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Altitudinal Zonation And Ecosystem Function: A Study Of Biomass, Carbon And Soil Attributes In Central Himalayan Forests

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Abstract: This study examines the altitudinal influence on forest structure, carbon storage, and soil properties across three distinct forest types: Oak mixed (*Q. leucotrichophora*) at 1500m (Jawal), Pine (*P. roxburghii*) at 1800m (Chitgal), and Sal (*S. robusta*) forest at 900m (Timta). Key parameters investigated include tree biomass, carbon stock, soil moisture content (MC), water holding capacity (WHC), pH, soil organic carbon (SOC), and organic matter (OM). A clear altitudinal gradient is evident in carbon sequestration, with the Oak forest exhibiting the highest tree biomass (266.99 ton/ha) and carbon stock (133.49 ton C/ha). The Pine forest follows with 256.65 ton/ha biomass and 128.65 tonC/ha carbon stock, while the Sal forest shows the lowest (233.52 ton/ha biomass, 116.76 ton C/ha carbon stock), consistently maintaining 50% carbon of total biomass. Regarding soil properties, the Oak forest soil demonstrates superior water retention (36-38% MC, 64% WHC). In contrast, Pine and Sal forest soils exhibit much lower MC (14-20%) and WHC (25-45%). Chemically, Sal forest soil is the least acidic (pH 5.9-6.8), whereas Pine and particularly Oak soils are more acidic (pH as low as 5.2). SOC and OM are consistently higher in topsoil across all sites, with the Pine forest showing the highest top-layer organic matter. This research highlights the intricate interplay between altitude, vegetation, and ecosystem services, emphasizing the pronounced carbon sequestration and water retention capabilities of mid-altitude Oak forests.

***Index Terms* -** Biomass, Carbon stock, Soil Physio-chemical properties, Altitudinal gradient, Forest type.

I. INTRODUCTION

These forests also play a vital role in enhancing soil quality through organic matter input, affecting parameters like soil pH, moisture, nutrient content, and microbial activity. Understanding the interrelationship between forest types, carbon dynamics, and soil health in the Western Himalayas is essential for informed forest management and conservation strategies aimed at sustaining the ecosystem services these forests provide. The forests of the Western Himalayas provide a wide array of ecosystem services that are crucial for environmental stability, biodiversity conservation, and human well-being. Among these, biomass production, carbon sequestration, and the maintenance of soil physicochemical properties are particularly significant in the context of climate change and ecological resilience. Different forest types such as *Quercus leucotrichophora*, *Pinus roxburghii*, and *Shorea robusta* exhibit varying capacities to store biomass and sequester atmospheric carbon due to differences in species composition, and productivity.

A portion of the Indian Central Himalayas, the Kumaun Himalaya, is home to a variety of forest habitats, particularly those that are dominated by *Shorea robusta*, *Pinus roxburghii*, and *Quercus leucotrichophora*. These forests are essential for retaining soil health and sequestering carbon, which helps to mitigate climate change and preserve ecological equilibrium. Sustainable forest management and conservation techniques depend on an understanding of these forests' biomass, carbon stock, and soil physicochemical characteristics.

Several studies have highlighted the significant role of Himalayan forest ecosystems in providing regulating services such as carbon storage and maintaining soil fertility. Broadleaf forests like *Quercus leucotrichophora* exhibit higher carbon stock and better soil nutrient profiles compared to coniferous forests such as *Pinus roxburghii*, owing to greater litter input and organic matter decomposition (Gosain *et al.*, 2015).

The total biomass and carbon sequestration potential vary considerably across forest types, with *Shorea robusta* forests in the foothills demonstrating substantial above-ground biomass due to dense canopy and rapid growth rates (Sharma *et al.*, 2020). These forests also contribute to improved soil physicochemical properties, including enhanced soil organic carbon (SOC), nitrogen, and moisture retention, all of which are critical for sustaining ecosystem productivity and resilience in the fragile Western Himalayan landscape.

II. **Materials and Methods**

Study Area

The present study will be carried out in the Kumaun region of Uttarakhand, which lies within the Western Himalayan biogeographic province of the Indian Himalayan Region (IHR). This region is characterized by diverse forest ecosystems, varying altitudinal gradients, and rich biodiversity. Three study sites, each representing distinct forest types, will be selected for intensive investigation. These sites will be located in areas under recognized forest management regimes, such as wildlife sanctuaries or reserve forests, and will be chosen to reflect minimal anthropogenic disturbance.

