Online ISSN 2456-6489

Review Article

Indian Journal of Agroforestry
Vol. 28, No. 2, April–June 2026

Soil Organic Carbon Across Diverse Land Use and Forest Types in the Indian Himalayan Region: A Review

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https://doi.org/10.48165/ija.2026.28.02.01

ARTICLE INFO
Received: 06.12.2025
Accepted: 30.04.2026

Keywords:
Carbon Sequestration
Forest Types
Indian Himalayan Region
Land Use
Soil Organic Carbon

ABSTRACT

The Himalaya, commonly known as the Earth's third pole, is India's and many other highly populated Asian countries' primary source of freshwater. The Indian Himalayan Region (IHR) covers 530,000 km2 of territory, and runs from Jammu and Kashmir in the north-west to Arunachal Pradesh in the east. The IHR is characterized by a forested landscape that covers around 42 percent of the IHR geographical area, and accounts for one-third of India's forest cover. In 2019, India ranked third in term of greenhouse gas (GHG) emissions after China and the United States. Soil carbon sequestration can be a beneficial mitigating tool as the soil carbon pool is a major component of the world's third-largest carbon pool-the terrestrial carbon pool, and sequestering carbon in the soil boosts the soil's fertility rate.In the present study, the soil organic carbon (SOC) stock value has been reviewed in the three provisions of the IHR: the North-Western Himalaya, the Central Himalaya, and the North-Eastern Himalaya. In comparison to lower altitudes, the higher altitudes store more carbon to upto a certain extent due to low temperature, high moisture and precipitation, and less human interruption. Further, beyond more than 3000m asl, the SOC content starts declining because of the extremely cold conditions, low vegetation cover and snowfall. This review highlights that among different land uses, natural forests have the favourable conditions for SOC storage, and among the forest types, temperate forests have the highest SOC values.

INTRODUCTION

One of the most prominent environmental issues of the 21st century is the anthropogenic climate change. (Pierrhumbert 2011; Sherwood 2011; Somerville and Hassol2011). According to ice core records, the principal greenhouse gases (GHGs) in the atmosphereare methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O), all of which are present in atmosphere in greater quantities now than they were 800,000 years ago (Krishna 2020). The IPCC Special Report (2019) defines global warming as "the combined rise in air and sea surface temperatures over the past 30 years." Land use and land cover changes have impacted the majority of the Earth's land surface in recent years, and these changes are the result of deforestation for industrialization, urbanisation, and agricultural expansion (Kumar *et al.* 2022). An average atmospheric global carbon dioxide concentration has risen from the pre-industrial period from 280 parts per million (ppm) to 407 ppm in 2018 (Krishna 2020), and at present, it is around 421.02 ppm. (IPCC 2021). Despite continued increase in atmospheric concentrations (measured in AR5), in 2019, annual averages for methane, carbon dioxide, and nitrous oxide have reached 410 ppm, 1866 parts per billion (ppb), and 332 ppb respectively (IPCC 2021). The current rate of temperature rise is expected to reach 1.5°C between 2030-2052 (IPCC 2018).To achieve significant reduction in the GHGs requires to understand the way energy is generated and utilized. The management of the GHGs differs from the management of classical criterion air pollutants. Through the burning of fossil fuel, changes in land-use, and forestry activities, humans have accelerated the rate of increase in atmospheric CO_2 concentration.Anthropogenic climate change and global warming can be addressed in three ways: (i) the reduction of global energy consumption, (ii) using natural and human-engineered methods to sequester carbon dioxide from point sources to the atmosphere, and (ii) producing low- or no-carbon fuels (Schrag 2007).

CARBON SEQUESTRATION

The term "carbon sequestration" refers to natural and human-induced processes that have the ability to minimise CO_2 emissions or remove CO_2 from the atmosphere resulting in less CO_2 being released into the atmosphere in the long-term. Except for that deposited in rocks and sediments, roughly two-thirds of soil carbon (C) is found in standing forests, forest understorey green plants, leaves, plant debris, and forest soils (Sedjo *et al.* 1998). The carbon in the soil has longer residential duration than the carbon in plants (Lal 2015). Soils in agricultural and grassland areas also have a significant carbon-capture potential. According to Lal and Bruce (1999), repairing damaged forests and soils can trap carbon in terrestrial ecosystems at a global scale equivalent to 50–75 per cent of the past losses.

