru and Gebrekidan, 2013).

Electrical conductivity of the soil sample ranged from 100 to 460 µs/cm, with a mean value 217.50 µs/cm with std. deviation ±111.68. These low EC values show non-saline soil conditions.

Soil organic carbon and organic matter: Data in Table 9 revealed that the soil organic carbon content in the soil ranged from 0.04- 2.31%, with a mean value, 1.31% and std. deviation ±0.59. The variation in organic carbon content may be due to the variation in ongoing management practices followed by the farmers, including the use of organic manure and inorganic fertilizers. The soil organic matter content in the soil ranged from 0.07-3.99%, with a mean value, 2.26% with std. deviation ±1.01.

Available nitrogen: The data in Table 9 revealed that the soil available nitrogen content in the soil ranged from 163.07-539.39 kg/ha, with a mean value, 332.42kg/ha with std. deviation ±87.15. It was observed that the available nitrogen content decreased with increasing soil depth. The lower content of available nitrogen in the lower depths is ascribed to the lower content of organic matter in the lower depths.

Available phosphorus: The data revealed that the available phosphorus of the soil ranged from 35.84-58.91 Kg/ha, with a mean value, 44.14 Kg/ha and a standard deviation, ±5.63. The variation in phosphorus availability may be due to changes in inputs of phosphorus and biomass.

Exchangeable potassium: The data revealed that the exchangeable potassium of the soil ranged from 85.12 to 1061.76 Kg/ha, with a mean value, 300.61kg/ha, with std. deviation ±221.32. The

Available sulphur: The available variability in the content of exchangeable potassium in the soils of the studied area may be attributed to the application of variable amounts of organic and inorganic fertilizers. sulphur of the soil ranged from 94.85 to 977.21 Kg/ha, with a mean value,407.72 Kg/ha and a standard deviation of 291.74. The variation in the soil organic matter (SOM) concentration at various soil depths can be the cause of the variances in accessible sulphur content Das et al., 2021; Singh, 2017; and Singh et al., 2017).

Bulk density: The data in Table 9 revealed that the bulk density of the soil sample varied from 0.65 to 1.40 g/cm^3, with a mean value, 0.96 Kg/ha and a standard deviation of ±0.21. In general, a bulk density value less than 1.50 g/cm3 is considered low and less compact.

Moisture content: Data in Table 9 revealed that the moisture content in the soil ranged from 58.32 to 96.28%, with a mean value, 79.49% and std. deviation ±11.11. The MC% value suggests that the soil has good water-holding capacity.

Microbial biomass carbon: The data revealed that the microbial biomass carbon of the soil ranged from 0 to 1480.26 mg C/kg, with a mean value of 468.75 mg C/kg, with a standard deviation 420.97.

Microbial biomass nitrogen: Microbial biomass nitrogen of the soil ranged from 0.33 to 12.10 mg N/kg, with a mean value, 4.25 mg N/kg and std deviation of ±3.56. According to Maini et al. (2020), the ongoing deposition of organic matter through leaf litter and FYM serves as a source of energy for soil organisms, promotes the expansion of microbial populations, and ultimately leads to the formation of carbon in soil microbial biomass.

Heavy metal concentration: The data presented in Table 9 revealed that the heavy metals, like Pb, Cd, Mn, and Mg, present in soil ranged from 0.67 to 25.28 ppm. Cd was undetectable in all samples. The concentration of Pb was also negligible in all sites. Manganese (Mn) levels range from 0.67 to 2.09, with a mean value, 1.30 ppm and a standard deviation

±0.43. Magnesium (Mg) concentration ranges from 12.18 to 25.28 ppm, with a mean value of Mg is 20.74 and std. deviation ±3.35.

Table 9 to be inserted

IN MUSSOORIE: The data present in Table 10 shows the descriptive statistics of selected physical, chemical, and biological parameters of soils collected from various forest types in Mussoorie – A1(Deodar Forest), B1(Oak Forest), C1(Pine FOREST), D1 (Mixed Forest).

Soil pH and Electrical conductivity: The pH of the soil sample ranged from 6.45 to 7.71. The deodar forest recorded the highest mean value, 7.34, with std. deviation ±0.16. While Pine Forest had the lowest mean value of 6.69, it indicates that it is quite acidic with std. deviation ±0.27. The soil pH across the sites ranged from slightly acidic to neutral. The pH variation may be caused by ongoing management practices, precipitation, and the use of inorganic fertilizers (Emiru and Gebrekidan, 2013).

The data presented in Table 10 revealed that the electrical conductivity of the soil sample ranged from 130 to 2750 μs/cm. The mixed forest recorded the highest mean value, 1042 μs/cm, with std. deviation ±1132.55. While devdar and oak forest both had the lowest mean value of 252.00 μs/cm, with std. deviation ±168.43 and ±56.75.

Soil organic carbon and organic matter: Soil organic carbon content in the soil ranged from 0.04- 2.83%. The pine forest had recorded the highest mean value, 1.60%, with std. deviation ±0.87. while mixed forest had the lowest mean value, 0.10% with std. deviation ±0.07. The variation in organic carbon content may be due to the variation in ongoing management practices followed by the farmers, including the use of organic manure and inorganic fertilizers. These results are consistent with earlier research by Maqbool et al. (2017) and Weldesemayat and Nandita (2020), which also discovered that forests typically have higher SOC% than agricultural fields. After being broken down by soil microbes, the large amounts of leaf litter, dead branches, and other organic matter that forests accumulate add significantly to the soil's organic matter and SOC. The soil organic matter content in the soil ranged from 0.07-4.88%. The pine forest recorded highest mean value 2.77%, with with std. deviation ±1.50 while mixed forest had the lowest mean value,0.18%, with std. deviation ±0.1.

Available nitrogen: The data in Table 10 revealed that the available nitrogen in the soil ranged from 275.97 to 664.83 kg/ha. The mixed forest recorded the highest mean value, 474.16kg/ha, with std. deviation ±138.67. while Pine Forest had the lowest mean value, 361.27kg/ha with std. deviation ±68.36. It was observed that the available nitrogen content decreased with increasing soil depth. The lower content of available nitrogen in the lower depths is ascribed to the lower content of organic matter in the lower depths. These results are consistent with the research of Kumari (2015), Chandel (2020), Shekhawat (2018), and Ahmad et al. (2021), who also reported a decline in available nitrogen content down the horizon.

Available phosphorus: The data revealed that the available phosphorus of the soil ranged from 1.57 to 54.99 Kg/ha. The mixed forest recorded the highest mean value, 43.81 kg/ha, with std. deviation ±10.47. while deodar forest had the lowest mean value, 13.69 Kg/ha, with a standard deviation, ±8.46. The variation in phosphorus availability may be due to changes in inputs of phosphorus and biomass.

Exchangeable potassium: The data in Table 10 revealed that the exchangeable potassium of the soil ranged from 4.48-616 Kg/ha. The site Panditwari recorded the highest mean value, 380.35 kg/ha, with std. deviation ±167.19. while Shishambara had the lowest mean value, 69.89 Kg/ha, with a standard deviation of ±46.49. The variability in the content of exchangeable potassium in the soils of the studied area may be attributed to the application of variable amounts of organic and inorganic fertilizers.

Available sulphur: Available sulphur of the soil ranged from 239.68 to 2390 Kg/ha. The pine forest recorded the highest mean value, 1005.76 kg/ha, with std. deviation ±230.98. while deodar forest had the lowest mean value, 363.33 Kg/ha, with a standard deviation of ±110.78. The variation in the soil organic matter (SOM) concentration at various soil depths can be the cause of the variances in accessible sulphur content Das et al. (2021), Singh (2017), and Singh et al., 2017).

Bulk density: Bulk density of the soil sample varied from 1.03 to 2.21 g/cm^3. The Pine Forest recorded the highest mean value, 1.81 g/cm^3, with std. deviation ±0.37. while Deodar Forest had the lowest mean value, 1.43 Kg/ha, with a standard deviation of ±0.30. In general, a bulk density value less than 1.50 g/cm3 is considered low and less compact. Agroforestry systems recorded a medium BD range between 1.49 to 1.39 g/cm3, which, by the works of Brilliant et al. (2022), Weldesemayat and Nandita (2020), and Pandey et al. (2018).

Moisture content: Moisture content in the soil ranged from 2.32 to 21.91%. The Deodar Forest recorded the highest mean value, 15.74%, with std. deviation ±1.71. while Pine Forest had the lowest mean value, 8.31% with std. deviation ±4.24.

Microbial biomass carbon: Microbial biomass carbon of the soil ranged from 98.68 to 1578.95 mg C/kg. The Deodar Forest recorded the highest mean value, 690.79 mg C/kg with std. deviation is ±608.33. While mixed forest had the lowest mean value, 217.11 mgC/kg, with a standard deviation ±44.13. According to Maini et al. (2020), the ongoing deposition of organic matter through leaf litter and FYM serves as a source of energy for soil organisms, promotes the expansion of microbial populations, and ultimately leads to the formation of carbon in soil microbial biomass.

Microbial biomass nitrogen: Microbial biomass nitrogen of the soil ranged from 0.36 to 7.64 mgN/kg. The deodar forest recorded the highest mean value, 3.79 mg N/kg with std. deviation is ±2.97. While Oak Forest had the lowest mean value, 1.14 mgN/kg, with a standard deviation of ±0.68. According to Maini et al. (2020), the ongoing deposition of organic matter through leaf litter and FYM serves as a source of energy for soil organisms, promotes the expansion of microbial populations, and ultimately leads to the formation of carbon in soil microbial biomass.

Soil aggregates: The data revealed that the Mean Weight Diameter (MWD), an indicator of soil aggregate stability, ranged from 0.14 to 1.99 mm. The Deodar Forest recorded the highest mean value,1.52 mm, with std. deviation is ±0.40. While Oak Forest had the lowest mean value,0.81 mm, with a standard deviation of ±0.70.

Heavy metal concentration: The data presented in Table 10 revealed that the heavy metals, like Pb, Cd, Mn, and Mg, present in soil ranged from 11.30 to 333.90 ppm. The concentration of Pb was also negligible in all sites. The highest mean of Cd level was recorded at Pine Forest was 20.72 ppm with std. deviation ±6.01, while Mixed Forest had the lowest mean 16.20 ppm, with std. deviation ±4.11. The highest mean of Mn concentration was recorded at Pine Forest, 122.06 ppm, with std. deviation ±53.81. While Oak Forest had the lowest mean value, 26.94 ppm with std. deviation ±6.04. And Mixed Forest has the highest mean value of magnesium concentration is 20.58 ppm with std. deviation ±2.77. And Pine Forest had the lowest mean value of Mg is 17.93 ppm with std. deviation ±3.22. Variations in parent material and organic matter composition, along with site-specific nutrition management techniques, may be the cause of these variations. This indicates that lead contamination is modest and probably below ecological risk levels. The continuously low Pb level may be explained by the lack of industrial or vehicle activity close to these test locations. According to these findings, there is very little cadmium pollution, and neither crop safety nor soil health is immediately threatened. The extremely low concentration of Cd points to a possible absence of common sources of Cd, such as phosphate fertilizers, sewage sludge, and industrial effluent.

Table 10 to be inserted

STATISTICAL ANALYSIS OF THE DATA SET AND SQI CALCULATION: The results are statistically processed for Correlation Analysis, Principal Component Analysis, and Hierarchical Cluster Analysis using the IBM SPSS Statistics 2019-v26 package. The following scoring and weighting processes through PCA are used to obtain values that are fed into the additive model to derive the numerical Soil Quality Index (SQI).

To calculate the Soil Quality Index, the scores (Si) and the corresponding weight factors (Wi) are combined for each indicator using the formula (SQI = Σ Wi X Si).

CORRELATION ANALYSIS:

Correlation analysis of Dehradun soil: In Shishambara, soil pH was positively correlated with electrical conductivity (EC) and manganese (Mn), but negatively associated with bulk density (BD), organic carbon (OC), and organic matter (OM). EC showed a strong negative relationship with BD, and moderate negative correlations with OC and OM, but a positive correlation with Mn. OC and OM were highly interrelated and positively correlated with microbial biomass carbon (MBC), while negatively associated with pH, EC, and Mn. Nitrogen (N) had positive links with pH, BD, and magnesium (Mg), and a negative one with potassium (K). Phosphorus (P) was negatively related to MBN and MBC, and moderately to Mg. K showed negative correlations with N, sulfur (S), and soil aggregates (MWD), but positive ones with OC and OM. Sulfur was strongly negatively correlated with EC, and moderately with pH, N, and Mn. Moisture content (MC) showed no significant correlation except a moderate negative link with cadmium (Cd). Mn correlated positively with pH and EC. Mg was positively associated with N and S, and moderately with P and K. Soil aggregates were negatively correlated with S.

Table 11 to be inserted

In Selaqui, pH was positively correlated with EC and negatively with Mn, S, and MBN, while positively associated with MBC. EC was similarly positively correlated with pH and negatively with MBN. OC and OM were strongly interlinked and negatively correlated with MBN, but positively with P and Mg. Nitrogen was positively correlated with MC and soil aggregates, and negatively with K and Mg. P showed strong positive links with OC and OM. K was negatively related to N, BD, and MWD, and positively with Mn. Sulfur had positive correlations with MC, BD, MBN, and Mn, but negative correlations with pH, EC, and MBC. BD positively correlated with MC and negatively with K and Mg. MC showed negative relationships with pH, EC, MBC, and Mg, but strong positive ones with S and BD. MBN had negative correlations with EC, pH, Mg, OC, and OM, and was positively associated with N, S, and BD. Mn showed negative correlations with pH, EC, and MBC, and positive with N and S. Mg was positively linked to OC and OM and negatively to N, BD, MC, and MBN. Soil aggregates were positively related to N and negatively to K.