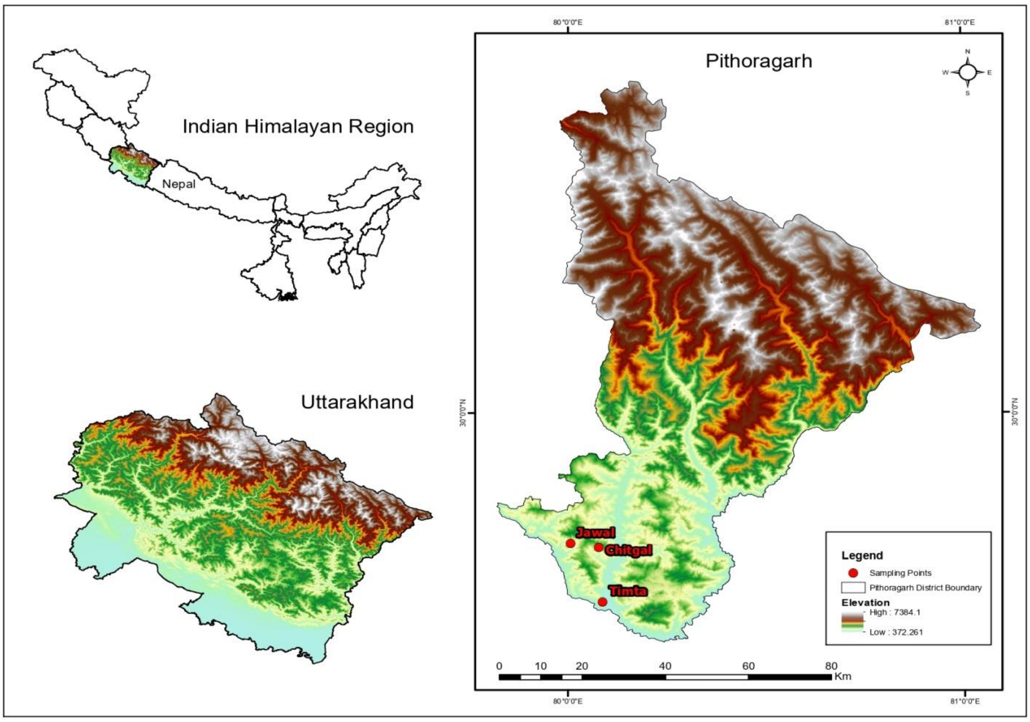

Fig. 1 Study site map.

Sampling Design

A stratified random sampling approach will be employed to capture spatial variability in forest structure and biomass. At each site, three sample stands measuring 50 × 50 meters will be demarcated randomly. Within each stand, five quadrats of 10 × 10 meters will be established for detailed vegetation assessment, following standard phytosociological methods. Tree species within each quadrat will be identified and enumerated. The circumference at breast height (CBH) of all individual trees (≥10 cm CBH) will be measured at 1.37 meters above the ground. These measurements will be used to estimate above ground biomass (AGB) using species-specific or generalized allometric equations.

Biomass and Carbon Stock Estimation

Above ground biomass of tree components will be estimated using non-destructive methods, applying existing allometric equations of the form:

Ln Y = a + b Ln X. Allometric models developed by Chaturvedi and Singh (1987), Rawat and Singh (1988), and Singh and Singh (1987) will be applied based on the species composition and forest type. The carbon stock of standing trees will be estimated by multiplying the biomass values with a conversion factor of 0.47, following the methodology of Magnussen and Reed (2004) C = Biomass × 0.47

Soil Sampling and Analysis

To estimate soil biomass and carbon sequestration potential, soil samples will be collected from two depths (0–15 cm) and (15-30 cm) within each 50 × 50 meter forest stand. From each stand, five quadrats (10 × 10 m) will be selected, and three replicates per depth will be randomly collected from each quadrat. Collected soil samples will be air-dried and passed through a 0.5 mm sieve to remove coarse particles, roots, and organic debris before further physico-chemical analysis. Standard soil analytical methodology used to determine soil carbon content and biomass contribution.