The Kyoto Protocol decided to include forest and soil carbon sequestration (SCS) among the allowable offsets, and acknowledged the importance of trees and soil in mitigating GHG emissions (Upadhyay *et al.* 2005). The Paris Agreement acknowledges the vital role of natural carbon sinks, including soils and forests, in achieving long-term climate goals (Paris Agreement 2015). Soil is one of the most essential elements for life to exist on this planet. Soil fertility is heavily influenced by carbon since it aids in the preservation of the physico-chemical characteristics of the soil. Changes in the abundance or composition of soil organic matter (SOM), which is such an important component of the terrestrial ecosystem, have a significant impact on a range of ecological processes. The outer layer of soil contains the majority of the soil organic carbon (SOC). Anthropogenic disturbances, such as, land use changes and farming can degrade it easily. The only viable technique for reducing rising levels of GHGs (CO_2 in particular) in the biological system is for atmospheric CO_2 to flow via the physiological system, green plants, and finally into the soil. As a result, green plants store carbon before passing it to the animals. The waste is finally decomposed by microbial processes, and the SOC is added to the soil. Studies have established that carbon sequestration by trees and forests provide relatively low-cost net emission reductions (Melkania 2009).

SOIL CARBON SEQUESTRATION: A MITIGATORY SOLUTION TO GLOBAL CLIMATE CHANGE

Soil Carbon sequestration is the process of eliminating carbon dioxide from the atmosphere and storing it in various long-lived global pools, such as, the oceanic, pedologic, and biotic pools, as well as geological deposits, in order to reduce the net rate of carbon dioxide accumulation in the atmosphere" (Lal 2008). Carbon (C) gets sequestered among five-global pools: the largest is oceanic pool, then geological pool (comprises fossil fuels), pedologic pool (comprises SOC and SIC), atmospheric pool, and the biotic pool (Fig. 1.1). The importance of soil as a terrestrial carbon regulator has escalated since the Paris Agreement signed in December 2015, which calls for improved GHG sink capacity (FAO 2016). The process of absorbing carbon dioxide from the atmosphere through green plants and storing it in the form of soil organic matter is known as soil carbon sequestration (Lal 2004). The primary objective of soil carbon sequestration is to increase SOC density and distribution to a particular depth in the soil, then encapsulate the SOC into micro-aggregates to stabilize it and prevent it from recalcitrant carbon or microbial processes that may make it a long-lived carbon source.

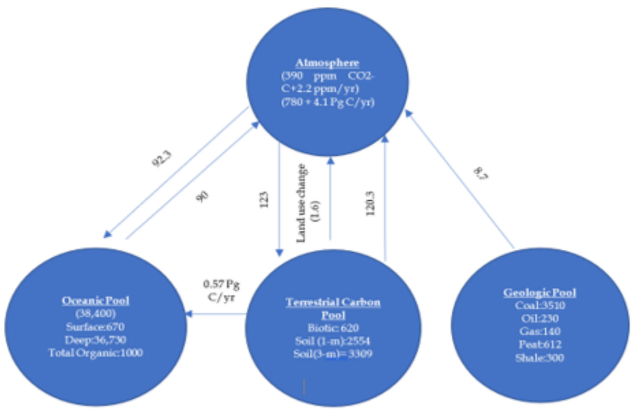

Figure 1: 1Carbon cycle pools(Pg C) and fluxes (Pg C/year) over the short-term (Source: Lal et al. 2012)

The SOC is associated with the amount of organic matter in the soil, as well as temperature, climate, and management. However, by restoring large degraded soil and ecosystems, planting perennial plantations in marginalised areas of agricultural sites, and following recommended management practises (RMPs), such as, mulch farming, reduced tillage, precision farming, integrated pest management (IPM), and integrated nutrient management (INM), the sink capacity of carbon from the atmosphere can be increased. With a long turnover period, the sequestered SOC from the atmosphere mostly returns to the refractory soil organic poolresulting in atmospheric build-up. Soil diversity is important in soil carbon sequestration because ecosystems with high biodiversity retain more carbon in the soil than ecosystems with low biodiversity. The technological alternatives for sequestration of atmospheric carbon dioxide in various pools are depicted in Fig. 1.2.

ANTHROPOGENIC CLIMATE CHANGE AND THE HIMALAYA

According to the IPCC's Climate Change 2021 report, snow cover has decreased in Asian high mountains, including the Himalaya; glaciers have shrunk, receded, and lost mass since the 1970s, despite the fact that the Karakoram glaciers have not shown any significant receding tendency. It is predicted that during the twenty-first century, snow-covered areas and snow volume will continue to drop, snowline heights will rise, and glacier mass will likely continue to diminish as emissions rise. Landslides and Glaciallake outburst floods (GLOFs) over moraine-dammed lakes will become more common as global temperature and rainfall rise. The high mountains of Uttarakhand (= Indian Central Himalaya) and Himachal Pradesh (= Indian Western Himalaya) in India have recently experienced a series of flooding and landslide tragedies each year.

In the last three decades, land usage in the Himalayan region has changed dramatically due to changes in agricultural cropping patterns, increased urbanisation, industrialisation, hydropower generation, and tourism. Changes in climatic circumstances have also resulted in a shift in land-use preferences. Undoubtedly, urbanisation in the Himalaya has created jobs, offered a wide range of social and economic services, as well as contributed to the infrastructural development, all of which have resulted in socio-economic increase in their wide hinterland via trickle-down effects (Tiwari *et al.* 2018). However, in this fragile mountainous region, expanding and uncontrolled urbanisation has depleted natural resources, interrupted vital ecosystem services, raised social and economic inequities, and also made peripheral areas more vulnerable to a range of natural threats (Anbalagan 1993).