Table 12 to be inserted

In Premnagar, pH correlated positively with P, OC, and OM, and negatively with S, Mn, and MWD. EC showed positive relationships with N and MBC. OM and OC were highly correlated and positively related to pH and MBN, but negatively with S and MWD. N had strong positive links with MBC and EC, and a negative one with MC. P was positively related to pH, MBN, and MBC, and negatively to MC and Mn, while showing a strong positive correlation with BD and a strong negative one with Mg. K was negatively associated with BD and MBN but positively with Mg. Sulfur was negatively related to OC and OM and positively with MWD and Mn. BD was strongly associated with P and MBN and negatively with Mg. MC showed mostly negative correlations except for Mn and Mg. MBN had positive links with BD and negative ones with Mn, Mg, K, MC, and MWD. MBC was strongly associated with N and positively with EC and P, but negatively with MC and Mg. Mn correlated negatively with MBN and positively with MC and Mg. Mg showed negative correlations with P, BD, and MC, and positive ones with K, MC, and MBC. MWD was negatively related to OC and OM and positively with S and Mn.

Table 13 to be inserted

In Panditwari, pH was positively associated with EC and negatively with N. EC was negatively correlated with MWD, MBC, and lead (Pb), and positively with pH and K. OC and OM were highly correlated and negatively related to S and MBN. N showed mainly negative correlations, except for positive links with P and MC. P was positively correlated with N and MC, and negatively with MBN and Mg. K was negatively associated with S, BD, Mn, Pb, and MBC, and positively with EC. S had strong positive links with MBN and Pb and was positively associated with BD, MBC, Mn, and Mg, while negatively related to OM, OC, and N. BD was strongly positively related to Mn and positively with S, MBC, Pb, and Mg, and negatively with N and K. MC was negatively correlated with S, MBC, Mn, and Pb, and positively with N, P, and K. MBN had strong positive links with S and moderate ones with MBC, Mn, Pb, and Mg, but negative relationships with OC, OM, N, and P. MBC was positively associated with Mn and Pb and moderately with S, BD, MBN, Mg, and MWD, and strongly negatively with K and MC. Mn was positively associated with BD, MBC, S, MBN, Pb, and Mg, and negatively with MC, N, and K. Pb showed strong positive correlations with S and MBC, and moderate ones with BD, MBN, Mn, Mg, and MWD, but negative with EC, K, and MC. Mg was positively correlated with S, BD, MBN, MBC, Mn, and Pb, and negatively with N, P, and MC. MWD was negatively associated with EC and positively with MBC and Pb**.**

Table 14 to be inserted

Correlation analysis of Asan wetland soil: The correlation analysis of Asan Wetland soil revealed that pH is positively related to electrical conductivity (EC) and negatively to nitrogen. EC shows a strong negative correlation with soil aggregates, MBC, and Pb, but is positively associated with potassium. Organic carbon and organic matter are closely related and negatively correlated with sulfur and MBN. Nitrogen is negatively correlated with Mg, sulfur, bulk density, MBC, MBN, and Mn, but positively with phosphorus. Potassium is negatively associated with MBC, BD, sulfur, Mn, and Pb, and positively with EC. Sulfur has negative links with moisture, nitrogen, OC, and K, but positive correlations with Pb, BD, Mn, and MBC. Moisture content is positively correlated with N, P, and K, and negatively with most heavy metals and microbial properties. MBC and MBN are strongly linked with Mn, Pb, and sulfur, while soil aggregates are negatively correlated with EC and positively with MBC and Pb.

Table 15 to be inserted

Correlation analysis of Mussoorie soil: The correlation analysis of Asan Wetland soil revealed that the Ph is positively highly correlated with Pb. Electrical conductivity is highly correlated with Phosphorus and Potassium. Organic matter and organic carbon show a highly positive correlation with each other and a highly negative correlation with moisture content. Phosphorus is highly positively correlated with Electrical conductivity. Potassium is highly positively correlated with Electrical conductivity and highly negatively correlated with Moisture content. Bulk density shows a highly negative correlation with moisture content. Moisture content shows a highly negative correlation with organic carbon, organic matter, and Potassium. And a negative correlation with Bulk density. MBN has a highly positive correlation with Mb. MBC shows a highly positive correlation with Cd. Heavy metal Mn shows a highly positive correlation with MBN and a positive correlation with Soil aggregates. Cd is highly negatively correlated with Ph and has a highly positive correlation with MBC. Soil aggregates show a highly positive correlation with Mn.

Table 16 to be inserted

PRINCIPAL COMPONENT ANALYSIS:

Principal Component Analysis of Shishambara (Dehradun): For PCA, all of the soil parameters (indicators) from various forest stands were combined into components. The first four PCs were picked for the MDS given that, as Table 17 indicates, they had eigenvalues >1, with values ranging from 2.323 to 5.622, each explaining at least 10% of the variation in the data and accounting for 100% of the overall variance. The proportion of variance explained was 35.139 % for the first PC, 25.311 %, 25.034 %, and 14.517 % for the other three PCs, respectively

Table 17 to be inserted

Principal Component Analysis of Selaqui (Dehradun): For PCA, all of the soil parameters (indicators) from various forest stands were combined into components. The first four PCs were picked for the MDS given that, as Table 18 indicates, they had eigenvalues >1, with values ranging from 2.521 to 4.828, each explaining at least 10% of the variation in the data and accounting for 100% of the overall variance. The proportion of variance explained was 32.185 % for the first PC, 27.860 %, 23.151 %, and 16.804 % for the other three PCs, respectively

Table 18 to be inserted

Principal Component Analysis of Premnagar (Dehradun): For PCA, all of the soil parameters (indicators) from various forest stands were combined into components. The first three PCs were picked for the MDS given that, as Table 19 indicates, they had eigenvalues >1, with values ranging from 3.512 to 5.495, each explaining at least 10% of the variation in the data and accounting for 94.99% of the overall variance. The proportion of variance explained was 36.636 % for the first PC,34.947 %, and 23.416 %, for the other two PCs, respectively

Table 19 to be inserted

Principal Component Analysis of Panditwari (Dehradun): For PCA, all of the soil parameters (indicators) from various forest stands were combined into components. The first four PCs were picked for the MDS given that, as Table 20 indicates, they had eigenvalues >1, with values ranging from 3.462 to 5.452, each explaining at least 10% of the variation in the data and accounting for 100% of the overall variance. The proportion of variance explained was 34.075 % for the first PC, 22.535 %, 21.750 %, and 21.640 % for the other three PCs, respectively

Table 20 to be inserted

Principal Component Analysis of Asan wetland: For PCA, all of the soil parameters (indicators) from various forest stands were combined into components. The first five PCs were picked for the MDS given that, as Table 21 indicates, they had eigenvalues >1, with values ranging from 1.764 to 3.081, each explaining at least 10% of the variation in the data and accounting for 75.34% of the overall variance. The proportion of variance explained was 22.007% for the first PC, 15.171 %, 12.847%, 12.714%, and 12.602% for the other four PCs, respectively

Table 21 to be inserted

Principal Component Analysis of Mussoorie site: For PCA, all of the soil parameters (indicators) from various forest stands were combined into components. The first five PCs were picked for the MDS given that, as Table 22 indicates, they had eigenvalues >1, with values ranging from 1.501 to 3.031, each explaining at least 10% of the variation in the data and accounting for 75.06% of the overall variance. The proportion of variance explained was 18.944 % for the first PC, 18.463 %,14.4%, 13.875%, and 9.384% for the other four PCs, respectively

Table 22 to be inserted

HIERARCHICAL CLUSTER ANALYSIS: Hierarchical cluster analysis (HCA) was used to organize the monitoring network locations according to spatial similarities. One popular distance coefficient that may be used to convey both the similarity and the distance between two samples is the Euclidean distance, which is based on the difference in the analytical values of the two samples. (Singh et al. 2004; Zhou et al. 2007).

HIERARCHICAL CLUSTER ANALYSIS OF DEHRADUN SITE:

Hierarchical Cluster Analysis of Shishambara Dehradun: The dendrogram (Figure 7) reveals the structure of the clusters according to their spatial similarities. Sample 3 or sample 5 belongs to one group, sample 1 and sample 4 belong to one group, and sample 2 has separate properties. The same group may have the same source and controlling factor.

Figure 7 to be inserted

Hierarchical Cluster Analysis of Selaqui Dehradun: The dendrogram (Figure 8) reveals the structure of the clusters according to their spatial similarities. Sample 2 or sample 3 belong to one group, sample 2 and sample 4 belong to one group, Sample 1 belongs to the group of samples 2 and 4. and sample 5 has separate properties. The same group may have the same source and controlling factor.

Figure 8 to be inserted

Hierarchical Cluster Analysis of Prem Nagar Dehradun: The dendrogram (Figure 9) reveals the structure of the clusters according to their spatial similarities. Sample 3 or sample 4 belong to one group, sample 1 and sample 3 belong to one group, and sample 5 and sample 2 have separate properties. The same group may have the same source and controlling factor.

Figure 9 to be inserted

Hierarchical Cluster Analysis of Panditwari Dehradun: The dendrogram (Figure 10) reveals the structure of the clusters according to their spatial similarities. Sample 3 or sample 4 belongs to one group, sample 2 and sample 5 belong to one group, and sample 1 has separate properties. The same group may have the same source and controlling factor.

Figure 10 to be inserted

Hierarchical Cluster Analysis of Asan wetland Dehradun: The dendrogram (Figure 11) reveals the structure of the clusters according to their spatial similarities. Sample 10 or sample 6 belong to one group, sample 20 and sample 3 belong to one group, sample 12,18 or 11 belong to one group, sample 1 or sample 9 belong to same group, pr sample 1 or sample 5 also belong to same group, sample 7 sample 8 sample 17 and sample 13 belong to same group, sample 14 also belong to sample 17 group. Sample 15 or sample 2 belong to the same group, and sample 16 or 15 belong to the same group, and sample 4 has separate properties. The same group may have the same source and controlling factor.

Figure 11 to be inserted

Hierarchical Cluster Analysis of Mussoorie: The dendrogram (Figure 12) reveals the structure of the clusters according to their spatial similarities. Sample 6, sample 17, sample 5, or sample 10 belong to one group, sample 12,16,14,18,11, and sample 15 belong to one group, sample 2,9,3, or sample 8 belong to one group, sample 4 or sample 13 belong to the same group, and sample 19 or sample 20 has separate properties. The same group may have the same source and controlling factor.

Figure 12 to be inserted

SOIL QUALITY INDEX AND INTERPRETATION:

Soil Quality Index of Shishambara (Dehradun) site: The final SQI is calculated to be 0.54. This means the SQI is moderate for the soils of Shishambara. The results of Principal Component Analysis (PCA) (Table 17) show that this value represents a balance between limiting and favourable soil characteristics. The following factors are the main causes of the moderate SQI: Poor organic matter status is indicated by PC1's negative loadings of OC% (-0.769) and OM% (-0.769), which restrict soil structure, microbial activity, and nutrient retention. In PC1, High Bulk Density (BD) displayed a significant negative loading (-0.800), suggesting compaction of the soil. This condition harms the general health of the soil by limiting gas exchange, water infiltration, and root growth. PC3 was linked to phosphate (P), whereas nitrogen (N) and potassium (K) had moderate positive loadings. Despite their presence, the nutrients are not at the ideal concentrations to sustain high soil productivity. Cadmium (Cd) showed a notable negative loading (–0.804) in PC3, suggesting possible contamination that could impede microbiological activity and present environmental hazards.

Stable soil aggregates are indicated by high MWD values in PC2, which is advantageous. However, low organic matter and compaction may result in structural restrictions. In PC4's moisture content shown high loading is shown, but it cannot raise SQI over moderate levels by itself without balanced organic and nutritional inputs. Hence, the soil has an average potential to support plant growth.

Table 17 to be inserted

Soil quality index of Selaqui (Dehradun) site: The final SQI is calculated to be 0.70 (Table 18). This means the SQI is good for the soils of Selaqui. The results of Principal Component Analysis (PCA) (Table 18) show that the site has good soil quality overall and provides good support for microbial activity, plant growth, and ecosystem sustainability. The following factors are the main causes of the good SQI: PC1's high pH (0.992) and EC (0.881) readings show that the soil system is well-buffered and has ideal nutrient availability conditions. The soil is rich in organic matter, which improves nutrient cycling, water retention, and soil structure, as evidenced by the very high loadings of OC% and OM% (both 0.995) in PC2. Significant positive loadings of nitrogen (0.724), potassium (0.662), and phosphorus (0.874) are observed throughout PCs, indicating a well-balanced nutrient profile that is necessary for the growth of healthy plants. MBN (0.705) and MBC (0.806) show strong microbial activity, which is essential for the breakdown of organic matter and the transformation of nutrients. A healthy soil structure Stable aggregates are highlighted by PC4's high MWD value (0.985), which lowers the risk of erosion and enhances water infiltration and aeration. Trace elements such as Cd and Mg, as well as bulk density (0.140), are within moderate ranges and do not immediately threaten the quality of the soil. Hence, the soil has potential to support plant growth.