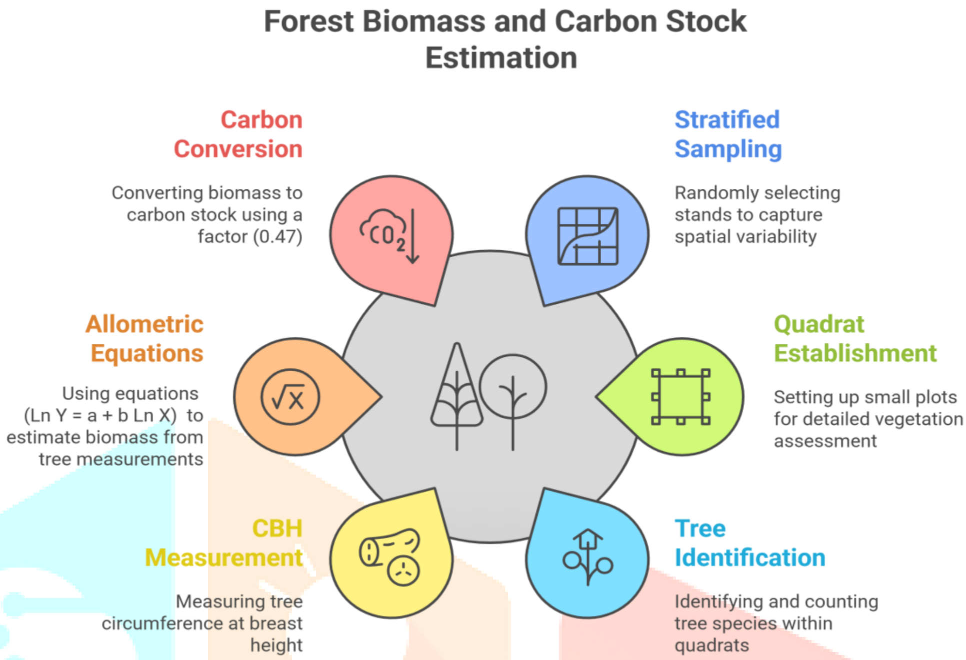

Fig.2 Methodology for Biomass and Carbon stock estimation

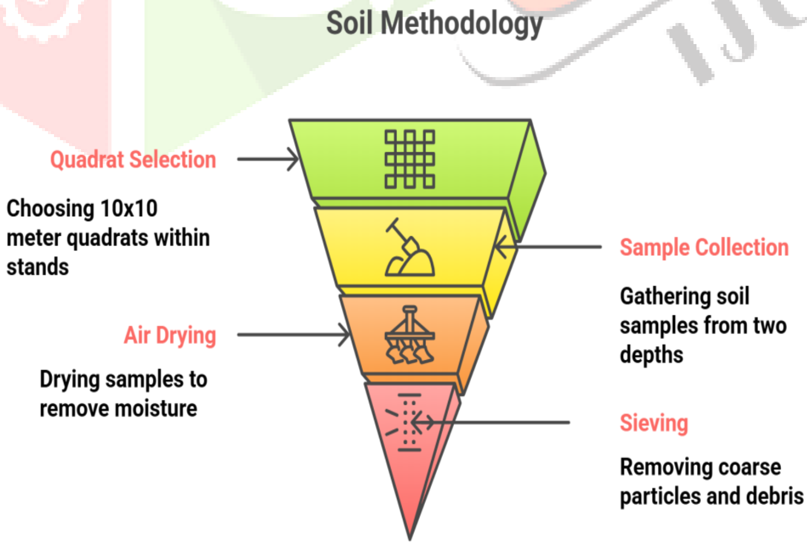

Fig. 3 Methodology for soil analysis

III. Results:

Biomass and carbon stock:

Present study indicates, a clear altitudinal gradient and a corresponding pattern in carbon storage can be observed across the three forest types. The Oak mixed forest (*Q. leucotrichophora*) at the mid-altitude site of Jawal (1500m) demonstrates the highest tree biomass at 266.99 ton/ha, leading to the largest carbon stock of 133.49 ton/ha. Closely following is the Pine forest (*P. roxburghii*) at the highest altitude of Chitgal (1800m), with a biomass of 256.65 ton/ha and a carbon stock of 128.65 ton/ha.

In contrast, the Sal forest (*S. robusta*) at the lowest altitude of Timta (900m) has the lowest tree biomass (233.52 ton/ha) and consequently the lowest carbon stock (116.76 ton/ha). Across all three forest types, the carbon stock is consistently estimated to be approximately 50% of the total tree biomass, highlighting the significant role of these forest ecosystems in carbon sequestration and their varying capacities to store carbon depending on the dominant tree species and altitude.

