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Soil Physico-Chemical Properties in Different Forests of Tehri & Pauri-Garhwal Himalayas, Uttarakhand, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Garhwal Himalaya is part of the Himalayan biodiversity hotspot and represents the western Himalayan landscape of the Indian Himalayas. The aim of the present investigation was to analyze soil properties in different forest areas across different altitudes of the Garhwal Himalayas, i.e., *Quercus leucotrichophora* Forest (>1900 m), *Anogessious latifolia* Forest (1300 m), Mixed Forest (900 m), and Shrub-dominated Forest (600 m). Physical and chemical properties of the soil were estimated using all the standard procedures, such as the Walkley-Black method for SOC and the Kjeldahl method for Nitrogen, in the department laboratory of HNB Garhwal University. The results of this study revealed that the high-altitude temperate *Quercus luecotrichophora* Forest has dominated in all soil properties and has greater potential to store soil organic carbon stock and

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Nitrogen (29.64 ± 3.48 t ha-1) (Nitrogen 254.22 ± 27.16 kg ha-1) than sub-tropical *Anogeissus latifolia* Dominated Forest, Mixed Forest, and Shrub Dominated Forest with SOC stock values of 18.34 ± 2.90, 14.52 ± 2.27, and 10.74 ± 1.57 t ha^{-1} and Nitrogen values of 205.47±7.10, 197.07±1.50, 193.79±8.15.

Keywords: Garhwal Himalaya; Quercus luecotrichophora; Anogeissus latifolia; forests; carbon sink; climate change; soil physico-chemical properties.

1. INTRODUCTION

The Himalayas are the rich diverse and most fragile forest ecosystem, with tropical forests to alpine forests. Garhwal Himalayas are situated in the western part of the Central Himalayas with a wide altitudinal gradient range and rich biodiversity making it interesting for research studies [1], and have great potential to sequestrate carbon and mitigate climate change.

Vegetation plays an important role in soil formation. The vegetation enhances the aeration, hydraulic conductivity, water-holding capacity, soil structure, and infiltration rate [2].

Forests play an important role in soil formation and also influence physicochemical characteristics. The forest soil influences the composition of the forest stand, ground cover, rate of tree growth, and other variables. Forest soil’s physiochemical properties vary through time and place because of changes in terrain, climate, physical weathering processes, plant cover, microbiological activity, and a number of other biotic and abiotic factors. Soil gets colour through processes called lithochromatic and pseudo-chromatic processes. Soil colour is influenced by its mineral composition, organic matter, water content, and other factors. The soils with high calcium content are white to grey colour and soils with high iron content are in red-brown to black coloured.

Plant tissues (aboveground and belowground detritus) are the main source of soil organic matter (SOM), influencing physicochemical characteristics. Soil organic carbon depends on organic matter availability in the soil, and it is an important factor in indicating soil quality and productivity. The plants greatly influence the soil's physical and chemical characteristics [3]. Soil organic carbon (soc) sequestration is the transfer and storage of atmospheric carbon into the soil through decomposition. Estimates of SOC stocks are required to assess the role of soil in the world carbon cycle [4]. Soil pH is the concentration of H+ ions used in measurement. The soil pH of 5.5 – 7.0 is the optimal suitable range for the most of the plant growth [5]. The soil's water holding capacity (WHC) determines how much water is retained by soil particles. It is affected by soil structure and aggregate stability of the soil. Bulk density is defined as the soil mass per unit volume. It indicates the compactness of the soil and its structure. It affects root growth, proliferation, aeration, soil water regime, and biomass productivity [6]. The other soil physical properties like moisture content, texture, and soil porosity influence the microbial activity, infiltration rate and gaseous exchange, nutrient uptake, overall plant growth, and Nutrient retention.