Table 18 to be inserted

Soil quality index of Premnagar (Dehradun) site: The final SQI is calculated to be 1.03 (Table 19). This means the SQI is very good for the soils of Premnagar. The results of Principal Component Analysis (PCA) (Table 19) show that the site has very good soil quality overall and provides good support for microbial activity, plant growth, and ecosystem sustainability. The following factors are the main causes of the very good SQI: Excellent organic matter status is indicated by very high loadings of OC% and OM% (both 0.972) in PC2, which improve soil fertility, microbial biomass, and structure. A very active and strong microbial community is reflected in the microbiological indices MBN (0.885) in PC1 and MBC

(0.854) in PC3, which are critical for the turnover of organic matter and the cycling of nutrients. Good soil aggregation is indicated by the high mean weight diameter (MWD = 0.797) in PC2, which aids in water retention, aeration, and erosion resistance. Microbial activity, moderate nitrogen levels (0.442), and available phosphorus (0.713) all contribute to healthy nutrient dynamics for plant growth. Both PC2 (0.841) and PC3 (0.916) displayed significant loadings of EC, indicating a well-balanced soluble salt concentration that promotes nutrient availability without being harmful. A positive BD loading of 0.894 indicates ideal soil compaction levels that permit adequate microbiological activity and root penetration. The magnitude of positive indicators across other components balanced the negative loadings of potassium (-0.926) and magnesium (-0.928) in PC1, and their values are probably within acceptable agronomic norms. Hence, the soil has good potential to support plant growth.

Table 19 to be inserted

Soil quality index of Panditwari (Dehradun) site: The final SQI is calculated to be 0.68 (Table 20). This means the SQI is good for the soils of Panditwari. The results of Principal Component Analysis (PCA) (Table 20) show that the site has good soil quality overall and provides good support for microbial activity, plant growth, and ecosystem sustainability. The following factors are the main causes of the good SQI: Significant positive loadings of microbial biomass nitrogen (MBN = 0.767) and carbon (MBC = 0.874) across PCs indicate active microbial communities, which are essential for the breakdown of organic matter and the cycling of nutrients. In PC1's bulk density (BD = 0.918) and moisture content (MC = 0.804), both attest to the soil's favourable structure, which promotes root growth, aeration, and water retention. The site's electrical conductivity (EC = 0.984) and pH (0.752) were ideal, suggesting a well-buffered soil system that is appropriate for nutrient availability without being stressed by salinity. The extremely high factor loadings (0.983) of organic carbon (OC%) and organic matter (OM%) showed the soil's organic richness, which is crucial for aggregate formation and nutrient retention capability. Magnesium (Mg = 0.780), phosphorus (P = 0.684), and potassium (K = 0.937) all contribute positively to PC4, indicating adequate macro- and secondary nutrients to sustain microbial activity and plant growth. The site's nutrient profile was also influenced by the presence of lead (Pb = 0.637) and manganese (Mn = 0.910), but Pb needs to be closely watched to stay under acceptable limits. Hence, the soil has the potential to support plant growth and vegetation productivity.

Table 20 to be inserted

Soil quality index of Asan wetland site: The final SQI is calculated to be 0.68 (Table 21). This means the SQI is moderate for the soils of Asan wetland. Principal Component Analysis (PCA) (Table 21) shows that this value represents a balance between limiting and favourable soil characteristics. The following factors are the main causes of the moderate SQI: High OC% and OM% loadings (both = 0.926) in PC1 indicate a healthy amount of organic matter, which promotes soil fertility and structure. Across several PCs, moderate nutrient availability of phosphorus (P = 0.867), potassium (K = 0.629), and nitrogen (N = 0.592) all contributed, showing adequate but not remarkable nutrient status. The presence of micronutrients that support plant enzymatic activity and nutrient uptake, such as manganese (Mn = 0.868), is heavily loaded in PC3. In PCs, microbial biomass nitrogen (MBN = -0.377) and carbon (MBC = -0.614) contributed negatively. Which is essential for the breakdown of organic matter and the transformation of nutrients. Moderate EC (0.418–0.554) and BD (0.861) indicate tolerable soil salinity and compaction. In PC1's negative pH loading (-0.724) indicates possible acidity problems that might affect microbial productivity and nutrient uptake.

Table 21 to be inserted

Soil quality index of Mussoorie site: The final SQI is calculated to be 0.59 (Table 22). This means the SQI is moderate for the soils of Mussoorie. Principal Component Analysis (PCA) (Table 22) shows that this value represents a balance between limiting and favourable soil characteristics. The following factors are the main causes of the moderate SQI: the high loadings of OC% and OM% (both = 0.923), in PC1, which improve soil structure, microbial activity, and nutrient availability. Nitrogen (while negatively loaded in PC1, still moderate overall), potassium (K = 0.701), and phosphorus (P = 0.820) all contribute to a balanced nutritional profile that supports healthy plant growth. Active microbial populations are indicated by high MBN (0.902) and MBC (0.450, 0.343), which are crucial for soil biochemical processes and nitrogen cycling. Good soil aggregation and aeration are indicated by moderate to high MWD (0.589) and BD (0.577) values, which promote root growth and water infiltration. Additionally, manganese (Mn = 0.902) and magnesium (Mg = 0.879) support plant enzymatic processes and soil fertility. The fact that EC (0.777) stayed within a good range indicates that stress linked to salinity is not present. The greater contributions of favourable indicators exceeded the few negative connections (for example MC% and pH in PC1 and PC4.

Table 22 to be inserted

CONCLUSION

The study titled *"Assessment of Soil Quality, Carbon Stock and Sequestration Potential Across Diverse Land Cover and Land Use Types in the Himalayan Region"* evaluated carbon storage, sequestration potential, and soil quality across varied ecosystems in Dehradun, Mussoorie, and the Asan Wetland. Results highlighted significant variation in biomass and carbon stock, with Cedrus deodara forests in Mussoorie and Dehradun (Selaqui) exhibiting the highest total biomass, indicating superior carbon storage capacity. In contrast, sites like Premnagar, Asan Wetland, and pine forests showed notably lower carbon stocks. Despite lower biomass, the Asan Wetland showed substantial soil and sediment carbon storage, underscoring its ecological importance. Soil quality assessments revealed high alkalinity in Shishambara, high organic carbon and microbial biomass in Selaqui, and nutrient-rich conditions in Panditwari. The Asan Wetland soils were moist and biologically active, while Mussoorie soils, particularly in deodar forests, had high pH, organic matter, and moisture. Correlation analysis showed strong associations between pH, EC, and heavy metals, while microbial biomass had negative links with moisture and metals. PCA explained up to 100% of soil variability, with simpler structures in Premnagar and more complex profiles in Asan Wetland and Mussoorie. The Soil Quality Index (SQI) was highest in Premnagar (1.03), followed by moderate values in Panditwari, Selaqui, and Asan Wetland, and lowest in Shishambara (0.54), reflecting differences in organic matter, microbial activity, and potential contamination. Overall, soil health varied from moderate to excellent across sites, shaped by vegetation, land use, and environmental conditions.

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The authors did not receive any specific grant from funding agencies for this study.

Clinical Trial Registration

Not applicable, as this research does not include any interventional or clinical study requiring trial registration.

Consent to Publish

All authors have read and approved the final manuscript and consent to its publication

Ethics and Consent to Participate

Not applicable

Data Availability Statement

The datasets generated and/or analysed during the current study are not publicly available as they form part of an ongoing research project. However, the data are available from the corresponding author on reasonable request.

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List of Table

Table 1: Methods for soil quality assessment:

Sr. No.	Parameters	Methods	Reference (s)
1	Bulk density	Core tube method	Black & Hartge (1986)
2	Soil aggregates	wet sieving method	Yoder (1936)
3	Moisture content	gravimetric method	
4	Soil (pH) (2:5)	Measured with a digital pH meter	Jackson (1973)
5	Electrical conductivity(µS/cm^{-1})	Measured with a digital EC meter	Jackson (1973)
6	Organic carbon (OC)	Rapid titration method	Walkley and Black (1934)
7	Organic matter	Rapid titration method OM=OC*1.724	Walkley and Black (1934)
8	Available N (kg ha^{-1})	Alkaline potassium permanganate method	Subbiah and Asija (1956)

9	Available P (kg ha^{-1})	0.5 M$NaHCO_3$ (pH 8.5) extractable	Olsen et al. (1954)
10	Exchangeable K (kg ha^{-1})	Flame photometric method (1NNH_4OAC extractable)	Merwin and Peech (1951)
11	Manganese, Magnesium, Led. & Cadmium	Acid Digestion & Spectroscopy Method	Lindsay and Norvell, (1978)
12	Available sulphur (kg ha^{-1})	Turbidimetric method	Williams and Steinberg, 1969
13	Microbial biomass carbon (MBC)	Fumigation-extraction	Vance et al. (1987)
14	Microbial biomass nitrogen (MBN)	Chloroform fumigation	Jenkinson and Ladd (1981)

Table 2: Classification of Soil Quality Index (Mulyono et al., 2019)

Sr. No.	SQI Rating	SQI Score
1	Very Good	0.8 to 1

2	Good	0.6 to 0.79
3	Moderate	0.35 to 0.59
4	Low	0.2 to 0.34
5	Very Low	0.00 to 0.19

Table 3: Above ground Biomass, below-ground biomass, carbon stock and CO_2 sequestration of the Dehradun, Asan wetland site, and Mussoorie site

serial no.	Location Name	AGB (Above ground Biomass (t/ha)	BGB (Below ground biomass (t /ha)	Total Biomass (t/ha)	Carbon stock (t/ha)	CO_2 Sequestration (t/ha)
1	Shishambara (Dehradun)	23.98	6.23	30.21	14.2	52.11
2	Selaqui (Dehradun)	44.07	11.46	55.52	26.1	95.77
3	Premnagar (Dehradun)	22.68	5.9	28.58	13.43	49.3
4	Panditwari (Dehradun)	26.53	6.9	33.43	15.71	57.66
5	Asan wetland	18.66	4.85	23.51	11.05	40.55
6	Mussoorie A1 (Deodar Forest)	51.88	13.49	65.37	30.72	112.76
7	Mussoorie B1(Oak Forest)	33.34	8.67	42.01	19.74	72.46
8	Mussoorie C1(Pine Forest)	15.55	4.04	19.59	9.21	33.79

9	Mussoorie D1 (Mixed Forest)	20	5.2	25.19	11.84	43.46

Table 4: Carbon stock and CO_2 sequestration of the Dehradun, Asan wetland site, and Mussoorie site

SERIAL NO.	SITE NAME	CARBON STOCK (t/ha)	CO2 SEQUESTRATION t/ha)
1	Shishambara (Dehradun)	5.52	20.27
2	Selaqui (Dehradun)	7.58	27.81
3	Premnagar (Dehradun)	2.85	10.47
4	Panditwari (Dehradun)	7.30	26.78
5	Asan wetland	26.68	97.93
6	Mussoorie A1 (Deodar Forest)	7.54	27.67

7	Mussoorie B1(Oak Forest)	6.61	24.27
8	Mussoorie C1(Pine Forest)	6.53	23.97
9	Mussoorie D1 (Mixed Forest)	6.58	24.14

Table 5: Carbon stock and CO_2 sequestration of the Dehradun, Asan wetland site, and Mussoorie site

SERIAL NO.	SITE NAME	CARBON STOCK ($t\ ha^{-1}$)	CO2 SEQUESTRATION (t/ha)
1	Shishambara (Dehradun)	0.01	0.02
2	Selaqui (Dehradun)	0.015	0.054
3	Premnagar (Dehradun)	0.014	0.053
4	Panditwari (Dehradun)	0.012	0.045
5	Asan wetland	0.02	0.09

6	Mussoorie A1 (Deodar Forest)	0.020	0.073
7	Mussoorie B1(Oak Forest)	0.019	0.071
8	Mussoorie C1(Pine Forest)	0.022	0.080
9	Mussoorie D1 (Mixed Forest)	0.018	0.065

Table 6: Carbon stock and CO_2 sequestration of the Dehradun, Asan wetland, and Mussoorie site

serial no.	site Name	Carbon stock (t/ha)	CO2 Sequestration(t/ha)
1	Shishambara (Dehradun)	4.72	17.32
2	Selaqui (Dehradun)	22.57	82.83
3	Premnagar (Dehradun)	21.87	80.26
4	Panditwari (Dehradun)	20.48	75.15
5	Asan wetland	36.87	135.33

6	Mussoorie A1 (Deodar Forest)	5.72	20.99
7	Mussoorie B1(Oak Forest)	13.00	47.72
8	Mussoorie C1(Pine Forest)	20.85	76.53
9	Mussoorie D1 (Mixed Forest)	1.22	4.49

Table 7: Carbon stock and CO_2 sequestration of the Asan wetland site

Serial no.	Site Name	SOC stock (t/ha)	CO2 Sequestration (t/ha)
1.	ASAN WETLAND	36.87	135.33
	MIN	0.23	
	MAX	11.8	

Table 8: Descriptive Statistics of Physical, Chemical, and biological parameters of soils Dehradun region