Table 1. Biomass and carbon stock:

S.No.	Study sites	Forest type	Altitude (m asl)	Tree biomass (ton/ha)	Carbon stock (ton/ha)
1.	Chitgal	*P. roxburghii*	1800	256.65	128.65
2.	Jawal	*Q. leucotrichophora*	1500	266.99	133.49
3.	Timta	*S. robusta*	900	233.52	116.76

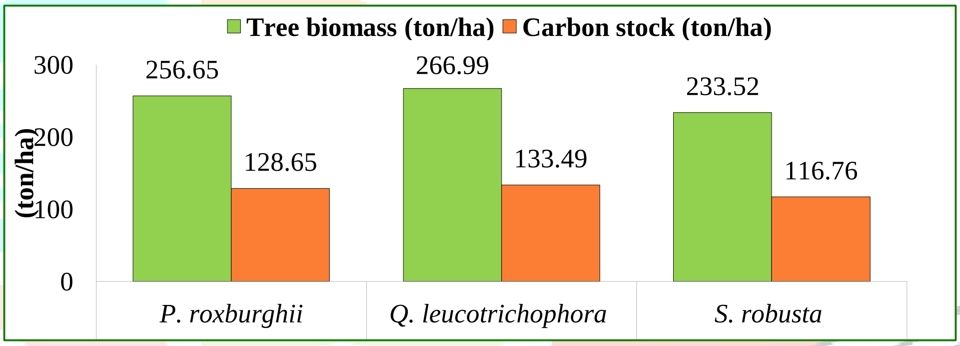

Fig. 4 Biomass and Carbon stock in different selected forest

Soil Physio-chemical properties:

Present study indicates, a clear relationship exists between altitude, forest type, and key soil properties. The Oak mixed forest (*Q. leucotrichophora*) at 1500m (Jawal) stands out with its exceptionally high soil moisture content (MC) of 36-38% and a remarkable water holding capacity (WHC) of over 64% in both soil layers, making it the most effective site for water retention. This is in stark contrast to the Pine forest (*P. roxburghii*) at 1800m (Chitgal) and the Sal forest (*S. robusta*) at 900m (Timta), which exhibit much lower MC (14-20%) and WHC (25-45%).

In terms of chemical properties, the Sal-forest soil at Timta is the least acidic with a pH ranging from 5.9 to 6.8, whereas the soils under both Pine and Oak forests are more acidic, with pH values dropping as low as 5.2 at deeper layers in the Oak site. Across all sites, soil organic carbon (SOC) and organic matter (OM) are consistently higher in the topsoil (0-15 cm) and decrease with depth, with the Pine forest showing the highest concentration of organic matter in its top layer. Overall, the data illustrates how vegetation type and altitude directly influence soil chemistry and hydrology, highlighting the superior water-retaining capacity of the mid-altitude oak forest and the less acidic, but drier, nature of the low-altitude Sal forest.

Table 2. Soil Physio-chemical Properties:

Study sites	Forest type	Altitude (m asl)	Soil depth (cm)	pH	SOC (%)	OM (%)	M.C (%)	WHC (%)
Chitga	*P. roxburghii*	1800	0-15	5.9±0.04	1.12±0.08	1.92±0.06	18.67±0.76	42.25±0.48
			15-30	5.5±0.06	1.10±0.06	1.89±0.01	14.10±1.24	45.94±0.46
Mean value:				**5.7**	**1.11**	**1.90**	**16.38**	**44.09**
Jawal	*Q. leucotrichophora*	1500	0-15	5.7±0.05	0.90±0.06	1.54±0.28	36.36±0.21	65.04±1.46
			15-30	5.2±0.02	0.88±0.02	1.51±0.21	38.20±0.32	64.21±1.42
Mean value:				**5.4**	**0.89**	**1.52**	**37.28**	**64.12**
Timta	*S. robusta*	900	0-15	6.8±0.01	0.96±0.02	1.65±0.23	18.79±1.11	29.10±1.32
			15-30	5.9±0.04	0.78±0.06	1.34±0.17	20.21±1.44	25.22±0.06
Mean value:				**6.3**	**0.87**	**1.49**	**19.50**	**27.16**