Soil nitrogen is available in the soil as ammoniacal, nitrate, and nitrite forms is taken up and utilized by the plants, influencing plant growth, promoting productivity, species diversity, and sustainability of forest ecosystems. It is estimated that more than 90% of the nitrogen reserves are in soil organic pool through N mineralization. This nitrogen is a limiting factor for the productivity of forest ecosystems [7]. The C:N ratio of soil refers to the proportion of carbon to nitrogen. In organic matter, carbon constantly predominates over nitrogen, the abbreviated C:N ratio is typically expressed as a single value [8]. The increase in greenhouse gas emissions and climate change on earth have all eyes shifting towards mitigation activities, while forest terrestrial ecosystems are the major source of soil carbon pools and nitrogen pools.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

This study was carried out in the Silkakal (30°14’59.9064’’ N 78° 46’ 43.4676’’ E), Badiyalgarh (30° 14’ 20.1552’’ N, 78° 48’ 27.846’’ E) (Tehri Garhwal) and Adwani (30° 4’ 20.4924’’ N, 78° 42’ 58.626’’ E) (Pauri Garhwal) regions of Garhwal Himalaya forest areas in districts of Tehri and Pauri of Uttarakhand, India (Fig. 1). The present investigation includes four sites of different forest lands areas i.e., *Anogeissus latifolia* Dominated Forest (ALDF: towards

Silkakal), Mixed Forest Area (MF: towards Silkakal), Shrub Dominated Forest (SDF: towards Badiyalgarh), and *Quercus luecotrichophora* Forest (QLDF: Pauri, Adwani), across different altitude ranges from 600 to 2000m asl. The average annual rainfall is around 800 – 1500 mm and average temperature rises up to 35℃ in summers and fall up to 15℃ in the winters.

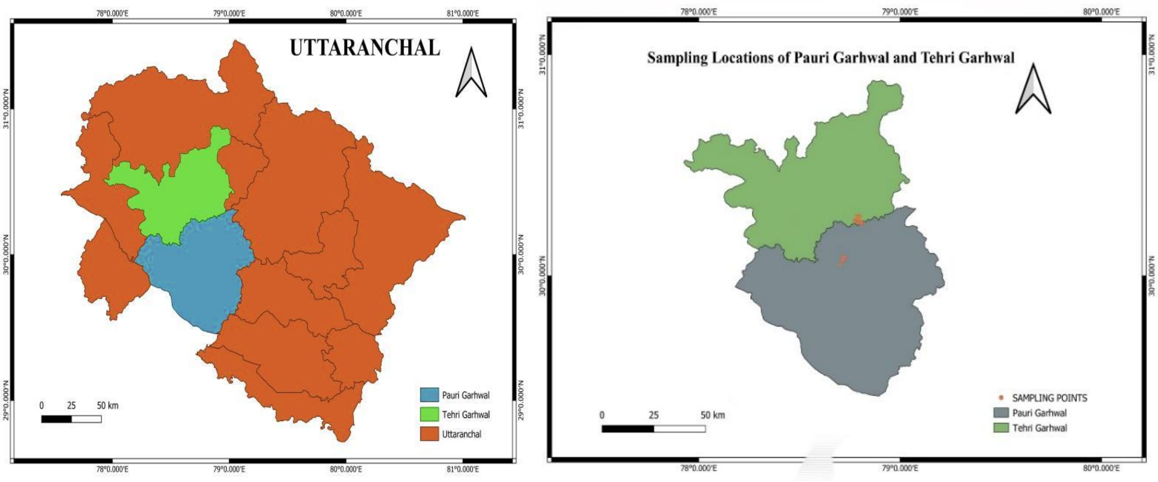

Fig. 1. View of Indian state of Uttarakhand (Left) and Study area (Right)