	SHISHAMBARA					SELAQUI					PREMNAGAR					PANDITWARI				
Parameters	Max.	Min.	Mean	Std. Deviation	Std. Error	Max.	Min.	Mean	Std. Deviation	Std. Error	Max.	Min.	Mean	Std. Deviation	Std. Error	Max.	Min.	Mean	Std. Deviation	St. Error
PH	8.70	7.50	8.32	0.48	0.22	7.80	6.50	6.94	0.54	0.24	7.30	5.60	6.40	0.65	0.29	7.70	5.70	6.56	1.00	0.45
EC (µS/cm-1)	137.90	63.90	110.86	29.02	12.98	225.00	73.50	146.14	67.66	30.26	130.00	80.00	104.00	23.02	10.30	190.00	90.00	138.00	46.04	20.59
OC%	0.56	0.08	0.28	0.19	0.08	2.53	1.54	1.81	0.42	0.19	2.03	1.36	1.76	0.31	0.14	1.62	1.38	1.51	0.11	0.05
OM%	0.96	0.14	0.48	0.33	0.15	4.37	2.65	3.12	0.73	0.32	3.51	2.34	3.03	0.53	0.24	2.79	2.37	2.60	0.18	0.08
Av.N kg/ha	451.58	313.60	378.83	58.43	26.13	476.67	275.97	386.36	89.32	39.94	401.41	250.88	328.65	56.38	25.21	489.22	363.78	421.48	52.17	23.33
Av.P kg/ha	52.98	23.74	36.98	11.72	5.24	67.09	8.51	31.52	21.69	9.70	65.18	52.30	57.46	5.28	2.36	71.23	65.63	68.34	2.38	1.06
K kg/ha	127.68	4.48	69.89	46.49	20.79	526.40	4.48	190.40	203.00	90.78	452.48	132.16	225.34	131.65	58.88	616.00	168.00	380.35	167.19	74.77
Av. S (kg/ha)	844.85	418.38	697.79	200.29	89.57	550.74	183.09	350.74	152.33	68.12	506.62	124.26	237.50	164.88	73.74	719.85	175.74	362.50	210.27	94.04
BD(g/cm3)	2.88	1.39	2.18	0.54	0.24	2.24	1.38	1.68	0.34	0.15	1.91	1.56	1.71	0.06	0.03	1.92	1.67	1.81	0.10	0.05
MC%	18.29	8.56	13.31	3.74	1.67	12.97	5.36	8.29	3.22	1.44	7.37	4.63	5.78	1.10	0.49	6.20	3.10	5.15	1.27	0.57
MBN (mg N/kg)	4.20	0.72	2.24	1.44	0.64	4.97	0.38	2.42	1.86	0.83	1.91	0.45	1.05	0.64	0.29	2.07	0.00	0.92	0.77	0.35
MBC (mg C/kg)	493.42	0.00	236.84	237.66	106.29	1184.21	197.37	453.95	427.88	191.36	394.74	98.68	256.58	112.52	50.32	493.42	98.68	256.58	149.66	66.93
Mn(ppm)	1.22	0.00	0.91	0.52	0.23	2.07	0.74	1.54	0.49	0.22	1.54	0.72	1.13	0.32	0.14	1.43	0.76	1.05	0.25	0.11
Pb(ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.02	0.05	0.02
Cd(ppm)	0.17	0.00	0.03	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg(ppm)	24.02	19.95	22.93	1.70	0.76	21.22	19.49	20.25	0.67	0.30	19.90	19.17	19.50	0.34	0.15	21.36	13.84	17.53	3.02	1.35
MWD (mm)	1.38	0.76	1.07	0.29	0.13	1.82	0.18	1.09	0.59	0.26	1.64	0.56	1.03	0.43	0.19	1.89	0.53	1.22	0.61	0.27

Table 9: Descriptive analysis of physical, chemical, and biological parameters of soils collected from Asan wetland

ASAN WETLAND					
PARAMETERS	MINIMUM	MAXIMUM	MEAN	Std. Deviation	Std. Error
PH	6.62	8.36	7.51	0.35	0.08
EC (µS/cm-1)	100.00	460.00	217.50	111.68	24.97
OC%	0.04	2.31	1.31	0.59	0.13
OM%	0.07	3.99	2.26	1.01	0.23
Av. (N kg/ha)	163.07	539.39	332.42	87.15	19.49
Av. P(kg/ha)	35.84	58.91	44.14	5.63	1.26
K (kg/ha)	85.12	1061.76	300.61	221.32	49.49
Av. S (kg/ha)	94.85	977.21	407.72	291.74	65.24
BD (g/cm3)	0.65	1.40	0.96	0.21	0.05
MC%	58.32	96.28	79.49	11.11	2.48
MBN (mg N/kg)	0.33	12.10	4.25	3.56	0.80
MBC (mg C/kg)	0.00	1480.26	468.75	420.97	94.13
Mn (ppm)	0.67	2.09	1.30	0.43	0.10
Pb (ppm)	0.00	0.00	0.00	0.00	0.00
Cd (ppm)	0.00	0.00	0.00	0.00	0.00
Mg (ppm)	12.18	25.28	20.74	3.35	0.75

Table 10: Descriptive analysis of physical, chemical, and biological parameters of soils collected from Mussoorie

	Mussoorie A1 (DEODAR FOREST)					MUSSOORIE B1(OAK FOREST)					MUSSOORIE C1(PINE FOREST)					MUSSOORIE D1 (MIXED FOREST)				
PARAMETERS	MINIMUM	MAXIMUM	MEAN	Std. Deviation	Std. Error	MINIMUM	MAXIMUM	MEAN	Std. Deviation	Std. Error	MINIMUM	MAXIMUM	MEAN	Std. Deviation	Std. Error	MINIMUM	MAXIMUM	MEAN	Std. Deviation	Std. Error
PH	7.17	7.56	7.34	0.16	0.07	6.67	7.40	7.14	0.28	0.13	6.45	7.14	6.69	0.27	0.12	6.51	7.71	7.04	0.47	0.21
EC (µS/cm-1)	130.00	540.00	252.00	168.43	75.33	170.	330.00	252.00	56.75	25.38	190.00	360.00	308	69.79	31.21	260.00	2750.0	1042	1132.5	506.49
OC%	0.10	1.06	0.59	0.42	0.19	0.08	2.83	1.04	1.14	0.51	0.20	2.51	1.60	0.87	0.39	0.04	0.22	0.10	0.07	0.03
OM%	0.17	1.82	1.02	0.72	0.32	0.14	4.88	1.79	1.96	0.88	0.34	4.33	2.77	1.50	0.67	0.07	0.38	0.18	0.12	0.05
Av.N kg/ha	301.06	564.48	439.04	93.87	41.98	351.2	489.22	413.95	56.80	25.40	275.97	464.13	361.2	68.36	30.57	275.97	664.83	474.16	138.67	62.01
Av.P kg/ha	1.57	24.30	13.69	8.46	3.78	10.75	31.92	24.30	9.02	4.03	16.46	41.33	26.0	11.16	4.99	27.10	54.99	43.81	10.47	4.68
K kg/ha	239.68	477.12	363.33	110.78	49.54	403.2	822.08	511.62	178.00	79.60	757.12	1314.88	1005.7	230.98	103.30	367.36	2390.0	972.61	807.78	361.25
Av. S (kg/ha)	175.74	396.32	266.91	103.54	46.31	227.2	837.50	530.15	260.92	116.69	146.32	572.79	278.6	183.31	81.98	197.79	771.32	363.97	236.07	105.58
BD(g/cm3)	1.07	1.69	1.43	0.30	0.13	1.03	1.82	1.45	0.29	0.13	1.38	2.21	1.81	0.37	0.17	1.07	1.80	1.47	0.35	0.16
MC%	14.09	18.06	15.74	1.71	0.76	2.74	21.91	12.79	8.87	3.97	2.32	12.64	8.31	4.24	1.90	5.49	17.23	11.97	5.00	2.23
MBN (mg N/kg)	0.56	7.64	3.79	2.97	1.33	0.42	2.10	1.14	0.68	0.30	0.70	4.42	2.73	1.44	0.65	0.36	4.34	1.92	1.97	0.88
MBC (mg C/kg)	98.68	1578.9	690.79	608.33	272.05	98.68	986.84	552.63	379.65	169.78	197.37	1480.26	513.1	546.79	244.53	197.37	296.05	217.11	44.13	19.74
Mn(ppm)	50.60	333.90	229.00	126.90	56.75	20.00	34.20	26.94	6.04	2.70	67.20	207.40	122	53.81	24.06	20.00	342.20	88.54	141.87	63.45
Pb(ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cd(ppm)	15.00	23.40	18.70	3.22	1.44	11.30	23.10	19.14	4.57	2.04	13.40	29.40	20.7	6.01	2.69	11.30	20.40	16.20	4.11	1.84
Mg(ppm)	18.50	21.30	20.04	1.05	0.47	12.30	29.40	19.40	7.13	3.19	12.30	20.40	17.9	3.22	1.44	17.40	24.40	20.58	2.77	1.24
MWD (mm)	0.86	1.93	1.52	0.40	0.18	0.14	1.93	0.81	0.70	0.31	0.76	1.58	1.26	0.33	0.15	0.52	1.99	1.37	0.76	0.34

Pearson Correlation matrix of Shishambara soil

Parameters	pH	EC (µS/cm-1)	OC%	OM%	N kg/ha	P kg/ha	K kg/ha	S conc. PPM	BD(g/cm3)	MC%	MBN (mg N/kg)	MBC (mg C/kg)	Mn(ppm)	Pb(ppm)	Cd(ppm)	Mg(ppm)	MWD (mm)
pH	1	.905*	-.840	-.840	.666	.176	-.441	-.160	-.712	.000	.202	-.461	.898*	.[b]	.441	.137	-.001
EC (µS/cm-1)	.905*	1	-.606	-.606	.533	.124	-.043	-.518	-.881*	-.142	.315	-.325	.880*	.[b]	.307	-.105	.378
OC%	-.840	-.606	1	1.000**	-.327	-.514	.543	-.125	.241	.128	.220	.797	-.719	.[b]	-.588	.001	.383
OM%	-.840	-.606	1.000**	1	-.327	-.514	.543	-.125	.241	.128	.220	.797	-.719	.[b]	-.588	.001	.383
N kg/ha	.666	.533	-.327	-.327	1	-.484	-.668	.154	-.658	.489	.595	.258	.525	.[b]	.096	.748	-.050
P kg/ha	.176	.124	-.514	-.514	-.484	1	.113	-.298	.144	-.117	-.887*	-.917*	.402	.[b]	-.033	-.733	.028
K kg/ha	-.441	-.043	.543	.543	-.668	.113	1	-.703	-.024	-.492	-.040	.123	-.254	.[b]	-.248	-.756	.688
S kg/ha	-.160	-.518	-.125	-.125	.154	-.298	-.703	1	.627	.078	.063	.114	-.464	.[b]	.410	.695	-.944*
BD(g/cm3)	-.712	-.881*	.241	.241	-.658	.144	-.024	.627	1	-.186	-.464	-.060	-.782	.[b]	.089	-.037	-.632
MC%	.000	-.142	.128	.128	.489	-.117	-.492	.078	-.186	1	-.124	.250	.205	.[b]	-.711	.438	.105
MBN (mg N/kg)	.202	.315	.220	.220	.595	-.887*	-.040	.063	-.464	-.124	1	.700	-.062	.[b]	.286	.583	.105
MBC (mg C/kg)	-.461	-.325	.797	.797	.258	-.917*	.123	.114	-.060	.250	.700	1	-.530	.[b]	-.325	.534	.201
Mn(ppm)	.898*	.880*	-.719	-.719	.525	.402	-.254	-.464	-.782	.205	-.062	-.530	1	.[b]	.054	-.129	.308
Pb(ppm)	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]
Cd(ppm)	.441	.307	-.588	-.588	.096	-.033	-.248	.410	.089	-.711	.286	-.325	.054	.[b]	1	.156	-.590
Mg(ppm)	.137	-.105	.001	.001	.748	-.733	-.756	.695	-.037	.438	.583	.534	-.129	.[b]	.156	1	-.498
MWD (mm)	-.001	.378	.383	.383	-.050	.028	.688	-.944*	-.632	.105	.105	.201	.308	.[b]	-.590	-.498	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
b. Cannot be computed because at least one of the variables is constant.

Table 11: Pearson correlation coefficients among soil indicators of Shishambara site

Pearson Correlation Matrix of Selaqui Soil																	
parameters	pH	EC (µS/cm-1)	OC%	OM %	N kg/ha	P kg/ha	K kg/ha	S conc. PPM	BD(g/cm3)	MC %	MBN (mg N/kg)	MBC (mg C/kg)	Mn(ppm)	Pb(ppm)	Cd(ppm)	Mg(ppm)	MWD (mm)
pH	1	.918*	.148	.148	.016	.256	-.480	-.730	-.174	-.589	-.730	.775	-.939*	.[b]	.[b]	.164	.142
EC (µS/cm-1)	.918*	1	.510	.510	-.216	.524	-.356	-.781	-.312	-.680	-.908*	.544	-.770	.[b]	.[b]	.508	.045
OC%	.148	.510	1	1.000**	-.328	.879*	-.099	-.322	-.233	-.305	-.581	-.419	.027	.[b]	.[b]	.767	.067
OM%	.148	.510	1.000**	1	-.328	.879*	-.099	-.322	-.233	-.305	-.581	-.419	.027	.[b]	.[b]	.767	.067
N kg/ha	.016	-.216	-.328	-.328	1	-.101	-.823	.439	.827	.663	.591	-.117	-.257	.[b]	.[b]	-.845	.695
P kg/ha	.256	.524	.879*	.879*	-.101	1	-.294	-.508	-.289	-.405	-.449	-.328	-.231	.[b]	.[b]	.522	.488
K kg/ha	-.480	-.356	-.099	-.099	-.823	-.294	1	-.018	-.641	-.289	-.041	-.070	.609	.[b]	.[b]	.450	-.697
S kg/ha	-.730	-.781	-.322	-.322	.439	-.508	-.018	1	.763	.961**	.758	-.574	.686	.[b]	.[b]	-.489	-.140
BD(g/cm3)	-.174	-.312	-.233	-.233	.827	-.289	-.641	.763	1	.896*	.536	-.280	.088	.[b]	.[b]	-.648	.233
MC%	-.589	-.680	-.305	-.305	.663	-.405	-.289	.961**	.896*	1	.774	-.541	.492	.[b]	.[b]	-.623	.095
MBN(mg N/kg)	-.730	-.908*	-.581	-.581	.591	-.449	-.041	.758	.536	.774	1	-.464	.482	.[b]	.[b]	-.788	.312
MBC (mg C/kg)	.775	.544	-.419	-.419	-.117	-.328	-.070	-.574	-.280	-.541	-.464	1	-.750	.[b]	.[b]	-.070	-.169
Mn(ppm)	-.939*	-.770	.027	.027	-.257	-.231	.609	.686	.088	.492	.482	-.750	1	.[b]	.[b]	.118	-.421
Pb(ppm)	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]
Cd(ppm)	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]	.[b]

Mg(ppm)	.164	.508	.767	.767	-.845	.522	.450	-.489	-.648	-.623	-.788	-.070	.118	.[b]	.[b]	1	-.477
MWD(mm)	.142	.045	.067	.067	.695	.488	-.697	-.140	.233	.095	.312	-.169	-.421	.[b]	.[b]	-.477	1
*. Correlation is significant at the 0.05 level (2-tailed).																	
**. Correlation is significant at the 0.01 level (2-tailed).																	
b. Cannot be computed because at least one of the variables is constant.																	