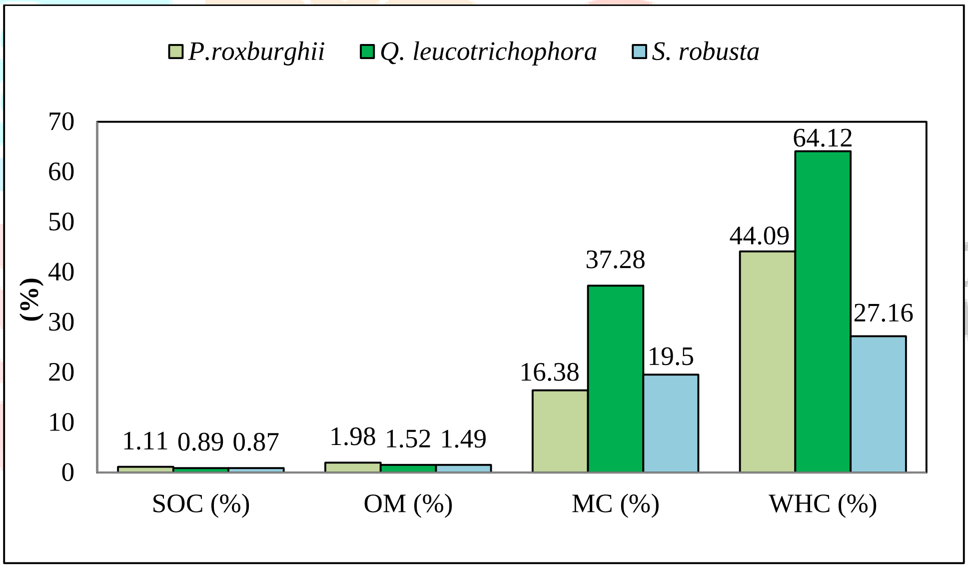

Fig.5 Soil organic carbon (SOC), Organic matter (OM), Moisture content (MC) and Water holding capacity (WHC).

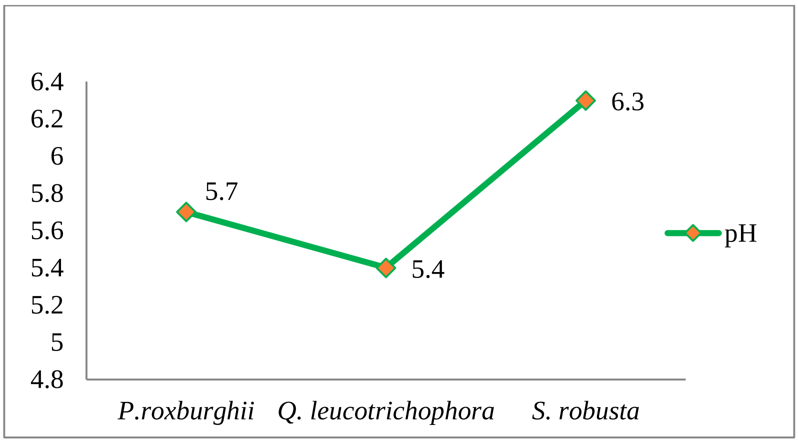

Fig.6 Soil pH in different selected forest.

IV. Discussion:

Pine forest

The present study's findings for the Pine forest at 1800m in Gangolihat, Pithoragarh, reveal a robust biomass of 256.65 t/ha and a corresponding carbon stock of 128.65 t C/ha. These values fall comfortably within the wide ranges reported for Pine forests across the Himalayas, demonstrating the stand's significant carbon storage potential. For instance, while studies by Lal and Lodhyal (2016) in Nainital (1600m) reported a range of 154-301 t/ha, and Sharma *et al.*, (2010) in Garhwal Himalaya (1400-1600m) observed 169.2-442.7 t/ha, the present study's biomass value sits remarkably at the higher end of the Nainital range and well within the broader Garhwal range. This positioning strongly suggests that the study site at Gangolihat represents a well-stocked, mature, and highly productive Pine stand, contributing substantially to the regional carbon budget.

Oak forest

The Oak forest at 1500m in Gangolihat demonstrates an exceptionally high tree biomass of 266.99 t/ha and a significant carbon stock of 133.49 t C/ha according to the present study. This productivity is particularly noteworthy when compared with existing literature. While Sharma (2010) reported a lower range of 171.8-228.3 t/ha for Oak forests in Garhwal Himalaya, the present study's value significantly surpasses this. Furthermore, it falls well within the upper biomass ranges (145-503 t/ha) identified by Verma and Garkoti (2019) for Oak forests in the Central Himalaya. This elevated biomass not only confirms the immense productivity of the Oak stand at the study site but also underscores its critical role as a substantial and efficient carbon sink within the Kumaun Himalayan landscape, vital for regional ecological stability and climate change mitigation efforts.