Table 1. Methodology used for the analysis of different soil parameters

S No	Soil Parameter	Formula/ Method	Reference
1.	Moisture Content (%)	Fresh weight of soil (g) – dry weight of soil (g) / Dry weight of soil (g) x100	Upreti, [9]
2.	Soil Texture and Class	Weight of sieved soil proportion / Total soil sample weight x 100 **Class:** Based on texture percentage values and assessed by using texture triangle method.	USDA, [10]
3.	Soil bulk density (g/cm^3)	Dry soil weight (g)/ Soil volume (cm^3) Soil volume (cm^3) = 3.14 x radius^2 x ring height (h)	ISO, [11].
4.	Water holding capacity (%)	W2-W3-W4 / W3-W1 x100	Upreti, [9]
5.	Soil pH	Determined using dynamic digital pH meter	Jackson, [12].
6.	Soil organic carbon (%)	10 (B-T) / B x 0.003 x 100 / weight of soil (g)	Walkley & Black, [13].
7.	SOC Stock ($t\ ha^{-1}$)	Soil bulk density x Soil depth x SOC (%)	Pearson, [14].
8.	Soil Nitrogen (kg/ha^{-1})	14 x Tv x 0.02N x 2.24 x 10^6 / Soil sample weight (gm) x 1000 Kg/ha x 0.4 = Kg/acre	Sáez-Plaza et al. [15].
9	Soil colour	Munsell colour chart	Munsell, [16].
10	Soil organic matter (SOM)	SOM% = Soil organic carbon (%) × 1.724.	Budiman et al., [17]
11	C:N ratio	The proportion of carbon to nitrogen	Flavel and Murphy, [8].

2.2 Data Collection

The 9 Soil samples were collected from 3 sites randomly from each forest area with 3 depths i.e., 0- 20cm, 20-40cm and 40-60cm. Thus, 36 samples were collected from all four forest areas. The soil's physicochemical properties were analyzed using all standard procedures (Table 1) in the department laboratory and mean values were reported among all samples (Table 3, Table 4 & Table 6).

3. RESULTS AND DISCUSSION

3.1 Soil Physical Properties

3.1.1 Moisture content (MC %)

In present study, the soil MC% ranges from 1.52 ± 0.62 to 7.48 ± 2.15%. The highest MC was found in Q. *leucotrichophora* dominated forest (7.48±2.15%) because of good WHC of soil and higher proportion of clay particles as well as dense forest cover and followed by forest areas of MF, ALDF and SDF with the values of 5.22 ± 0.77, 3.05 ± 0.42 and 1.52 ± 0.62% respectively.

Mahato et al*.,* [18] reported MC of 14.39% in forest lands of the Garhwal Himalaya. Chauhan et al*.,* [19] also reported the MC ranged from 9.01 to 16.09% in sub-tropical forest belt of the Garhwal Himalayas. These values of MC are higher than the present study.

3.1.2 Water holding capacity (WHC %)

The WHC of present study ranged from 15.29 to 63.68% in different forest areas. Amongst the study sites, the highest WHC (48.63%) was found in QLDF due to good amount of clay particles and hold maximum water content in the soil which followed by ALDF, SDF and MF with the reported values of 33.71, 31.37 and 29.52% respectively, all forests types have shown moderate level of WHC. Chauhan et al*.,* [19] also reported the values of WHC ranged from 24.84 to 55.23% in the similar *Anogeissus latifolia* forests of Garhwal Himalayas, the present study estimates also falls within the same range. Mahato et al*.,* [18], reported WHC value of 24.17% for the forest of Garhwal Himalaya and this value is lower than the present study.

3.1.3 Bulk density (BD g cm^{-3})

Bulk density in the present study ranges from 0.73 ± 0.07 to 0.84 ± 0.24 (Among over all individual sample values range 0.41 to 1.06 g cm3) in different forest areas. The highest BD was found in *Q. leucotrichophora* dominated forest 0.84 g cm3 followed by SDF, ALDF and MF with the values of 0.79, 0.73 and 0.70 g cm3. Chauhan et al*.,* [19] reported BD values from 0.90 to 1.06 g cm3. Bhat et al*.,* [20] in temperate Himalayan forests reported BD ranged from 1.41 to 1.59 g cm-3. Bam and Surendra [21] study BD of forest lands (1.0 g cm-3) and shrub lands (1.4 g cm-3). Mahato et al*.,* [18] in the study of community managed forest reported BD of 1.29 g cm-3. All other works reported BD values were higher than the present study. It might be because of higher proportion of gravel particles which contributed more than 50% of the tested samples, where compactness of soil reduces due to presence of gravel.