SOIL CARBON IN THE INDIAN HIMALAYAN REGION (IHR)

The Himalayan environment is very susceptible to anthropogenic climate change due to its delicate vegetation, steep topography, and biodiversity, which includes several rare, endangered and threatened species (RET species) (Layek *et al.* 2023). Despite this, it plays an essential part in the global carbon cycle due to its extensive forest cover, which contributes to massive carbon stocks (Fig. 1.3, Table 1.1) and has a high potential for anthropogenic climate change sensitivity (Yang *et al.* 2007). Forests at higher altitudes have better ability to trap carbon than the forests at lower altitudes, according to Zhu *et al.* (2010), Charan *et al.* (2012), and Wei *et al.,* (2013). As a result, the Himalaya can be designated an excellent carbon sink, as it has been discovered that managed forest can help to reduce atmospheric carbon by trapping it in various pools, such as, above- and below-ground biomass, litter, deadwood, and soil (IPCC 2007, FAO 2010). After the biomass carbon pool, the soil carbon pool is the most important in mitigating anthropogenic climate change (IPCC 2003,2006).

The IHR forests are being considered as the large pools of carbon because of thick and dense forest cover vegetation. The Himalayan zone in India contributes approximately 33 percent of the soil organic carbon (SOC) stocks (Bhattacharyya *et al.* 2008). As a result, they are extremely important in terms of carbon sequestration and reduction. According to Singh (2007), the IHR forests accumulate around 65mt of carbon alone in the AGB (above ground biomass) annually, and total carbon (biomass + soil) around 5.4 billion t C approximately

THE INDIAN HIMALAYAN REGION

Overview

The Himalaya, which has the largest concentration of ice outside of the polar regions, are dubbed "Asia's Water Tower" because they provide water to 1.3 billion people, or nearly a fifth of the world's population. The Himalaya in India (Fig. 1.4) is classified into three longitudinal belts: the Himadri (Greater Himalaya), Himachal (Lesser Himalaya), and Siwaliks (Outer Himalaya). It is located between 27°50' and 37°06' N lat-

Table 1.1. Carbon stock by forest type at the national level in India in various carbon pools with per ha stock

Forest type	Area (sq. km)	AGB (t/ha)	BGB (t/ha)	Dead Wood (t/ha)	Litter (t/ha)	SOC (t/ha)	Total (000, tonnes)
Tropical Wet Evergreen	20,170	1,46,982 (72.87)	54,379 (26.96)	3,569 (1.77)	8,764 (4.34)	1,30,952 (64.92)	3,44,646 (170.86)
Tropical Semi-Evergreen	71,807	2,48,659 (34.63)	54,733 (7.62)	2,504 (0.35)	21,432 (2.98)	3,91,665 (54.54)	7,18,993 (100.13)
Tropical Moist-Deciduous	1,35,834	4,16,660 (30.67)	91,713 (6.75)	7,128 (0.52)	37,087 (2.73)	7,66,982 (56.47)	13,19,570 (97.15)
Littoral and Swamp	5,527	16,310 (29.51)	6,034 (10.92)	160 (0.29)	382 (0.69)	32,786 (59.33)	55,672 (100.74)
Tropical Dry Deciduous	2,90,724	5,93,848 (20.43)	2,49,439 (8.58)	4,796 (0.16)	28,622 (0.98)	12,81,417 (44.08)	21,58,122 (74.23)
Tropical Thorn	14,552	14,659 (10.07)	6,154 (4.23)	132 (0.09)	1,298 (0.89)	54,395 (37,38)	76,638 (52.67)
Tropical Dry Evergreen	858	2,689 (31.35)	1,129 (13.17)	198 (2.30)	119 (1.39)	3,427 (39.95)	7,562 (88.15)
Sub-tropical Broad-Leaved Hill	31,993	1,14,599 (35.85)	48,132 (15.04)	913 (0.29)	7,233 (2.26)	2,73,023 (85.34)	4,43,900 (138.75)
Sub-tropical Pine forest	17,619	75,562 (42.89)	20,409 (11.58)	609 (0.35)	2,047 (1.16)	1,26,534 (71.81)	2,25,161 (127.79)
Sub-tropical Dry Evergreen	184	1,040 (56.54)	437 (23.75)	5 (0.28)	6 (0.35)	1,281 (69.67)	2,769 (150.58)
Montane Wet Temperate	20,653	69,081 (33.45)	18,652 (9.03)	2,832 (1.37)	4,335 (2.10)	2,60,850 (126.30)	3,55,750 (172.25)
Himalayan Moist Temperate	26,184	2,75,685 (105.29)	74,432 (28.43)	6,795 (2.60)	6,661 (2.54)	2,04,222 (77.99)	5,67,795 (216.85)
Himalayan Dry Temperate	5,565	63,519 (114.12)	18,420 (33.09)	1,734 (3.12)	808 (1.45)	36,786 (66.09)	1,21,267 (217.88)
Sub-Alpine	14,184	1,13,005 (79.67)	32,769 (23.10)	3,946 (2.78)	1,536 (1.08)	1,51,081 (106.51)	3,02,337 (213.15)
Moist Alpine Scrub	1,975	4,046 (20.48)	1,173 (5.94)	72 (0.37)	147 (0.75)	9,752 (49.37)	15,190 (76.9)
Dry Alpine Scrub	2,006	11,855 (59.12)	3,438 (17.14)	49 (0.24)	211 (1.05)	5,980 (29.82)	21,533 (107.37)
Plantation/ TOF	52,414	88,336 (16.85)	19,384 (3.70)	402 (0.08)	7,214 (1.38)	2,72,439 (51.98)	3,87,775 (73.98)
Total	7,12,249	22,56,535 (31.68)	7,00,827 (9.84)	35,844 (0.05)	1,27,902 (1.80)	40,03,572 (56.21)	71,24,680 (100.03)