Sal forest

The Sal forest at 900m in Gangolihat exhibited a biomass of 233.52 t/ha and a carbon stock of 116.76 t C/ha. These values are highly consistent with data from similar Sal forest types in the region, providing valuable context for their ecological classification. When juxtaposed with the ranges reported by Sharma *et al.*, (2010) for Dry Siwalik Sal (180.81 t/ha biomass, 83.17 t C/ha) and Moist Sal (259.01 t/ha biomass, 119.05 t C/ha) forests, the present study's findings for the Gangolihat site lie precisely between these two categories. This intermediate position is ecologically intuitive, reflecting the site's specific altitude and potential local climatic conditions. It suggests that this Sal forest is more productive and capable of greater carbon sequestration than a drier Sal forest, yet slightly less so than a truly moist Sal stand, thereby providing a nuanced understanding of its contribution to the carbon cycle.

Table 3. Comparison of Biomass and Carbon stock of present study with previous studies in the different Himalayan forests:

Forest Stand	Location/ District	Altitude (m asl)	Biomass (t/ha)	Carbon Stock (t C/ha)	References
Pine forest, Central Himalaya	Nainital	1600	154-301	73-143	Lal and Lodhyal, (2016)
Chir-pine forest, Garhwal Himalaya	Chamoli	1400-1600	169.2-442.7	77.8-203.7	Sharma *et al.*,(2010)
Chir-pine forest, Kumaun Himalaya	Gangolihat, Pithoragarh	1800	256.65	128.65	**Present Study**
Oak-forest, Garhwal Himalaya	Chamoli	2000	171.8-228.3	77.3-102.8	Sharma, (2010)
Oak forest, Central Himalaya	Almora	1790-1930	145-503	68.29-247.61	Verma and Garkoti (2019)
Banj-Oak forest, Kumaun Himalaya	Gangolihat, Pithoragarh	1500	266.99	133.49	**Present Study**
Dry Siwalik Sal Forest	Pauri	800-1100	180.81	83.17	Sharma *et al.*,(2010)
Moist Sal forest	Pauri	350-460	259.01	119.05	Sharma *et al.*,(2010)
Sal forest, Kumaun Himalaya	Gangolihat, Pithoragarh	900	233.52	116.76	**Present Study**

Soil Physical and chemical properties:

Present study indicates, a comparative analysis of the present study's findings with existing literature reveals both consistent trends and notable site-specific variations in key soil properties. For the Pine forest, the present study's pH range (5.9-5.5) aligns well with the mildly acidic conditions (5.4-6.1) reported by Joshi *et al.*, (2013) at a higher altitude (2000-2300m), and the moisture content (14.1-18.67%) falls within their broader range. However, the organic matter (OM) values in the present study (1.89-1.92%) are significantly lower than those from the referenced study (3.46-4.52%), suggesting that the higher altitude and mixed forest composition in the referenced study contribute to a richer accumulation of organic matter.

For the Oak forest, the consistent acidic pH (5.7-5.2) and exceptionally high water holding capacity (WHC) of over 64% in the present study are strongly corroborated by Joshi *et al.*, (2015), who reported similar pH (5.2-5.3) and WHC (65-66%) for Oak mixed forests, reinforcing its critical role in hydrological regulation. Interestingly, the present study shows a higher moisture content (36.36-38.20%) but a lower soil organic carbon (SOC) (0.90-0.88%) compared to the referenced study, indicating potential differences in sampling time or site-specific fertility.

In the Sal forest, the present study's data shows significant variation from the reference. The soil is more acidic (pH 6.8-5.9) with substantially lower WHC (25.22-29.10%) and OM content (1.34-1.65%) than the values reported by Bharti *et al.*, (2016) in Nainital (pH 7.2; WHC 54.80 %; OM 2.36 %). This highlights a vast difference in soil properties, where the local conditions at the study site in Gangolihat result in a less fertile and less water-retentive soil compared to the referenced site, underscoring the importance of localized studies and the influence of specific forest subtypes on soil characteristics.