3.1.4 Soil texture (%)

The particle of sand ranges from 51.67 (QLDF) to 66.67% (MF). silt particle also ranges from 7.35 (SDF) to 9.99% (ALDF) and clay particle ranges from 23.58 (MF) to 39.07% (QLDF). The highest proportion of soil particles was of sand followed by silt and clay in all the depths. The texture class was sandy clay loam and sandy clay. Chauhan et al*.,* [19] reported that the highest proportion reported of sand particle followed by silt and clay and texture class was sandy clay. Mahato et al*.,* [18] stated the highest proportion of sand particle followed by silt and clay. Munesh et al*.* [22] study on *A. latifoila* stands reported similar proportion of soil particles.

3.1.5 Texture class

A. latifolia dominated forest and mixed forest having texture class of Sandy Clay Loam and *Q. leucotrichophora* dominated forest and shrub forest have Sandy Clay. The no variation in texture class was reported with the soil depths.

3.1.6 Soil colour

Amongst the forest areas, various types of soil colour has been reported such as Pale Brown colour (*A. latifolia* dominated forest), Light Grey Colour (Mixed Forest), Yellowish Brown, Reddish Yellow & Pale Brown colour (Shrub Forest) and Brown to Yellowish Brown coloured (*Q. leucotrichophora* dominated forest) reported. The soil colour is also used to predict the presence mineral properties of soil (Table 2).

Table 2. Study area forest soil colour and its mineral interpretation

Forest area	Depth (cm)	Soil colour	Mineral pigment Beaudett, 2017. USDA, [23,24]
ALDF	0-20	Pale brown	Gypsum
	20-40	Greyish brown	-
	40-60	Brown	Geiothite, Brownz
MF	0-20	Light grey	Quartz
	20-40	Greyish brown	-
	40-60	Light grey	Quartz
SDF	0-20	Reddish yellow	Hematite, lepidocrocite
	20-40	Light yellowish brown	Gypusm
	40-60	Pale brown	Gypsum
QLDF	0-20	Brown	Geothite, humus
	20-40	Light yellowish brown	Gypsum

3.2 Soil Physical Properties

3.2.1 Soil pH

Soil pH value ranges from 5.25 to 7.67 in the present study area. The highest (6.91) pH was found in ALDF followed by QLDF (6.69), MF (6.26) and SDF (6.02). The study revealed that the soil pH of the all sites as Slightly Acidic. In depth wise, pH shown increasing trend with increasing depth. Chauhan et al. (2020) reported pH values ranged from 6.44 – 6.79. Mutanol et al*.,* [25] estimated pH value of *A. latifolia* stands as 6.5. These values are similar to the present study. Mahato et al*.,* [18] study on Community Forest of Garhwal Himalaya reported pH value of 5.9. Rawat et al*.,* [26] reported pH of 5.6. Shukla et al*.,* [27] reported pH values from 4.86-5.16 for Mixed Forest stands & Single dominant forest (Sal, Teak), these values are quite lower than the present study.

3.2.1.1 Effect of soil pH on nutrient availability

Jackson et al., [28] suggested that the function of pH and the availability of vital plant nutrients are closely connected. The plants' ability to get these nutrients is correlated with varied pH conditions. With the exception of phosphorus, the macronutrients such as Nitrogen, Calcium, Potassium, Magnesium, and Sulphur are more easily obtainable in the pH range of 6.5-8. However, the maximum micronutrients are available at a pH range of 5-7, which is slightly acidic. These are the ranges where nutrients are most readily supplied to plants in a sufficient amount. In present study, soil pH ranges from 5.25 to 7.67 i.e., slightly acidic soils, which depicted the better availability of nutrients in the soil for good plant growth in all present forest areas.