itude and 72°30' and 97°25' E longitude, with an elevation ranging less than 500 m to 8000 m asl. The Indian Himalayan region stretches 5.37 million km^2 from Jammu and Kashmir in the North West to Arunachal Pradesh in the North East, covering Union territory Ladakh, Jammu and Kashmir and states,viz., Himachal Pradesh, Uttarakhand, Arunachal Pradesh, Sikkim, Mizoram, Nagaland, Meghalaya, Tripura, and Manipur, with Assam and West Bengal only partially covered. It covers around 16.2 per cent of India's total land area, with upscale forest cover accounting for over 41.5 percent (Kumar *et al.* 2018). The Himalayan region is home to about 25.3 per cent plant species, including 1748 medicinal plants, 675 wild food species, 279 fodder species, 155 sacred plants, and 118 volatile oil-producing medicinal plants (Stephen *et al.* 2015).

Climate and Geology of IHR

The IHR has diverse range of climate, landform, ethnicity, resource availability, and agricultural practise; in particular, the temperate zone, which is located between 1000 and 4500 m asl, experiences a long winter, and a diverse range of climate. On the Indian side, this results in considerable precipitation (both rain and snow), but parched conditions in Tibet. Annual rainfall on the southern Himalayan slopes ranges from 1,530 mm in Shimla, Himachal Pradesh, and Mussoorie, Uttarakhand in the west to 3,050 mm in Darjeeling, West Bengal, in the east. In regions like Skardu, Gilgit, and Leh in the Kashmir region of the Indus valley, just 75 to 150 mm rainfall occurs north of the Great Himalaya (Joshi *et al.* 2014). Dhar *et al.* (2002) estimated total number of glaciers in the Himalaya to be around 15000, with a total ice volume of 14000 km^3. The glaciated region of the Indian sub-continent's three major river systems is: 14,050 km^2 in the Western Himalaya Indus basin,5,957 km^2 in the Ganga basin in the Central Himalaya, and 3,083 km^2 in the Eastern Himalayan Brahmaputra basin. The northernmost Trans-Himalaya, the Greater or Tibetan Himalaya, the Lesser or Lower Himalaya, and the southernmost Outer Himalaya together constitute the Himalaya. These four ranges run parallel to each other from west to east in vast belts, yet each has its own geologic history.

Land Uses in The Indian Himalayan Region

The Indian Himalaya has 131 biodiversity-sensitive protected areas, accounting for 9.6 per cent of the country's total protected area (roughly equal to the Western Ghats- 10 per cent). Among the protected areas are:

Table 1.2.Description of different LULC categories (Source: Taloor *et al.* 2020*)*

LULC category	General description
Agricul- ture	Crops grown are maize, wheat, barley, oats, potato, and tea plantations.
Horticul- ture	Cultivating plants in gardens for the purpose of producing food and medicinal substances, for comfort and ornamental purposes.
Agrisilvi- culture	Production of food, fruit, fodder, timber, and bund stability in both irrigated and rainfed settings
Natural grassland	Dominantgrasses are *Arundinella, Chrysopogon, Themeda, Heteropogon, Apluda, Dicanthium, Panicum, Ischaemum, Chloris, Imperata,* and *Cymbopogon.* Grazing animals can find food in these grasslands.
Silvopas- toral system	Combination of woody plants and grass species. The trees and bushes may be grown predominantly for eutherian mammal fodder, or may be introduced completely for timber, fuelwood, fruit, or soil improvement purposes.
Natural forest	Evergreen, semi-evergreen, deciduous and mixed forestsand all other land with woody vegetation
Waste- land	Uncultivated agricultural fields characterized byarid soil with little or nearby no vegetation cover

55 national parks, 146 wildlife sanctuaries, five tiger reserves, six biosphere reserves, and seven Ramsar sites (ENVIS 2019).