Table.4 Comparison of Soil physiochemical properties of present study with previous studies in the different Himalayan forests:

Study sites	Forest type	Altitude (m asl)	pH	Soil organic carbon (%)	Organic matter (%)	Moisture content (%)	Water holding capacity (%)	References
Chir-pine stand Kanar, Pithoragarh,	Pine mixed Forest, Kumaun Himalaya	2000-2300	5.4-6.1	-	3.46-4..52	8.94-20.40	45-48.95	Joshi *et al.* (2013)
Gangolihat, Pithoragarh	Pine forest, Pithoragarh	1800	5.9-5.5	1.12-1.10	1.92-1.89	18.67-14.10	42.25-45.94	**Present study**
Banj-oak stand, Chamoli, Garhwal	Oak mixed forest, Central Himalaya	-	5.2-5.3	1.83-2.11	-	15-33.00	65-66	Joshi *et al.*, (2015)
Gangolihat, Pithoragarh	Oak forest Pithoragarh	1500	5.7-5.2	0.90-0.88	1.54-1.51	36.36-38.20	65.04-64.21	**Present study**
Chorgaliya, Nainital	Sal forest, Central Himalaya	-	7.20	1.37	2.36	5.82	54.80	Bharti *et al.*, (2016)
Gangolihat, Pithoragarh	Sal forest Pithoragarh	900	6.8-5.9	0.96-0.78	1.65-1.34	18.79-20.21	29.10-25.22	**Present study**

V. **Conclusion:**

Based on the comprehensive data presented, it concluded that the forest stands in the present study are highly productive and play a significant role in carbon sequestration. The biomass and carbon stock values for Pine and Oak forests are at the upper end of the ranges reported in existing literature for the Himalayan region, highlighting their robust capacity as carbon sinks. Furthermore, the soil analysis reveals key insights: the Oak forest consistently exhibits an exceptionally high water holding capacity and acidic pH, reinforcing its critical role in hydrological regulation, while the Pine forest shows moderate physical properties. In contrast, the Sal forest's soil demonstrates significant site-specific variability in its chemical and physical properties, with lower water retention and organic matter compared to some referenced sites. Overall, this integrated assessment underscores that while broad forest types have general characteristics, local factors such as altitude and microclimate are paramount in defining the unique physiochemical properties and carbon sequestration potential of each forest ecosystem in the Kumaun Himalaya.

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REFERENCES

1. Bhandari, A. R., & Tomar, K. P. (1991). Morphology genesis and classification of some soils of Northwestern Himalayas. *Journal of Indian Society of Soil Science, 39*, 139–146.
2. Bhattarai, K. P., & Mandal, T. N. (2018). Variation in carbon stock in litterfall, fine root and soil in Sal (*Shorea robusta* Gaertn.) forests of eastern Nepal. *Our Nature*, *16*(1), 68-73.
3. Bharti, M., Tewari, L., Tewari, A., & Joshi, N. (2016). Impact of Alien invasive species on soil physiochemical characteristics in tropical Sal forest, Uttarakhand, India. Journal of Chemical Engineering and Chemistry Research, 3(11), 1057-1061.
4. Chauhan, S. K., Singh, S., Sharma, S., Sharma, R., & Saralch, H. S. (2019). Tree biomass and carbon sequestration in four short rotation tree plantations. *Range Management and Agroforestry*, *40*(1), 77–82.
5. Ghimire, P. (2019). Carbon Sequestration Potentiality of *Pinus roxburghii* Forest in Makawanpur District of Nepal. *ResearchGate*.
6. Gosain, B. G., Negi, G. C., Dhyani, P. P., Bargali, S. S., & Saxena, R. (2015). Ecosystem Services of Forests: Carbon Stock in Vegetation and Soil Components in a Watershed of Kumaun Himalaya, India. *International Journal of Ecology and Environmental Sciences*, 41(1-2), 1–10.
7. Jina, B. S., Sah, P., Bhatt, M. D., & Rawat, Y. S. (2008). Estimating carbon sequestration rates and total carbon stockpile in degraded and non-degraded sites of oak and pine forest of Kumaun Central Himalaya. *Ecoprint, 15*, 75–81.
8. Joshi,K.(2022). *Biomass and Carbon Stock of Pinus roxburghii Sarg. in Jammu & Kashmir* (Doctoral dissertation, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu).
9. Joshi, M. (2015). *Carbon sequestration potential of different forest types in Kumaun Himalaya, Uttarakhand* [Published doctoral dissertation], Kumaun University.
10. Joshi, V. C., Negi, V. S., Bisht, D., Sundriyal, R. C., & Arya, D. (2021). Tree biomass and carbon stock assessment of subtropical and temperate forests in the Central Himalaya, India. *Trees, Forests and People*, *6*, 100147.
11. Kumar, R., Kumar, A., Kumar, S., Singh, J., & Singh, A. K. (2025). Biomass and carbon stock of conifer and broad-leaf forest stands in Talra Wildlife Sanctuary across Northwest Himalayas, India. *Frontiers in Forests and Global Change*.
12. LaL, B., & Lodhiyal, L. S. (2016). stand structure, productivity and carbon sequestration potential of oak dominated forests in Kumaun Himalaya. Current World Environment, 11(2), 466.