3.2.2 Soil organic matter (SO M%)

It was analyzed that SOM ranges from 4.79 to 0.27%. On mean the highest SOM was found in *Q. leucotrichophora* dominated forest was 2.99% followed by *A. latifolia* dominated forest, mixed forest and shrub dominated forest with the values of 2.14, 1.70 and 1.15% respectively.

3.2.3 Soil organic carbon (SOC %)

SOC % ranged from 0.67±0.32 to 1.73±0.16% (Among over all individual samples the values ranged from 0.16 to 4.08%) with the highest SOC found in QLDF (1.73 ± 0.16) followed by ALDF (1.24±0.16%), MF (0.99±0.08%) and SDF (0.67±0.32 %). Chauhan et al*.,* [19] reported SOC from 1.09–1.36%. Mahato et al*.,* [18] study on Community Forest of Garhwal Himalaya reported SOC% of 1.28. Gupta and Rout [29] study on Mixed-forest *(A. latifolia & Lannea coromandelica*) reported SOC of 2.99%.

3.2.4 SOC Stock (t ha-1)

SOC stock ranges from 10.74 ± 1.57 to 29.64 ± 3.48 t ha-1 (Among over all individual sample values ranged from 2.81 to 46.70 t ha-1). The highest SOC stock was found in high altitude QLDF (29.64 ± 3.48 t ha-1) followed by ALDF, MF and SDF with values of 18.34 ± 2.90, 14.52 ± 2.27 and 10.74 ± 1.57 t ha-1. Munesh et al*.,* [22] studied in *A. latifolia* forests and reported SOC stock of species *Rhus parviflora* (168.00 t ha−1) and *Lantana camara* (164.16 t ha−1). These values were higher compared to A. latifolia forest (161.28t ha−1). Shahid and Joshi et al., [30] studied that Carbon Stock Variation in Different Forest Types of Western Himalaya where carbon stock density varied between 129.81 and 136.00 Mg C ha−1. Mahato et al*.* [18] reported SOC

Table 3. Mean values of soil physicochemical properties

Physicochemical properties of soil in different forest areas							
Parameter	**Forest area**				**Depth wise**		
	ALDF (1300 m)	**MFA (900 m)**	**SDF (600 m)**	**QLDF (1900 m)**	**0-20**	**20-40**	**40-60**
Moisture (%)	3.05 ± 0.42	5.22 ± 0.77	1.52 ± 0.62	7.48 ± 2.15	4.36± 1.14	4.9±1.51	3.67±0.78
WHC (%)	33.71 ± 4.20	29.52 ± 3.72	31.37 ± 6.58	48.63 ± 14.15	43.52 ± 3.60	33.51± 4.83	30.27± 4.46
Soil pH	6.91 ± 0.17	6.26 ± 0.07	6.02 ± 2.06	6.69 ± 2.29	6.23±0.16	6.48±0.18	6.73±0.21
SOC (%)	1.25 ± 0.16	0.99 ± 0.08	0.67 ± 0.32	1.73 ± 0.16	1.45±0.19	1.23±0.11	0.81±0.6
BD (g cm^3)	0.73 ± 0.07	0.704 ± 0.06	0.79 ± 0.18	0.84 ± 0.24	0.82±0.03	0.84±0.04	0.63±0.04
SOC Stock (t ha^{-1})	18.34 ± 2.90	14.52 ± 2.27	10.74 ± 1.57	29.64 ± 3.48	28.73±5.20	49.29 ± 4.79	59.14 ± 1.94
Nitrogen (kg ha^{-1})	205.47 ± 7.10	197.07 ± 1.50	193.79 ± 8.15	254.22 ± 27.16	221.76±14	220.75±25.40	199.26 ± 5.83
SOM (%)	2.14 ± 0.28	1.70 ± 0.14	1.15 ± 0.55	2.99 ± 0.42	2.31± 0.30	1.85±0.23	1.31± 0.21
C/N Ratio	8.93 ± 1.29	7.37 ± 0.48	5.54 ± 0.83	11.65 ± 1.01	12.95 ± 2.38	22.32 ± 2.60	29.67 ± 2.92