Land Use/ Land Cover in the Indian Himalayan Region

Land use, according to the FAO (2016) refers to human activities that are directly related to land, such as, using its resources or leaving an impact on it. Seven land use/land cover systems have been selected for the present study

ANALYTICAL METHODS USED FOR SOC MEASUREMENTS

This study assesses soil organic carbon on different slope aspects in land uses and forest types in the Indian Himalayan Region using review and meta-analysis of the published data. The top soil layer(0-30 cm deep) is where the majority of the SOC available. For estimating organic carbon, the soil samples are sieved at 0.2 mm using the Walkley and Black method. The modified Walkley-Black Method is used to calculate organic carbon (Walkley and Black 1934). In this method, the organic matter in the soil is oxidised with a solution of potassium dichromate ($K_2Cr_2O_7$) and concentrated H_2SO_4 in a volume equal to the sample holder's volume. The dirt is transferred to a container, weighed, and baked at 105°C until it attaines a steady weight. The oven dry soil sample's bulk density (BD) is calculated by dividing the sample's volume by the sample's dry weight. The soil used to calculate BD is not utilised to calculate the organic carbon content. Back titration of unused $K_2Cr_2O_7$ with ferrous sulphate ($FeSO_4.7H_2O$) or ferrous ammonium sulphate [$FeSO_4$. $(NH_4)2SO_4$. $6H_2O$], to convert SOC (%) to SOM, a factor of 1.724 (Van Bemmelen factor) is utilized

SOIL ORGANIC CARBON ACROSS LAND USES IN THE IHR

The North Western Himalaya

This part of IHR consists of the states Himachal Pradesh, Ladakh (Union Territory), Jammu and Kashmir. Table 1.3 and Fig. 1.5 reveal that the SOC in the surface layer of soil (0-30 cm deep) was highest under natural forest system and lowest in silvopastoral system. The SOC in different land use systems followed order as: NaturalForest (217t/ha) > natural grassland (75t/ha) > agriculture (86.7t/ha) > horticulture (30.3t/ha) >agrisilviculture (50.5t/ha) > wasteland (24.6t/ha) >silvopasture (20.5t/ha). Khaki *et al.* (2016) reported a similar result. This could have occurred as a result of increased leaf litter accumulation in tree and fruit-based land use systems. Under complex land use systems, copious leaf litter or trimmed biomass returns to soil, and together with root degradation, contributes to the enhancement of organic matter (Dar and Sundarapandian 2013). Similar findings have been recorded by Conant and Paustian (2002) who observed the range of soil carbon between 30 to 80 t/ha for temperate grasslands.

The Central Himalaya

It includes state Uttarakhand comprising of Kumaun and Garhwal administrativedivisions. Table 1.4 and Fig 1.6 reveal that the SOC in different land use systems followed order as: Natural forest (128 t/ha) > horticulture (105 t/ha) > agriculture (92 t/ha) > wasteland (92 t/ha) >natural grassland (75 t/ha) >silvopastoral (51 t/ha) >agri-silviculture (25 t/ha). Forest land use recorded highest SOC content. Similar findings were reported by Meena *et al.* (2018)who found that natural forest land had the highest SOC (161 t/ha), followed by natural grassland (134 t/ha), cultivated land (92 t/ha), and significantly lowest SOC in barren land (92 t/ha). Forest floor remains covered with leaf litter that assists in decomposition process and, hence, enhances the SOC.

The North Eastern Himalaya

The North Eastern Himalaya covers states, viz., Arunachal Pradesh, Sikkim, Meghalaya, Mizoram, Nagaland, Tripura and Manipur and partially only the Capital Hill districts of Assam, and Darjeeling and Kalimpong districts of West Bengal. Table 1.5 and Fig. 1.7 reveal that SOC in different land uses follow order as: Natural Forest (63.47 t/ha) > horticulture (53.7 t/ha) > natural grassland (39.76 t/ha) > agriculture (38.69 t/ha) >agri-silviculture (20.65 t/ha) >silvopastoral system (11.97 t/ha).