13. Lodhiyal, L. S., Lodhiyal, N., & Siddiqui, F. (n.d.). Assessment of Tree Productivity and Carbon sequestration of Sal Forests of Kumaun Region, Central Himalaya, India. *International Journal of Plant and Environment*.
14. Pant, H., & Tewari, A. (2014). Green Sequestration Potential of Chir Pine Forests Located in Kumaun Himalaya. *Forests and Global Change*, *70*(1), 64–73. (Please verify exact volume, issue, and page range for accuracy).
15. Pant, H., & Tewari, A. (2020). Green Sequestration Potential of Chir-Pine Forests Located in Kumaun Himalaya. *Forest Products Journal*, 70(1), 64–71.
16. Raikwal, P., Kumar, N., & Pandey, R. (2019). Population structure, soil characteristics and carbon stock of the regenerating banj oak forests in Almora, Central Himalaya. *Journal of Asia-Pacific Biodiversity*, *12*(2), 263–269.
17. Rawat, Y. S., & Singh, J. S. (1988). Structure and function of oak forests in Central Himalaya. *Journal of Applied Ecology*, *25*(2), 405–411.
18. Rodin, L. E., & Bazilevich, N. I. (1967). Production and mineral cycling in terrestrial vegetation. *Oliver and Boyd*.
19. Sajwan, N. (2022). *Phytosociology, Regeneration and soil properties in Quercus leucotrichophora (A. Camus) forests of Garhwal Himalaya, India* (Doctoral dissertation, College of Forestry, Ranichauri Campus, VCSG Uttarakhand University of Horticulture and Forestry).
20. Saxena, A. K., & Singh, J. S. (1982). A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. *Vegetation*, 50, 3–22.
21. Seth, S. K., Kaul, O. N., & Gupta, A. C. (1963). Some observations on nutrient cycle and return of nutrients in plantations at New Forest. *Indian Forester*, 89, 90–98.
22. Sharma, C. M., Baduni, N. P., Gairola, S., Ghildiyal, S. K., & Suyal, S. (2010). Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. Forest Ecology and Management, 260(12), 2170-2179.
23. Sharma, R., Chaudhry, S., & Sharma, N. K. (2020). Forest Biomass and Carbon Stock Estimation in Kumaun Himalaya using Geospatial Approach. *Indian Forester*, 146(4), 365–372.
24. Sharma, S., & Arunachalam, K. (2017). Soil Characteristics in the Disturbed and Undisturbed Plots of a Sal (*Shorea robusta*) Forest in the Shiwaliks of Indian Himalayan Region. *Indian Journal of Hill Farming*, *30*(2), 176–180.
25. Singh, A., & Rawat, Y. S. (2011). Biomass and carbon stock in different forest types of Kumaun Himalaya. *Journal of Environmental Biology*, *32*(4), 481–488.
26. Singh, J. S., & Singh, S. P. (1987). Forest productivity in the Himalayas: An ecological study. *Current Science*, *56*(9), 421–426.
27. Singh, J. S., & Singh, S. P. (1992). *Forests of Himalaya: Structure, function, and impacts*. Gyanodaya Prakashan.
28. Singh, K., & Gairola, S. (n.d.). Estimation of Biomass and Soil Carbon Stock in *Quercus leucotrichophora* and *Pinus roxburghii* Forests in Garhwal Himalaya, Uttarakhand. *Journal of Environmental Science and Engineering*.
29. Singh, S. P., Ralhan, P. K., Khanna, R. K., & Singh, J. S. (1985). A quantitative study of the forest floor biomass, litter fall and nutrient return in a Pinus roxburghii forest in Kumaun Himalaya. *Plant Ecology*, 63, 113–119.
30. Verma, R. K., Kumar, D., & Shilpa. (2019). Estimation of Biomass and Soil Carbon Stock in *Pinus roxburghii* and *Quercus leucotrichophora*, Forests of District Shimla, Himachal Pradesh. *Indian Journal of Forestry*, 42(3), 295–298.
31. Verma, A. K., & Garkoti, S. C. (2019). Population structure, soil characteristics and carbon stock of the regenerating banj oak forests in Almora, Central Himalaya. Forest Science and Technology, 15(3), 117-127.