Table 12: Pearson correlation coefficients among soil indicators of Selaqui site

Pearson Correlation Matrix of Premnagar soil																	
parameters	pH	EC (µS/cm-1)	OC%	OM%	N kg/ha	P kg/ha	K kg/ha	S conc. PPM	BD(g/cm3)	MC%	MBN(mg N/kg)	MBC (mg C/kg)	Mn(ppm)	Pb(ppm)	Cd(ppm)	Mg(ppm)	MWD(mm)
pH	1	.416	.798	.798	.230	.717	.087	-.611	.502	-.470	.433	.303	-.665	.[a]	.[a]	-.417	-.557
EC (µS/cm-1)	.416	1	-.201	-.201	.619	.325	.260	.422	.069	-.287	-.112	.648	.021	.[a]	.[a]	-.082	.482
OC%	.798	-.201	1	1.000**	-.073	.552	-.047	-.927*	.494	-.400	.586	-.023	-.795	.[a]	.[a]	-.422	-.904*
OM%	.798	-.201	1.000**	1	-.073	.552	-.047	-.927*	.494	-.400	.586	-.023	-.795	.[a]	.[a]	-.422	-.904*
N kg/ha	.230	.619	-.073	-.073	1	.528	-.210	.416	.478	-.853	.528	.995**	-.491	.[a]	.[a]	-.620	.187
P kg/ha	.717	.325	.552	.552	.528	1	-.593	-.227	.947*	-.757	.814	.600	-.743	.[a]	.[a]	-.901*	-.564
K kg/ha	.087	.260	-.047	-.047	-.210	-.593	1	-.129	-.794	.399	-.674	-.242	.309	.[a]	.[a]	.773	.401
S kg/ha	-.611	.422	-.927*	-.927*	.416	-.227	-.129	1	-.192	.056	-.309	.379	.548	.[a]	.[a]	.097	.852
BD(g/cm3)	.502	.069	.494	.494	.478	.947*	-.794	-.192	1	-.760	.912*	.537	-.747	.[a]	.[a]	-.975**	-.630
MC%	-.470	-.287	-.400	-.400	-.853	-.757	.399	.056	-.760	1	-.874	-.867	.864	.[a]	.[a]	.865	.347
MBN(mg N/kg)	.433	-.112	.586	.586	.528	.814	-.674	-.309	.912*	-.874	1	.558	-.906*	.[a]	.[a]	-.954*	-.694
MBC (mg C/kg)	.303	.648	-.023	-.023	.995**	.600	-.242	.379	.537	-.867	.558	1	-.519	.[a]	.[a]	-.662	.138
Mn(ppm)	-.665	.021	-.795	-.795	-.491	-.743	.309	.548	-.747	.864	-.906*	-.519	1	.[a]	.[a]	.789	.737
Pb(ppm)	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
Cd(ppm)	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
Mg(ppm)	-.417	-.082	-.422	-.422	-.620	-.901*	.773	.097	-.975**	.865	-.954*	-.662	.789	.[a]	.[a]	1	.547
MWD(mm)	-.557	.482	-.904*	-.904*	.187	-.564	.401	.852	-.630	.347	-.694	.138	.737	.[a]	.[a]	.547	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
a. Cannot be computed because at least one of the variables is constant.

Table 13: Pearson correlation coefficients among soil indicators of Premnagar site

Pearson Correlation Matrix of Panditwari soil

parameters	pH	EC (µS/cm-1)	OC%	OM%	N kg/ha	P kg/ha	K kg/ha	S conc. PPM	BD(g/cm3)	MC%	MBN(mg N/kg)	MBC (mg C/kg)	Mn(ppm)	Pb(ppm)	Cd(ppm)	Mg(ppm)	MWD(mm)
pH	1	.684	.430	.430	-.522	.009	-.005	-.286	.384	-.049	-.423	-.046	.141	-.369	.[a]	.133	-.488
EC (µS/cm-1)	.684	1	-.021	-.021	-.289	.195	.676	-.341	.105	.338	-.301	-.581	-.204	-.596	.[a]	.085	-.941*
OC%	.430	-.021	1	1.000**	.114	-.260	-.129	-.658	-.451	.272	-.561	-.178	-.424	-.479	.[a]	-.418	.267
OM%	.430	-.021	1.000**	1	.114	-.260	-.129	-.658	-.451	.272	-.561	-.178	-.424	-.479	.[a]	-.418	.267
N kg/ha	-.522	-.289	.114	.114	1	.590	.322	-.604	-.684	.778	-.548	-.507	-.745	-.484	.[a]	-.909*	.096
P kg/ha	.009	.195	-.260	-.260	.590	1	.263	-.390	.073	.543	-.637	-.308	-.260	-.427	.[a]	-.630	-.454
K kg/ha	-.005	.676	-.129	-.129	.322	.263	1	-.505	-.522	.753	-.254	-.937*	-.708	-.710	.[a]	-.291	-.742
S kg/ha	-.286	-.341	-.658	-.658	-.604	-.390	-.505	1	.661	-.885*	.899*	.766	.868	.950*	.[a]	.841	.301
BD(g/cm3)	.384	.105	-.451	-.451	-.684	.073	-.522	.661	1	-.737	.315	.704	.909*	.575	.[a]	.632	-.129
MC%	-.049	.338	.272	.272	.778	.543	.753	-.885*	-.737	1	-.735	-.913*	-.946*	-.905*	.[a]	-.845	-.427
MBN(mg N/kg)	-.423	-.301	-.561	-.561	-.548	-.637	-.254	.899*	.315	-.735	1	.514	.609	.831	.[a]	.839	.313
MBC (mg C/kg)	-.046	-.581	-.178	-.178	-.507	-.308	-.937*	.766	.704	-.913*	.514	1	.895*	.885*	.[a]	.558	.611
Mn(ppm)	.141	-.204	-.424	-.424	-.745	-.260	-.708	.868	.909*	-.946*	.609	.895*	1	.846	.[a]	.788	.223
Pb(ppm)	-.369	-.596	-.479	-.479	-.484	-.427	-.710	.950*	.575	-.905*	.831	.885*	.846	1	.[a]	.709	.573
Cd(ppm)	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
Mg(ppm)	.133	.085	-.418	-.418	-.909*	-.630	-.291	.841	.632	-.845	.839	.558	.788	.709	.[a]	1	.023
MWD(mm)	-.488	-.941*	.267	.267	.096	-.454	-.742	.301	-.129	-.427	.313	.611	.223	.573	.[a]	.023	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
a. Cannot be computed because at least one of the variables is constant.

Table 14: Pearson correlation coefficients among soil indicators of Panditwari site

Pearson Correlation Matrix of Asan wetland soil																	
parameters	pH	EC (µS/cm-1)	OC%	OM%	N kg/ha	P kg/ha	K kg/ha	S conc. PPM	BD(g/cm3)	MC%	MBN(mg N/kg)	MBC (mg C/kg)	Mn(ppm)	Pb(ppm)	Cd(ppm)	Mg(ppm)	MWD (mm)
pH	1	.684	.430	.430	-.522	.009	-.005	-.286	.384	-.049	-.423	-.046	.141	-.369	.[a]	.133	-.488
EC (µS/cm-1)	.684	1	-.021	-.021	-.289	.195	.676	-.341	.105	.338	-.301	-.581	-.204	-.596	.[a]	.085	-.941*
OC%	.430	-.021	1	1.000**	.114	-.260	-.129	-.658	-.451	.272	-.561	-.178	-.424	-.479	.[a]	-.418	.267
OM%	.430	-.021	1.000**	1	.114	-.260	-.129	-.658	-.451	.272	-.561	-.178	-.424	-.479	.[a]	-.418	.267
N kg/ha	-.522	-.289	.114	.114	1	.590	.322	-.604	-.684	.778	-.548	-.507	-.745	-.484	.[a]	-.909*	.096
P kg/ha	.009	.195	-.260	-.260	.590	1	.263	-.390	.073	.543	-.637	-.308	-.260	-.427	.[a]	-.630	-.454
K kg/ha	-.005	.676	-.129	-.129	.322	.263	1	-.505	-.522	.753	-.254	-.937*	-.708	-.710	.[a]	-.291	-.742
S kg/ha	-.286	-.341	-.658	-.658	-.604	-.390	-.505	1	.661	-.885*	.899*	.766	.868	.950*	.[a]	.841	.301
BD(g/cm3)	.384	.105	-.451	-.451	-.684	.073	-.522	.661	1	-.737	.315	.704	.909*	.575	.[a]	.632	-.129
MC%	-.049	.338	.272	.272	.778	.543	.753	-.885*	-.737	1	-.735	-.913*	-.946*	-.905*	.[a]	-.845	-.427
MBN(mg N/kg)	-.423	-.301	-.561	-.561	-.548	-.637	-.254	.899*	.315	-.735	1	.514	.609	.831	.[a]	.839	.313
MBC (mg C/kg)	-.046	-.581	-.178	-.178	-.507	-.308	-.937*	.766	.704	-.913*	.514	1	.895*	.885*	.[a]	.558	.611
Mn(ppm)	.141	-.204	-.424	-.424	-.745	-.260	-.708	.868	.909*	-.946*	.609	.895*	1	.846	.[a]	.788	.223
Pb(ppm)	-.369	-.596	-.479	-.479	-.484	-.427	-.710	.950*	.575	-.905*	.831	.885*	.846	1	.[a]	.709	.573
Cd(ppm)	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
Mg(ppm)	.133	.085	-.418	-.418	-.909*	-.630	-.291	.841	.632	-.845	.839	.558	.788	.709	.[a]	1	.023
MWD(mm)	-.488	-.941*	.267	.267	.096	-.454	-.742	.301	-.129	-.427	.313	.611	.223	.573	.[a]	.023	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
a. Cannot be computed because at least one of the variables is constant.

Table 15: Pearson correlation coefficients among soil indicators of Asan wetland site

Pearson Correlation Matrix of Mussoorie soil																
parameters	pH	EC (µS/cm-1)	OC%	OM%	N kg/ha	P kg/ha	K kg/ha	S conc. PPM	BD(g/cm3)	MC%	MBN (mg N/kg)	MBC (mg C/kg)	Mn(ppm)	Pb(ppm)	Cd(ppm)	Mg(ppm)	MWD (mm)
pH	1	.257	-.180	-.180	-.195	-.298	.003	.244	-.300	.058	.195	-.077	.288	.[a]	-.491*	.014	.055
EC (µS/cm-1)	.257	1	-.246	-.246	-.188	.531*	.758**	.330	.170	-.307	.164	-.236	.334	.[a]	-.281	.302	.112
OC%	-.180	-.246	1	1.000**	-.285	-.308	.068	-.244	.260	-.579**	.050	.346	-.065	.[a]	.374	.010	-.133
OM%	-.180	-.246	1.000**	1	-.285	-.308	.068	-.244	.260	-.579**	.050	.346	-.065	.[a]	.374	.010	-.133
N kg/ha	-.195	-.188	-.285	-.285	1	.209	-.406	-.255	-.275	.342	-.224	-.120	-.289	.[a]	.255	-.147	.083
P kg/ha	-.298	.531*	-.308	-.308	.209	1	.341	.394	.357	-.225	-.198	-.393	-.192	.[a]	.027	.018	.153
K kg/ha	.003	.758**	.068	.068	-.406	.341	1	.224	.259	-.455*	.275	-.083	.341	.[a]	-.077	.119	.149
S kg/ha	.244	.330	-.244	-.244	-.255	.394	.224	1	.141	-.113	-.042	-.299	.044	.[a]	-.180	-.160	.128
BD(g/cm3)	-.300	.170	.260	.260	-.275	.357	.259	.141	1	-.551*	.106	-.143	-.012	.[a]	.337	.170	.037
MC%	.058	-.307	-.579**	-.579**	.342	-.225	-.455*	-.113	-.551*	1	.050	-.015	.036	.[a]	-.221	-.024	-.131
MBN (mg N/kg)	.195	.164	.050	.050	-.224	-.198	.275	-.042	.106	.050	1	.113	.676**	.[a]	-.041	.049	.240
MBC (mg C/kg)	-.077	-.236	.346	.346	-.120	-.393	-.083	-.299	-.143	-.015	.113	1	.050	.[a]	.643**	.222	-.026
Mn(ppm)	.288	.334	-.065	-.065	-.289	-.192	.341	.044	-.012	.036	.676**	.050	1	.[a]	-.152	.155	.482*
Pb(ppm)	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
Cd(ppm)	-.491*	-.281	.374	.374	.255	.027	-.077	-.180	.337	-.221	-.041	.643**	-.152	.[a]	1	-.059	.103
Mg(ppm)	.014	.302	.010	.010	-.147	.018	.119	-.160	.170	-.024	.049	.222	.155	.[a]	-.059	1	-.285
MWD(mm)	.055	.112	-.133	-.133	.083	.153	.149	.128	.037	-.131	.240	-.026	.482*	.[a]	.103	-.285	1
*. Correlation is significant at the 0.05 level (2-tailed).																	
**. Correlation is significant at the 0.01 level (2-tailed).																	
a. Cannot be computed because at least one of the variables is constant.																	