stock 218.57 t ha-1 in Community Forest of Garhwal Himalaya. Sheikh et al*.* [31] reported 60.8-185.6 t ha-1 in Quercus of Garhwal Himalaya. The SOC stock values of all the studies were higher than the present study. Singh et al*.* [32] reported SOC stock of 64-72 t ha-1 in oak forest of Garhwal Himalaya. Shukla et al*.* [27] for mixed forest stands & Single dominant forest (Sal, Teak) estimated SOC stock of 75.9 -107.7 t ha-1. Chauhan et al. [19] study on *A. latifolia* forest stands of Garhwal Himalayas reported stock of 14.94 -23.78 t ha-1 were similar to the present study.

3.2.5 Soil nitrogen (kg ha-1)

Nitrogen ranges from 193.79±8.15 to 254.22 ± 27.16 (Among over all individual samples values ranged from 170.61 to 306.07 kg ha-1). The highest (254.22 ± 27.16 kg ha-1) nitrogen was found in QLDF followed by ALDF (205.47± 7.10 kg ha-1), MF (197.07 ± 1.50 kg ha-1) and SDF (193.79±8.15 kg ha-1). Chauhan et al*.,* [19] study on A. latifolia forest reported soil nitrogen values from 291.64 - 323.01 kg ha-1. Rawat et al*.,* [26] reported nitrogen of 217.38 kg ha-1 in Oak Forest. Mutanal et al*.* [25] study on A. latifolia forest reported nitrogen of 235.01 kg ha-1. All this studies, reported similar and close values to the present study. Shukla et al. [27] study on Mixed Forest stands & Single dominant forest (Sal, Teak) estimated stored soil nitrogen values ranged from 210 -260 kg ha-1.

3.2.6 C:N ratio

The C:N ratio ranged from 5.54 to 11.65. The highest mean C:N ratio was found in *Q. leucotrichophora* dominated forest (11.65 ± 1.01) followed by *A. latifolia* dominated forest (8.93 ± 1.29), mixed forest (7.37 ± 0.48) and lowest shrub dominated forest (5.54 ± 0.83) respectively. Chauhan et al*.* (2020) study reported C/N ratio of < 10 within range of present study. Donald et al. [33] estimated C/N ratio range of 11.6 – 45.3 in different tree species, the both N concentration and the C/N ratio was strongly related to tree species and C content. The Low C/N ratio was found in present study could be because of high soil Nitrogen compared SOC. When the C:N ratio is between 1 and 15, N is quickly mineralized and released, making it available for plant uptake. Thus, it is depicted that in the present study area the amount of nitrogen is more available for plant uptake. The faster nitrogen is released into the soil of usage of crops with the lower the C:N ratios [34].

The depth wise distribution of soil physico-chemical properties in the study area is demonstrated in the Table 6.

3.3 Soil Physicochemical Properties Correlation with Altitude

The present study evaluated that almost all the soil physicochemical properties are positively correlated with altitude as demonstrated in the below Table 4, the high-altitude Oak forests showed domination in almost all the soil parameters.