The SOC concentration evidently is substantially greater in natural forest and natural grassland ecosystems than the other land uses. The literature implies that natural forest and natural grasslands have better capability for accumulating and conserving SOC than the agriculture, because the shift from natural forest and natural grassland to agriculture is accompanied with a loss of SOC (Don 2013;Kassa *et al.* 2017; Martin *et al.* 2016; Vashumand Jayakumar 2016; Poeplau andKenye *et al.* 2019). Low SOC in cultivated land is on account of year-round cultivation/disturbance (puddling), soil erosion led losses, and nearly complete crop residue clearance from cultivated fields for numerous reasons (Majumdar *et al.* 2008). The C loss occurs on farmed land as a result of soil disturbance (Beare *et al.* 1994). An extensive root cycling system with a high lignin content is responsible for storing organic carbon in soil in the natural grassland, which is comparable to other tree-based systems (Lugo *et al.* 1990; Tornquist *et al.* 1999; Martens 2000). In the long-run, natural grassland attainssame ability to store total organic carbon as tree-based systems (Franzluebbers *et al.* 2000). In contrast to this finding, Mangalassery *et al.* (2014) observed in arid north western part of India that the silvopastoral systems help to accumulate more SOM, and, hence, more carbon storage than sole grass or sole tree system due to the addition of higher net biomass and exploitation of available resources.

Variation in SOC along the Altitudinal Gradient

In the present study, the SOC stock has been studied along different altitudes in the three IHR divisions, i.e., North-West Himalaya, Central Himalaya and North-East Himalaya. The research is significant as it contributes to a deeper comprehension of the IHR forest ecosystems' potential for sequestering atmospheric carbon into the soil carbon pool, or sink. Because the SOC content is higher in the top layer of soil due to fast decomposition and mixing of the forest litter, the majority of the SOC values were examined up to 30 cm depth (surface soil) in this study (Sheikh *et al.* 2020).

Soil is the greatest organic carbon pool in the terrestrial biosphere. As a result, even slight changes in SOC supply could have an impact on global carbon concentrations in the atmosphere (Johnston *et al.* 2004;Xu *et al.* 2011). In the North-West Himalaya, the maximum value of SOC stock has been found 54.1t/ha under the forest dominated by *Betulautilis*at 2500-3000 m altitude and 19.39 t/ha under the forest patch inhabited prominently by *Populus deltoids* at an altitude of 1500-2000 m (Table 1.3 and Fig1.5). Similar findings of increment in SOC stock with altitude have been concluded by Awasthi *et al.*(2005) and Yimer *et al.* (2006).

In the Central Himalaya, the maximum value of SOC stock 126.4 t/ha has been recorded under *Pinus roxburghii* between 500-1000 m altitude, and minimum (31.3 t/ha) under *Rhododendron arboretum* at 2000-3000 m altitude (Table 1.7 and Fig. 1.9). The low value of the SOC stock in soil of *Rhododendron arboretum* is possibly because the author's estimated SOC stock value by multiplying SOC g/kg with the factor of eight million assuming that 60 cm soil layer weighs 8.0 million kg in an area of one ha (Sheikh *et al.* 2009). Kumar *et al.* (2013) found a similar trendin which the SOC stock declined as altitude increased. Soil carbon under *Pinus roxburghii* forest in Nepal at 1200-2000 m altitude was observed to be depleted in higher altitude areas, compared to the lower altitude areas by Sah *et al.*(2003).

In the North-Eastern Himalaya, the maximum SOC stock value has been recorded to be 138 t/ha at 2500-3000 m under Fir (*Abies pindrow*) forest, and minimum value 24.5 t/ha at 1500-2000 m (Table 1.8 and Fig. 1.10) under the mixed forest type (*Engelhardtia spicata, Oroxylum indicum, Helicia excelsa* and *Castanopsis tribuloides* as dominant species). This study revealed that at higher altitudes (above 500 m), generally the SOC value is significantly high from the lower altitudes (Chakravorty and Chakravarti 1980, Minhas and Bora 1982, Banerjee *et al.* 2014, Martin *et al.* 2010, Dar and Sundarapandian 2015, Tashi *et al.* 2016, Simon *et al.* 2018). This could be possibly due to restricted human interventions and pressure because with higher elevation, the human population declines. According to Devi *et al.*(2019), SOC stock is greater at higher elevations because forest regions over 2000 m are better conserved than forest areas at lower altitudes, and are less affected by human involvement, such as, widespread conversion of forest lands into tea plantations and agricultural land.

As the altitude increases, atmospheric temperature decreases, and precipitation increases (Batjes 1996, Jobbágy and Jackson 2000); therefore, soil temperature also decreases. Soil temperature is one of the governing factors for soil respiration rate. In the cold conditions, soil respiration rate decreases that results in reduction of biological activity which is probably the reason for high SOC at higher altitudes as compared to the lower altitudes. This is because at higher temperature or low altitudinal areas, soil gets warmer which raises its respiration process or decomposition and biological activities that minimise the accumulation of carbon in the soil (Post *et al.* 1982, Blair *et al.* 1995, Dar *et al.* 2015). As precipitation also increases up to certain increasing altitude, it helps to maintain soil moisture which possibly facilitate formation of aggregates of soil particles and organic matter or soil which retain organic content and help increasing SOC value (Singh *et al.* 2011). The SOC is one component of SOM which decreases with high temperature and increases with precipitation (Jenny 1980, Burke *et al.* 1989, Itanna 2004, Bhat *et al.* 2012, Bao *et al.* 2016). The SOC stock shows negative correlation with the temperature, decomposition or turnover rate, acidic condition and anaerobic conditions (Devi *et al.* 2019) but have positive correlation with soil moisture (Bhat *et al.* 2012), precipitation and cold condition (Devi *et al.* 2019). As diverse ecosystem, the Himalaya is one of the biodiversity hotspots in India (Tolang and Moktan 2020). It has diverse range of plants from small to huge canopy forests. These forests help in the significant litter accumulation on the forest ground which helps to increase the SOC. Despite all these factors, after certain altitudes, the SOC values decrease. The trend does not follow an uniform pattern because of the dynamic environmental factors.