Table 16: Pearson correlation coefficients among soil indicators of Mussoorie site

Table 17: Rotated varimax principal component analysis with eigenvalue, variance, and factor loadings of Shishambara (Dehradun)

	Rotated Component Matrix			
	Component			
parameters	1	2	3	4
PH	**0.988**	-0.114	-0.024	-0.104
EC (µS/cm-1)	**0.934**	0.301	0.077	-0.177
OC%	**-0.769**	0.400	0.441	0.232
OM%	**-0.769**	0.400	0.441	0.232
N kg/ha	**0.688**	-0.311	0.563	0.336
P kg/ha	0.167	0.129	**-0.977**	-0.024
K kg/ha	-0.380	**0.871**	-0.057	-0.308
S kg/ha	-0.276	**-0.948**	0.135	-0.081
BD(g/cm3)	**-0.800**	-0.461	-0.340	-0.176
MC%	0.084	-0.178	0.086	**0.977**
MBN (mg N/kg)	0.208	0.028	**0.952**	-0.224
MBC (mg C/kg)	-0.409	0.103	**0.876**	0.233
Mn(ppm)	**0.941**	0.167	-0.233	0.179
Cd(ppm)	0.308	-0.444	0.049	**-0.840**
Mg(ppm)	0.102	**-0.689**	0.670	0.255
MWD (mm)	0.139	**0.949**	0.114	0.258
Eigen value	5.622	4.050	4.005	2.323
% Variance	35.139	25.311	25.034	14.517
% Cumulative variance	35.139	60.450	85.483	100.000
Weight factor	0.351390041	0.2531071	0.2503362	0.145166637
SQI	0.54			
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.				
a. Rotation converged in 11 iterations.				

Table 18: Rotated varimax principal component analysis with eigenvalue, variance, and factor loadings of Selaqui (Denradun)

Rotated Component Matrix				
Parameters	Component			
	1	2	3	4
PH	**-0.992**	0.096	-0.033	0.074
EC (µS/cm-1)	**-0.881**	0.455	-0.121	-0.045
OC%	-0.053	**0.995**	-0.081	-0.035
OM%	-0.053	**0.995**	-0.081	-0.035
N kg/ha	-0.016	-0.249	**0.724**	0.643
P kg/ha	-0.136	**0.874**	-0.211	0.417
K kg/ha	0.447	-0.150	**-0.662**	-0.582
S kg/ha	**0.679**	-0.238	0.677	-0.156
BD(g/cm3)	0.140	-0.143	**0.969**	0.142
MC%	0.550	-0.210	**0.806**	0.055
MBN (mg N/kg)	**0.705**	-0.508	0.321	0.377
MBC (mg C/kg)	**-0.832**	-0.488	-0.219	-0.144
Mn(ppm)	**0.923**	0.064	0.023	-0.378
Mg(ppm)	-0.119	**0.709**	-0.471	-0.511
MWD (mm)	-0.062	0.108	0.121	**0.985**
Eigen value	4.828	4.179	3.473	2.521
% Variance	32.185	27.860	23.151	16.804
% Cumulative variance	32.185	60.045	83.196	100.000
Weight factor	0.321850692	0.278601132	0.231512	0.168036
SQI	0.700			
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.				
a. Rotation converged in 7 iterations.				

Table 19: Rotated varimax principal component analysis with eigenvalue, variance, and factor loadings of Premnagar (Dehradun)

Rotated Component Matrix			
Parameters	Component		
	1	2	3
PH	0.080	**0.841**	0.450
EC (µS/cm-1)	-0.182	-0.096	**0.916**
OC%	0.223	**0.972**	-0.060
OM%	0.223	**0.972**	-0.060
N kg/ha	0.463	-0.138	**0.842**
P kg/ha	**0.713**	0.442	0.408
K kg/ha	**-0.926**	0.167	0.214
S kg/ha	0.030	**-0.936**	0.343
BD(g/cm3)	**0.894**	0.324	0.197
MC%	**-0.699**	-0.277	-0.591
MBN (mg N/kg)	**0.885**	0.404	0.159
MBC (mg C/kg)	0.487	-0.088	**0.854**
Mn(ppm)	-0.605	**-0.686**	-0.279
Mg(ppm)	**-0.928**	-0.240	-0.280
MWD (mm)	-0.489	**-0.797**	0.354
Eigen value	5.495	5.242	3.512
% Variance	36.636	34.947	23.416
% Cumulative variance	36.636	71.584	94.999
Weight factor	0.385648977	0.3678676	0.246483456
SQI	1.030		
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.			

Table 20: Rotated varimax principal component analysis with eigenvalue, variance, and factor loadings of Panditwari (Dehradun)

Rotated Component Matrix				
Parameters	Component			
	1	2	3	4
PH	0.361	**0.752**	-0.552	-0.016
EC (µS/cm-1)	-0.179	**0.984**	-0.018	0.018
OC%	-0.168	-0.069	**-0.983**	-0.020
OM%	-0.168	-0.069	**-0.983**	-0.020
N kg/ha	-0.613	-0.393	0.030	**-0.684**
P kg/ha	-0.040	0.213	0.276	**-0.937**
K kg/ha	**-0.803**	0.546	0.231	-0.054
S kg/ha	**0.599**	-0.236	0.574	0.506
BD(g/cm3)	**0.918**	0.278	0.282	0.029
MC%	**-0.804**	0.204	-0.143	-0.540
MBN (mg N/kg)	0.236	-0.267	0.534	**0.767**
MBC (mg C/kg)	**0.874**	-0.434	0.058	0.209
Mn(ppm)	**0.910**	-0.043	0.273	0.309
Pb(ppm)	**0.637**	-0.491	0.404	0.436
Mg(ppm)	0.516	0.172	0.309	**0.780**
MWD (mm)	0.210	**-0.926**	-0.246	0.193
Eigen value	5.452	3.606	3.480	3.462
% Variance	34.075	22.535	21.750	21.640
% Cumulative variance	34.075	56.610	78.360	100.000
Weight factor	0.341	0.225	0.217	0.216
SQI	0.680			
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.				
a. Rotation converged in 8 iterations.				

Table 21: Rotated varimax principal component analysis with eigenvalue, variance, and factor loadings of Asan wetland

Rotated Component Matrix					
Parameters	Component				
	1	2	3	4	5
PH	**-0.724**	-0.188	0.254	-0.316	0.218
EC (µS/cm-1)	0.323	0.418	-0.067	**0.554**	0.411
OC%	**0.926**	-0.129	0.047	0.013	0.064
OM%	**0.926**	-0.129	0.047	0.013	0.064
N kg/ha	**0.592**	-0.024	0.444	0.185	-0.074
P kg/ha	-0.309	0.037	0.100	0.038	**0.867**
K kg/ha	0.164	-0.058	-0.202	-0.074	**0.629**
S kg/ha	-0.207	0.102	**0.507**	0.240	-0.413
BD(g/cm3)	-0.261	**0.861**	0.171	-0.043	0.141
MC%	-0.031	-0.377	-0.369	**0.772**	-0.084
MBN (mg N/kg)	-0.097	**0.761**	-0.382	0.030	-0.105
MBC (mg C/kg)	-0.309	**-0.614**	-0.285	-0.100	0.403
Mn(ppm)	0.097	-0.034	**0.868**	-0.114	-0.066
Mg(ppm)	0.200	0.159	0.270	**0.808**	-0.111
Eigen value	3.081	2.124	1.799	1.780	1.764
% Variance	22.007	15.171	12.847	12.714	12.602
% Cumulative variance	22.007	37.178	50.025	62.739	75.341
Weight factor	0.292091084	0.2013691	0.170516417	0.168752387	0.167271
SQI	0.44				
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.					
a. Rotation converged in 9 iterations.					

Table 22: Rotated varimax principal component analysis with eigenvalue, variance, and factor loadings of Mussoorie

	Rotated Component Matrix				
	Components				
Parameters	1	2	3	4	5
OC%	**0.923**	-0.16	-	0.189	-
OM%	**0.923**	-0.16	-	0.189	-
MC%	**-0.726**	-0.515	-	-	-
N kg/ha	**-0.558**	-0.182	-0.241	0.472	-0.188
P kg/ha	**-0.292**	0.82	-0.235	0.225	-0.114
EC (µS/cm-1)	-0.128	**0.777**	0.279	-0.256	0.272
K kg/ha	0.214	**0.701**	0.371	-0.115	0.164
BD(g/cm3)	0.402	**0.577**	-	0.297	-
S kg/ha	-	**0.501**	-	-0.377	-0.336
Mn(ppm)	-	-	**0.902**	-0.168	-
MBN (mg N/kg)	-	-	**0.802**	-	-
MWD (mm)	-0.13	0.178	**0.589**	0.197	-0.577
Cd(ppm)	0.269	-	-	**0.868**	-
PH	-	-0.134	0.278	**-0.729**	-
MBC (mg C/kg)	0.279	-0.414	0.287	**0.45**	0.343
Mg(ppm)	-	0.147	-	-	**0.879**
Eigen value	3.031	2.954	2.304	2.22	1.501
% Variance	18.944	18.463	14.4	13.875	9.384
% Cumulative variance	18.944	37.407	51.807	65.683	75.067
Weight factor	0.252361224	0.245954	0.191829	0.184835	0.125008
SQI	**0.59**				

List of Figure

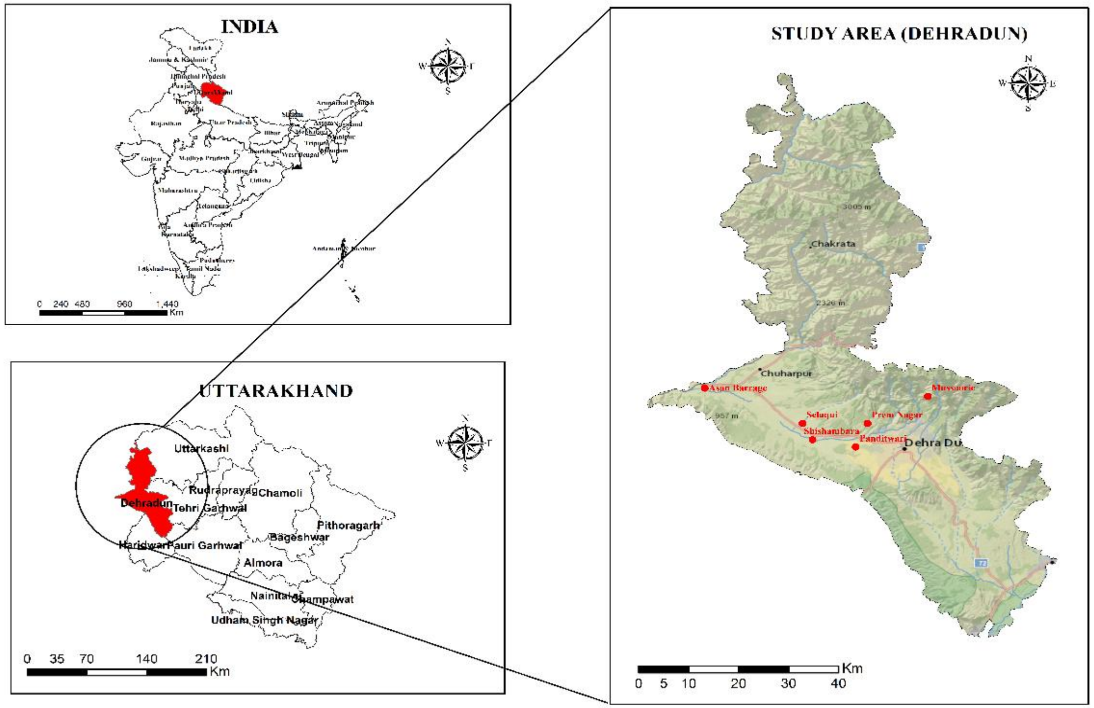


Figure 1: Study area and Sampling Locations map of Dehradun, Asan wetland and Mussoorie, Uttarakhand