Table 4. Correlation of soil physicochemical propertied altitude

Correlation with altitude	
Soil Parameter	Correlation ®
Moisture	0.797866708
WHC	0.905811478
Soil pH	0.780419622
SOC%	0.997027463
Bulk Density (BD)	0.508847713
SOC stock	0.990001912
Nitrogen stock	0.934730981
SOM%	0.997077060
C/N ratio	0.996959052
Sand%	0.598981424
Silt %	0.625572776
Clay%	0.523060862
Gravel%	0.850084267

Table 5. Mean values of soil texture and texture classes

Particle	**Forest areas**			
	ALDF	**MF**	**SDF**	**QLDF**
Sand (%)	61.21 ± 1.27	66.67 ± 1.29	57.63 ± 2.37	51.67 ± 1.22
Silt (%)	9.99 ± 0.49	9.27 ± 1.00	7.35 ± 0.43	9.27 ± 1.03
Clay (%)	28.91 ± 1.15	23.58 ± 1.46	34.05 ± 2.52	39.07 ± 0.80
Texture class	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay	Sandy Clay
Gravel (%)	67.19 ± 0.99 (Sand, silt, clay= 32.81%)	69.46 ± 2.40 (Sand, silt, clay=30.54%)	66.92 ± 3.36 (Sand, silt, clay=33.08%)	52.13 ± 5.84 (Sand, silt, clay=47.87%)

Table 6. Depth wise distribution of soil physicochemical properties in the study area

Forest area	Depth (cm)	SOC (%)	SOC stock (t ha^{-1})	Nitrogen (kg ha^{-1})	SOM (%)	BD (g cm^{-3})	Soil pH (1:2.5)	WHC (%)	Moisture (%)
ALDF (1300 m)	0-20	3.06	26.67	225.79	3.06	0.74	6.68	45.87	3.29
	20-40	2.17	19.81	210.73	2.17	0.84	6.92	31.04	3.09
	40-60	1.22	8.53	195.63	1.22	0.61	7.31	24.23	2.77
MF (900m)	0-20	2.16	39.56	199.66	2.16	0.88	6.08	43.6	6.11
	20-40	1.62	13.45	190.66	1.62	0.71	6.32	21.23	5.67
	40-60	1.34	8.05	200.7	1.34	0.52	6.38	23.23	3.88
SDF (650m)	0-20	1.41	12.68	195.68	1.41	0.75	5.8	32.32	1.14
	20-40	1.22	12.55	175.61	1.22	0.90	5.97	33.57	1.47
	40-60	0.84	6.37	210.07	0.84	0.75	6.3	28.22	1.94
QLDF (1900m)	0-20	2.62	36.44	265.92	2.62	0.94	6.37	52.29	6.88
	20-40	2.42	36.04	306.07	2.42	0.93	6.74	48.21	9.46
	40-60	2.03	16.44	190.66	2.03	0.65	6.93	45.38	6.12

Table 7. Comparative studies of earlier works

Vegetation type	Moisture (%)	WHC (%)	BD (g cm^{3})	Soil pH	SOC (%)	SOC Stock (t ha^{-1})	SOM (%)	Nitrogen (kg ha^{-1})	References
A. latifolia dominated forest (ALDF)	3.05	33.71	0.73	6.91	1.24	18.34	2.14	205.47	**Present study**
Mixed Forest (MF)	5.22	29.52	0.70	6.26	0.99	14.52	1.70	197.07	
Shrub dominated forest (SDF)	1.52	31.37	0.79	6.02	0.67	10.74	1.15	193.79	
Q. leucotrichophora dominated forest (QLDF)	7.48	48.63	0.84	6.69	1.73	29.64	2.99	254.22	
A. latifolia	-	30.90	-	-	-	161.28	-	-	Kumar et al. [22]
Shrubs forest (*Lantana camara* & *Rhus parviflora*)	-	-		-	-	168.00	-	-	Kumar et al. [22]
Mixed forest (*A. latifolia* & *Lannea*		49.80	1.31	7.60	2.99	-	-	-	Gupta and Rout. [29].