The variations in this trend showing low SOC values under some high altitudinal forest is because of the low plant density or due to the reduction of basal area with increasing altitude(Sheikh *et al.* 2020). Low temperature, low productivity, and eco-physiological variables could all contribute to a decrease in species richness at higher elevations (Korner 1998, Hardy et al. 2001). As a result, as the altitude rises, the amount of vegetation decreases, resulting in lower litter deposition and breakdown rates, leading to lower soil carbon (Sevgi *et al.* 2008, Kumar *et al.* 2013,Prakash 2015). The per acre carbon stock reduces with rising altitude, and vice versa, possibly due to the SOC stabilising better at lower altitudes (Sheikh *et al.* 2009). It is difficult to interpret such variations because along with the altitudinal factors, combined effect of factors, such as, soil, climate, and vegetation type also govern the SOC of an area (Elmore and Asner 2006). Another factor that could be responsible for the SOC reduction at higher altitude is steepnessof the slope. Strong correlation exists between the slope and SOC content(steeper slope could accelerate soil erosion;Bhatt 2012, Awasthi 2004).Despite the higher accumulation of the SOC stock value at high altitudes, there is no specific linear pattern showing uniform increase since factors, such as, temperature, precipitation or altitude cannot solely govern entire carbon pool; It is the cumulative effect of several factors (Ahirwal *et al.* 2021).

SOC ALONG THE ALTITUDINAL GRADIENT IN THE IHR

The North Western Himalaya

Table 1.9 enumerates variation in SOC with altitude among different land use systems. When the major influence of altitude was taken into account, the C levels were substantially greater in high-altitude land uses(2500-3000 m) than at low altitude (1000-1500 m) (Fig 1.11). Natural forest at high altitude had the highest total carbon, while silvopastoral system at low altitude had the lowest. Agricultural land has high SOC at low altitude (1000-1500 m). Similar results were also recorded by Singh *et al.* (2011) who reported highest SOC (101.8 t/ha at 0-30 cm depth) in temperate, and the lowest in sub-tropical climate (37 t/ha at 0-30 cm depth)

The Central Himalaya

The highest amount of SOC has been recorded in natural forest at 2500-3000 m asl and lowest in silvopastoral system at low altitude (Table 1.10, Fig. 1.12). Natural forest and natural grassland showed increase in SOC with increasing altitude. As high altitudes experience the cool temperature, it may be the reason for highest SOC at higher altitude. The same reason has alsobeen reported by Schlesinger (1997) recording the highest stock of soil organic carbon accumulation in cool and wet conditions, and the lowest in deserts

The North Eastern Himalaya

The SOC in natural grassland and tree-based system did not vary much. Highest SOC was recorded in natural forest at 1000-1500 m asl, followed by natural grassland at the same altitude. The SOC has been highest at medium altitude, compared to the higher altitude (Table 1.11; Fig. 1.13).

With cooler temperature and a lower annual average temperature, the decomposition rate of SOC may

Table 1.9. SOC (t/ha) along the altitudinal gradient (m asl) in the North Western Himalaya, India

Land use	Altitude (m)				
	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
Agriculture		13.99(1)	31.65(2)		43.94(3)
Horticulture	18.24(4)	35.6(5)	37.20(6)	66.34(7)	
Agri-silviculture			50.58(8)		68.67(9)
Silvopastoral			25.06(10)	20.55(11)	23.68(12)
Wasteland			22.27(13)	24.67(14)	30.45(15)
Naturalgrassland		50.53(16)	97.80(17)	46.90(18)	75.00(19)
Natural forest	48.77(20)	52.68(21)	19.39(22)	30.50(23)	217.25(24)

(Source: (1),(18) Rajput et al. (2017); (2),(10),(11),(12),(13),(14) Chisanga et al. (2018); (3) Acharya et al. (2012); (4) Rajput et al. (2016);(5),(6) Iqbal et al. (2020); (7),(9),(15),(19),(24) ul Zafar Geelani et al.(2018); (8) Goswami et al. (2014); (16),(17),(21) Devi et al. (2012); (20) Shah et al. (2013); and (23) Dar and Sundarapandian (2013)