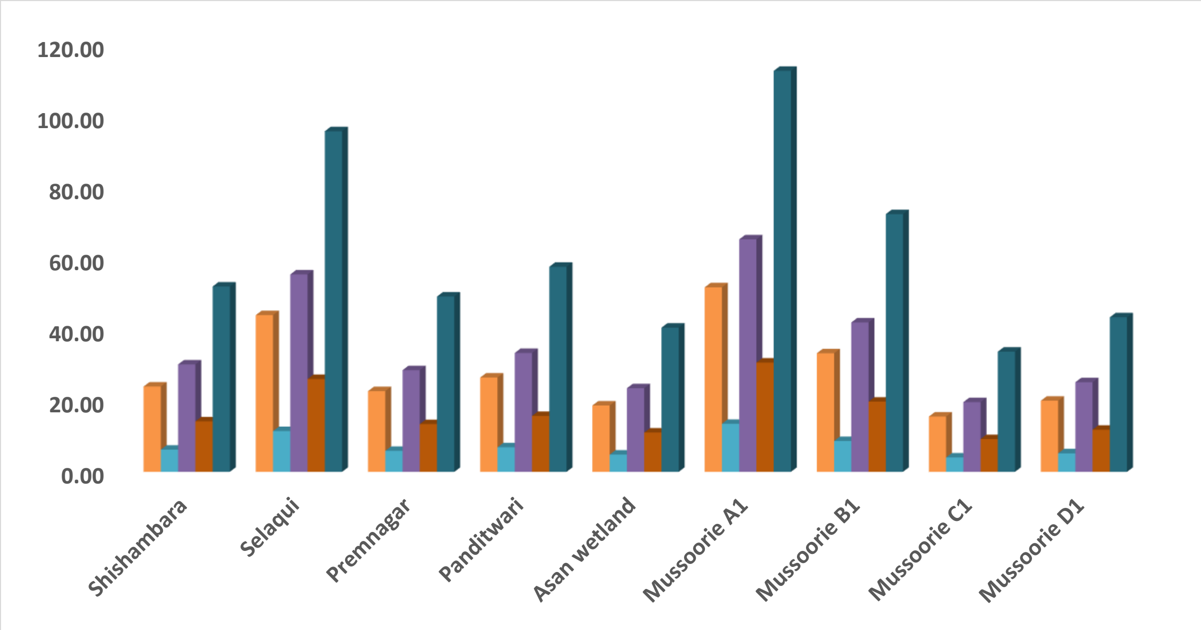


Figure 2: Above ground Biomass, below-ground biomass, carbon stock and CO_2 sequestration of the Dehradun, Asan wetland site, and Mussoorie site

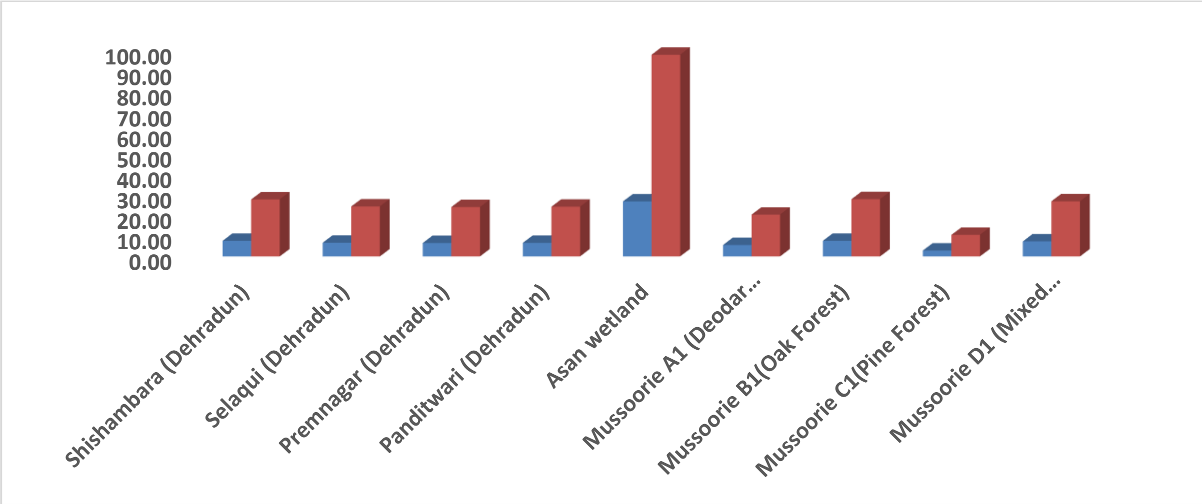


Figure 3: carbon biomass and CO_2 sequestration of the Dehradun, Asan wetland site, and Mussoorie site

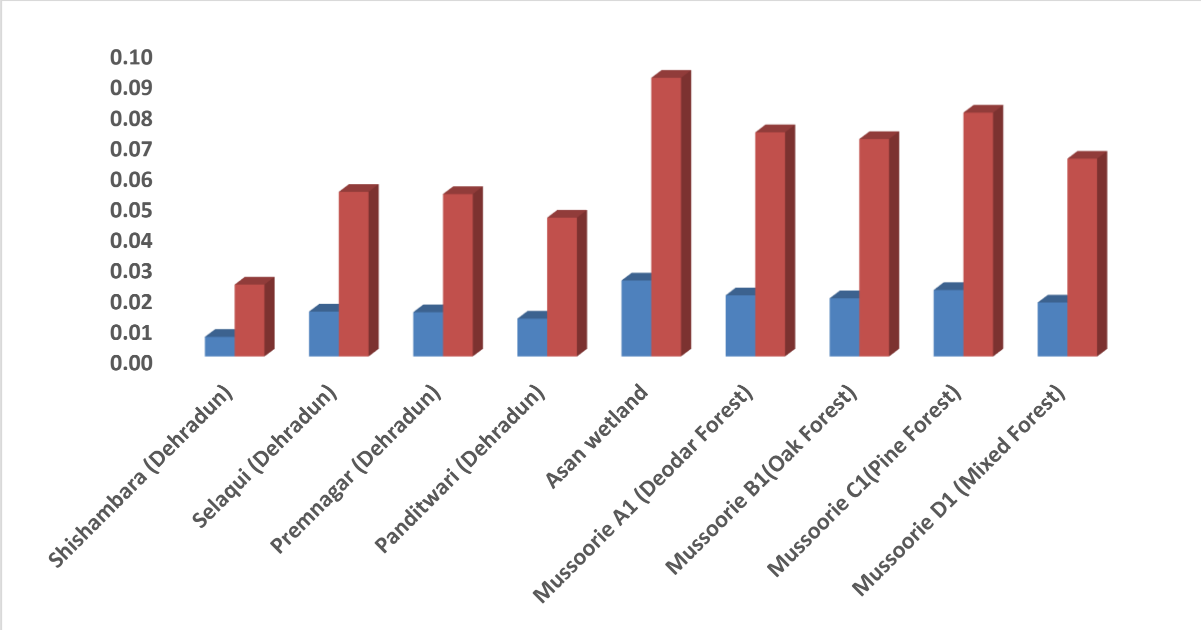


Figure 4: carbon biomass and CO_2 sequestration of the Dehradun, Asan wetland site, and Mussoorie site

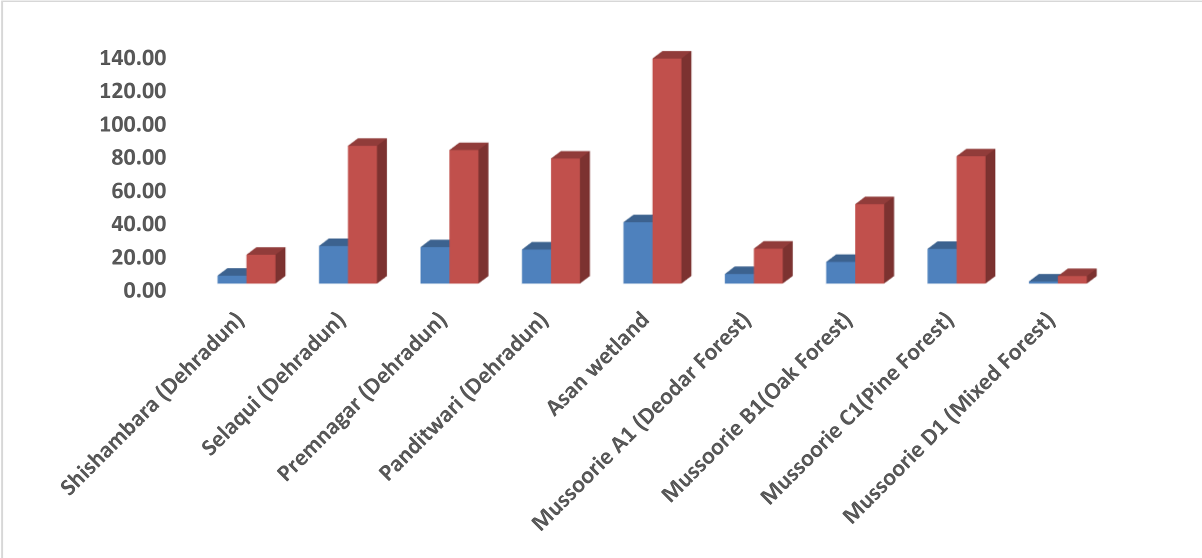


Figure 5: carbon biomass and CO_2 sequestration of the Dehradun, Asan wetland site, and Mussoorie site

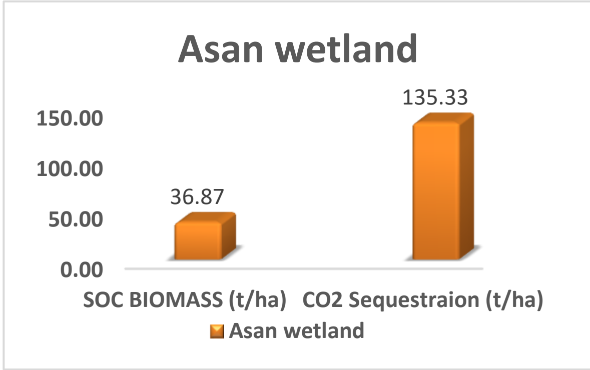


Figure 6: Carbon stock and CO_2 sequestration of Asan wetland

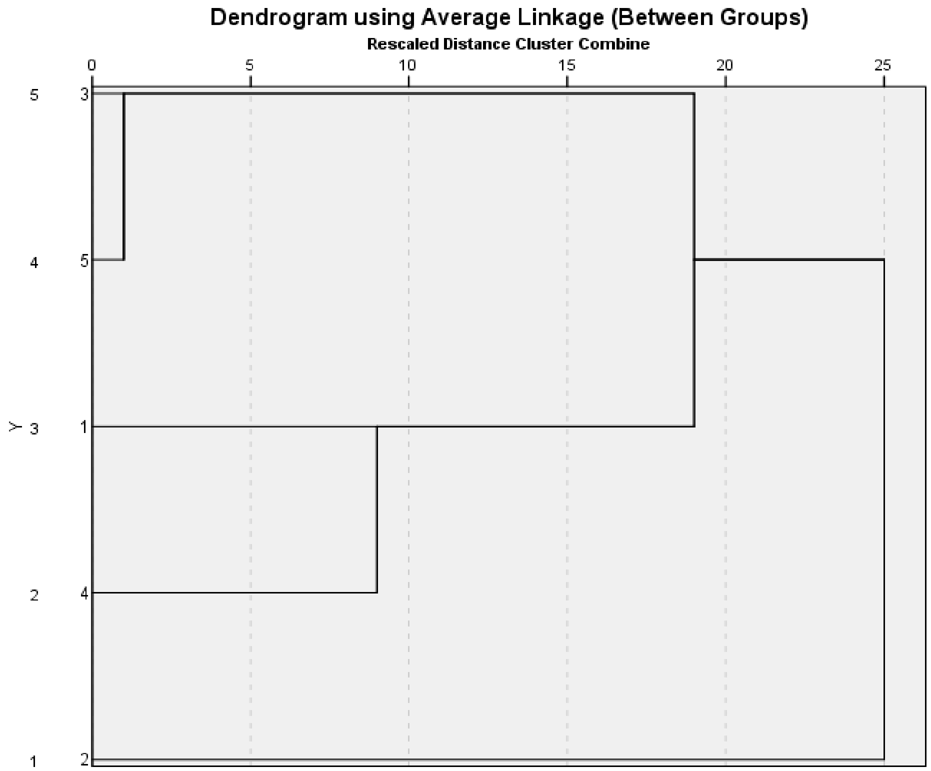


Figure 7: Dendrogram showing clustering of soil sampling sites of Shishambara (Dehradun)

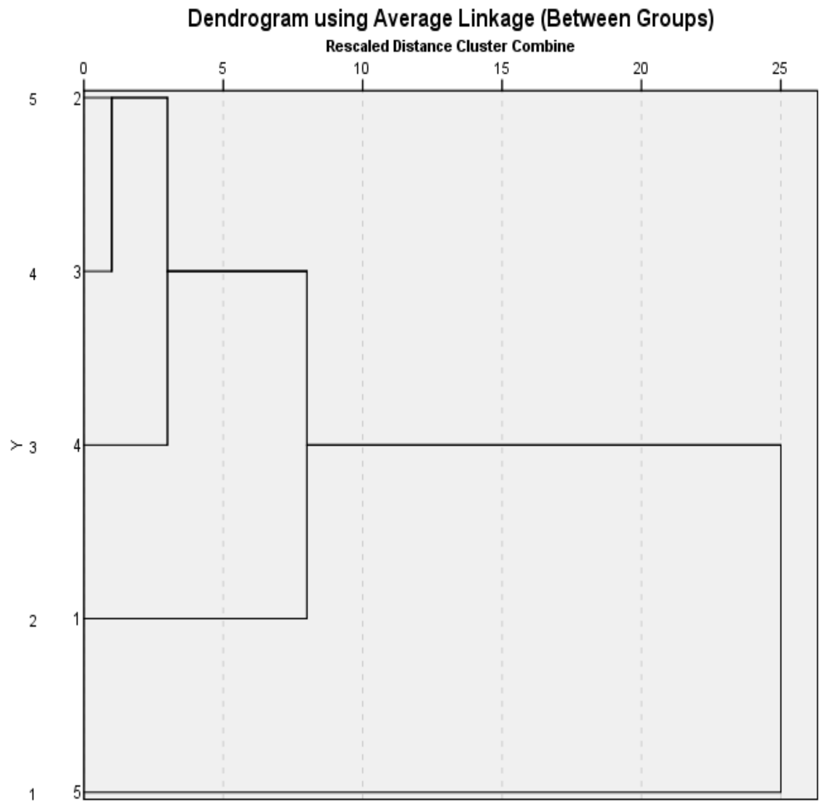


Figure 8: Dendrogram showing clustering of soil sampling site of Selaqui (Dehradun)