Vegetation type	Moisture (%)	WHC (%)	BD (g cm^3)	Soil pH	SOC (%)	SOC Stock (t ha^{-1})	SOM (%)	Nitrogen (kg ha^{-1})	References
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A. latifolia forest	-	-	1.30	6.5	-	-	-	235.01	Mutanal et al. [28].
Community Forest of Garhwal Himalaya	14.39	24.17	1.29	5.90	1.28	218.57	-	-	Mahato et al. [18].
Quercus leucotrichophora forest	-	-	-	-	-	64-72	-	-	Singh et al. [32].
Quercus leucotrichophora forest	-	-	-	-	-	60.8-185.6	-	-	Sheik et al. [31].
Shrub land	-	-	-	6.38	2.06	-	-	-	Worku et al. [35]
Quercus. L	-	-	-	5.6	1.95	-	-	217.38	Rawat et al. [26].
Mixed forest stands & Single dominant forest (Sal, Teak)	27.01-1.03	-	-	4.86-5.16	-	75.9-107.7	-	0.21-0.26	Shukla et al. [27].
A. latifolia Forest	9.01-16.09	24.84-55.23	0.90-1.06	6.35-6.79	1.36	14.94 -23.78	-	291.64 -323.01	Chauhan et al. [19].
Forest land	-	-	1.00	-	-	98.01	-	-	
Barren land	-	-	1.2	-	-	83.6	-	-	Bam & Surendra et al. [21]
Agriculture land	-	-	1.4	-	-	36.6	-	-	
Shrub land	-	-	-	-	-	10.8%	-	55.9%	Wang & Kang et al. [36]
Mixed forest (*Quercus* & *Rhododendron*)	25.83	-	1.47	-	-	23.2 mg/ha	-	-	Bhat et al. [20]
Grass land	33.21	-	1.53	-	-	25.0	-	-	
Tropical forest	-	-	-	-	-	64.3	-	-	Gachhadar et al. [37]
Sub-tropical forest	--	-	-	-	-	84.4	-	-	
Mountain forest	-	-	-	-	-	95.3	-	-	
Chauras Campus (Garhwal University)	3.30 ±0.28	31.53±0.72%	1.38±0.4 g/cm^{-3}	6.84±0.11	0.86±0.06%	302.62 t ha^{-1}	-	133.12±5.79	Prashanth et al. In Press [38].
Sal Forests of Garhwal.	10.92%	-	-	5.6	-		3.65%	139.23	Negi et al. [39]
Sub-tropical forests of Garhwal Himalaya	12.34	42.61	1.82	-	1.09%	-	-	0.031%	O.P Tiwari et al. [40]

4. CONCLUSION

This study revealed that soil physico-chemical properties change with different forest areas, altitude, and soil depth. The Highest SOC and Nitrogen were reported in the high altitude QLDF forest area, followed by ALDF, MF and SDF. The same trend followed in almost all soil properties (MC, WHC, SOC%, SOM, Nitrogen and SOC stock), the highest pH found in ALDF. Highest Bulk density was found in SDF, followed by QLDF, ALDF and MF.

The C/N ratio, Soil pH, Nitrogen, and SOC stock was increased with increase in depth, While MC, WHC, SOM, SOC (%), and BD decreased with soil depth.

This study concluded that among four different forest areas, the high-altitude temperate *Quercus luecotrichophora* Forest (QLDF) has greater potential to store soil organic carbon stock and Nitrogen than Sub – tropical *Anogeissus latifolia* Dominated Forest (ALDF), Mixed Forest (MF), and Shrub Dominated Forest (SDF). In almost all other soil properties are dominated by *Quercus luecotrichophora* Forest followed by *Anogeissus latifolia* Dominated Forest, Mixed Forest, and Shrub-dominated Forest. This study revealed the carbon sequestering potential of four major Himalayan region forest types and their key role in combating the climate change.

CONSENT

I on behalf of all authors confirms that all authors are read the copy of this manuscript and all authors are approved for submission of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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