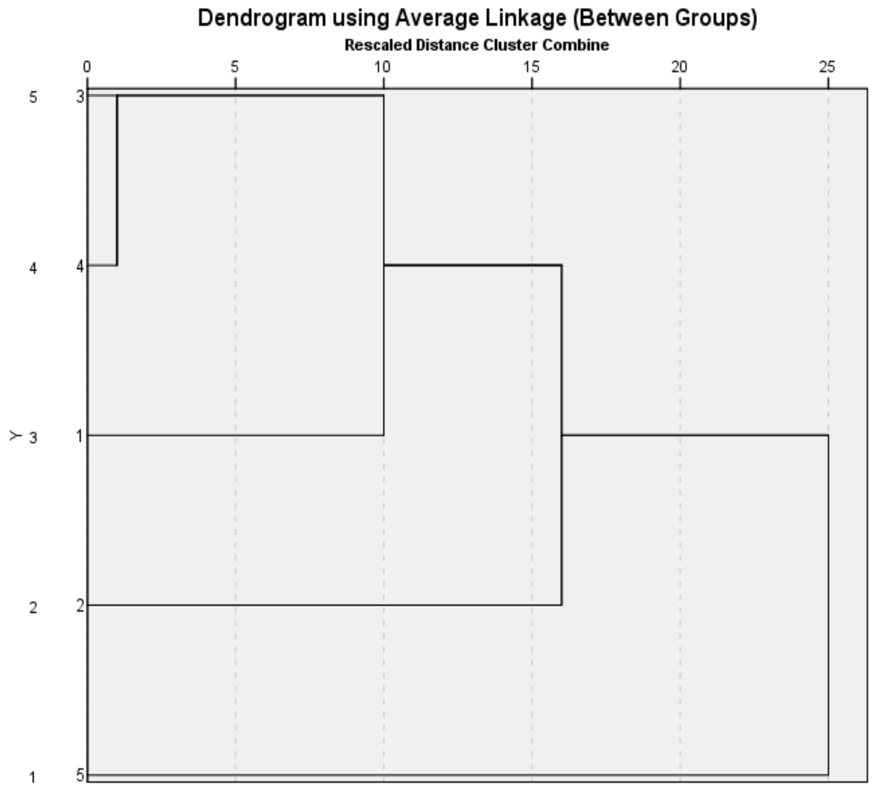


Figure 9: Dendrogram showing clustering of soil sampling site of Premnagar (Dehradun)

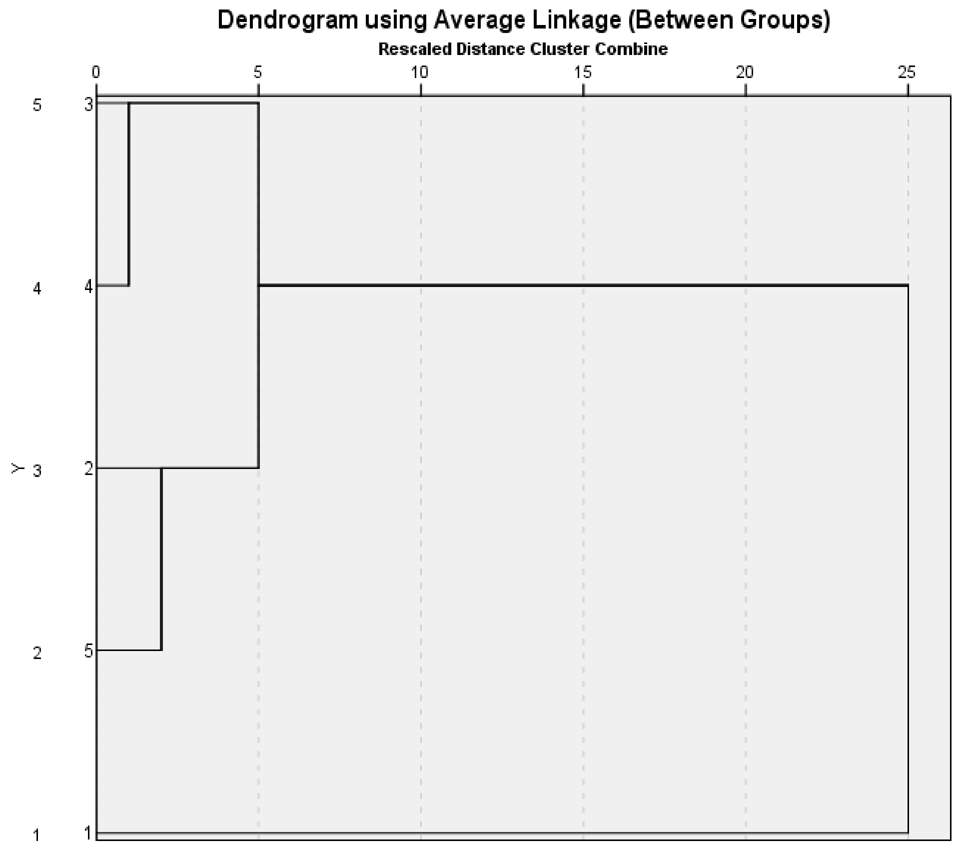
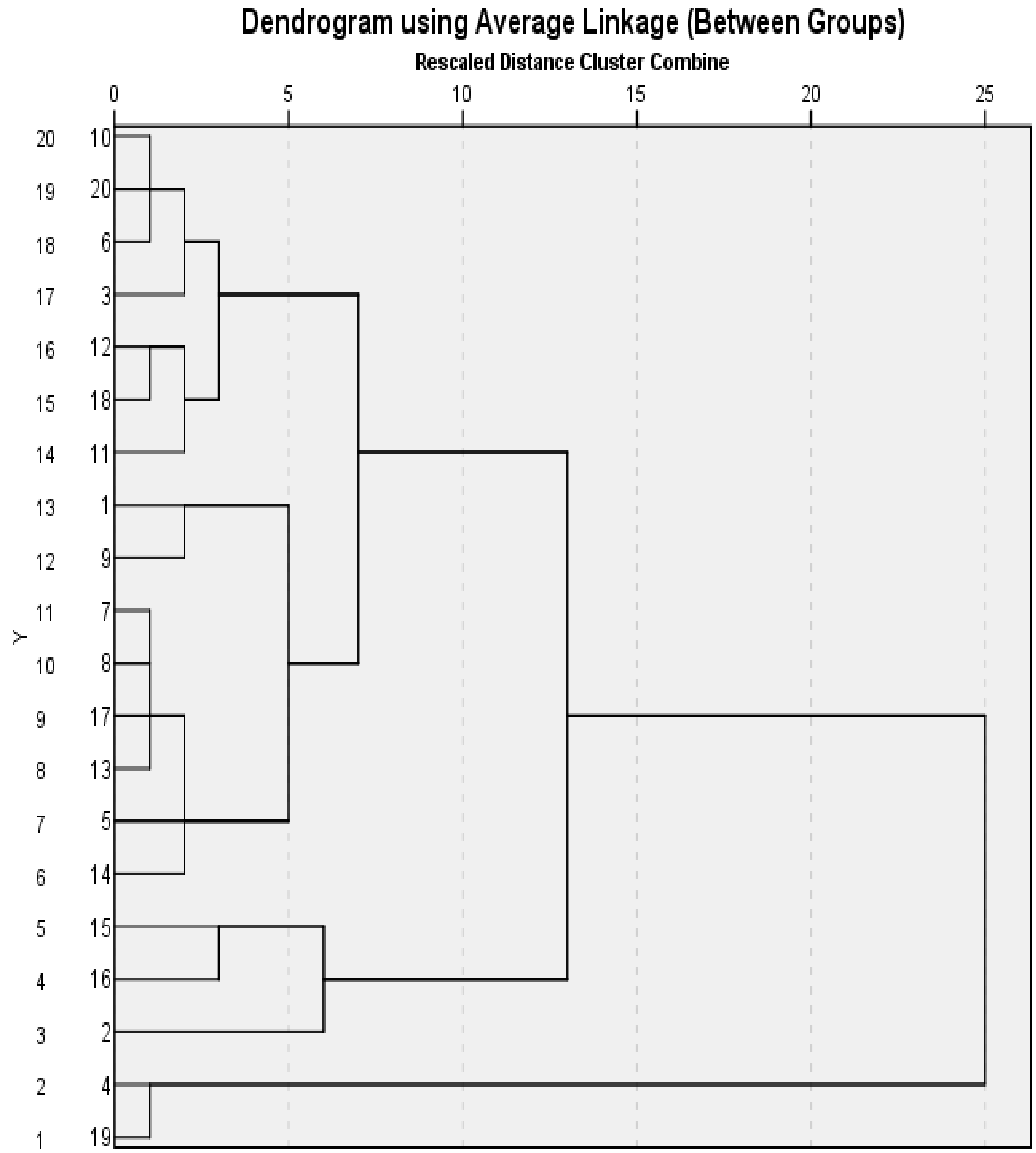


Figure 10: Dendrogram showing clustering of soil sampling site of Panditwari (Dehradun)


Dendrogram using Average Linkage (Between Groups)
Rescaled Distance Cluster Combine
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17 3
16 12
15 18
14 11
13 1
12 9
11 7
10 8
9 17
8 13
7 5
6 14
5 15
4 16
3 2
2 4
1 19

Figure 11: Dendrogram showing clustering of soil sampling sites of Asan wetland

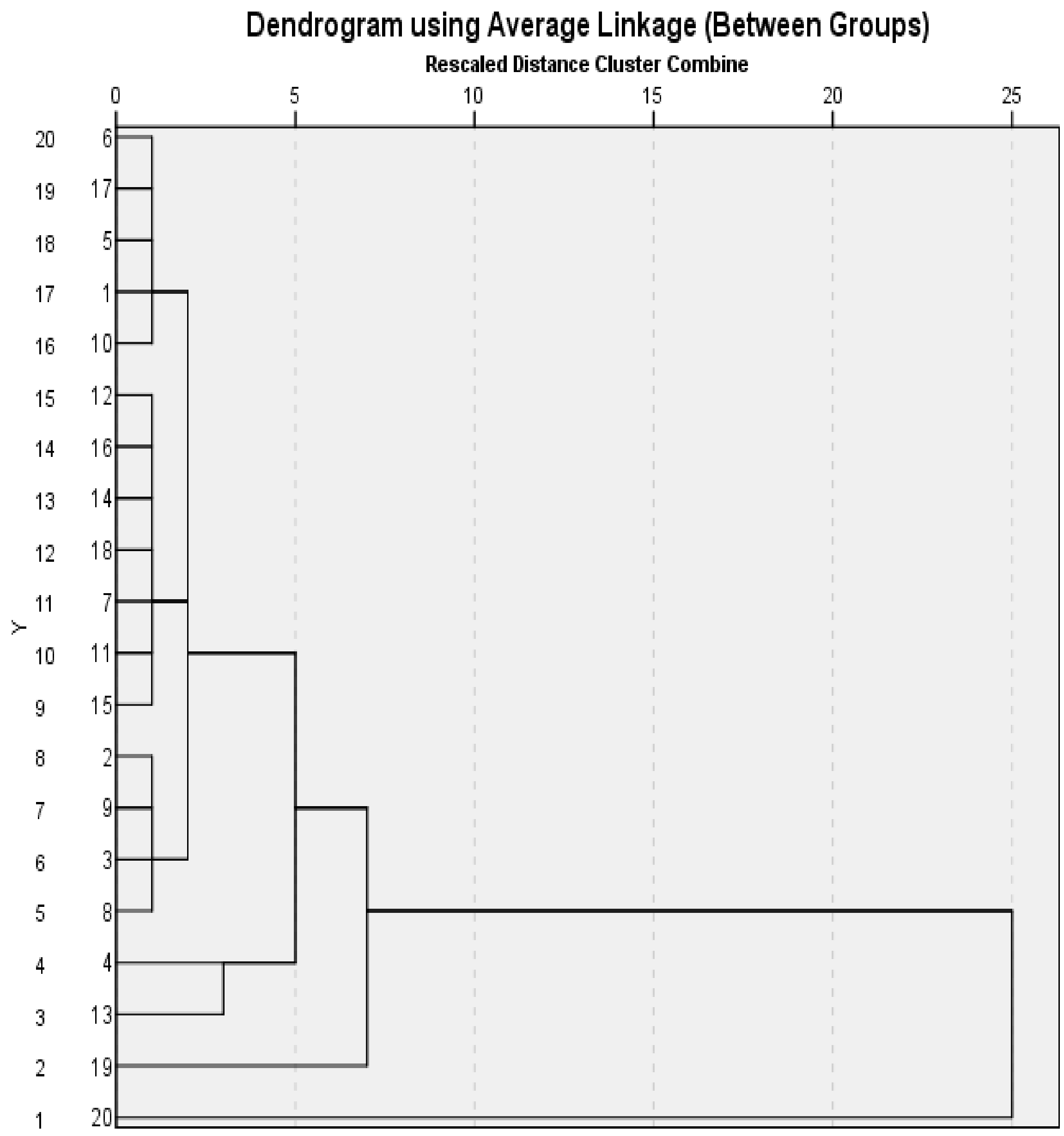
Dendrogram using Average Linkage (Between Groups)
Rescaled Distance Cluster Combine
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Figure 12: Dendrogram showing clustering of soil sampling sites of Mussoorie

Supplementary Files