Table 1.10. SOC (t/ha) along the altitudinal gradient (m asl) in the Central Himalaya, India

Land use	Altitude (m)				
	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
Agriculture		62.95(1)	92.00(2)		
Horticulture	37.80(3)			105.20(4)	
Agri-silviculture	29.01(5)	23.07(6)	54.90(7)	23.78(8)	25.85(9)
Silvopastoral			51.00(10)		
Wasteland	16.20(11)		92.00(12)	27.73(13)	
Natural grassland	37.09(14)	41.15(15)	65.88(16)	75.76(17)	142.14(18)
Natural forest	83.82(19)	65.26(20)	19.20(21)	31.80(22)	217.00(23)

(*Source*: (1) Kumar and Sharma (2016); (2),(12) Meena et al. (2018); (3) Gera et al. (2011); (4), (17) Gupta and Sharma (2011); (5), (6), (8) Vikrant et al. (2021); (7),(20) Yadav et al. (2019); (9) Vikrant et al. (2020);(10) Singh et al. (2019); (11) Gupta and Pandey (2008); (12) Negi and Gupta (2013); (14), (15),(18) Gupta (2013); (16) Yadav (2019);(19) Arora et al. (2014); (21), (22) Bhat et al. (2012); and (23) ul Zafar Geelani et al. (2018).

have been slowed, resulting in a greater amount of SOC stock at higher elevations. The reasons for this outcome are the same as those for soil carbon stock, viz., higher soil carbon build-up due to slow breakdown and increased organic matter deposition (Tsui *et al.* 2013; Tashi *et al.* 2016)

The SOC has been found to be higher in natural forests than in other land uses within the 0–30 cm soil depth. The majority of the SOC in natural forest and grassland is in a readily oxidisable labile state, implying that the accumulated carbon could be lost quickly if land use changes. The SOC increases when precipitation and the clay content increase, but reduces as temperature climbs (Jobbágy and Jackson 2000). Several workers have also noted that as altitude rises, SOC rises as well (Tewksbury and Miegroet 2007; Zhu *et al.* 2010; Zhang *et al.* 2011; Charan *et al.* 2012; Wei *et al.* 2013;Gupta and Sharma 2013). The greatest way to keep SOC decomposition rate low is to maintain temperature low at higher altitude (Wei *et al.* 2013); . The increased SOC density in the upper layer may be due to cooler temperature and more precipitation in high-altitude ecosystems, or it may be due to shallower root distribution (Jobbágy and Jackson 2000; Yang *et al.* 2007; Zhu *et al.* 2010); while the trend of SOC decline with depth could be due to an increased proportion of slower cycling of SOC pools at depth or vegetation types (Paul *et al.* 1997; Trumbore 2000; Jobby and Jackson 2000); as a result, climate and vegetation types are significant regulators of SOC vertical distribution patterns in land uses.

Variation in SOC among Major Natural Forest Types

In the IHR, 11 forest types are reported. In this study, the SOC under major forest types at different altitudes have been documented. The SOC stock in the moist tropical evergreen forest at 500-1000 m has been found to be 64 t/ha in undisturbed woods and 63.2 t/ha in disturbed forests, respectively (Table 1.12 and Fig. 1.14). At 1000-1500 m altitude, montane moist sub-tropical deciduous and montane dry sub-tropical deciduous forest are found with SOC stock value around 73.1 t/ha and 65 t/ha, respectively. With further increase in altitude to 1500-2000 m, montane sub-tropical evergreen forests are found with SOC stock of 95.9 t/ha. At 2000-2500 m altitude, montane wet-temperate forest prevails recording the SOC stock 110.2 t/ha, and moving further, at an altitude of 2500-3000 m, sub-alpine forest persists with SOC stock value around 35.4 t/ha.

The entire IHR can be grouped into three different levels of ecosystem along the altitude – tropical, temperate and alpine ecosystem. Table 1.12 and Fig. 1.14 depict major forest types of the IHR. The highest SOC storage value has been recorded in the Montane wet-

Table 1.11. SOC (t/ha) along the altitudinal gradient(m asl) inthe North Eastern Himalaya, India

Land use	Altitude (m)				
	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
Agriculture		38.69(1)	49.30(2)		31.10(3)
Horticulture			53.70(4)		
Agri-silviculture	20. 65(5)				
Silvopastoral	11.97(6)				
Natural grassland	39.76(7)	60.33(8)	16.09(9)	27.68(10)	
Natural forest	32.44(11)	63.47(12)	24.50(13)	62.58(14)	63.47(15)

(Source: (1),(12),(15),(8) Meetei et al. (2017); (2),(4)*https://www.researchgate.net/scientific-contributions/KM-Manjaiah-59160382*Ramesh et al. (2015); (3) Bordoloi et al. (2019); (5), (6), (9),(7), (11),(13) Kenye et al. (2019);and (10),(14) Singhet al. (2018*)*

temperateforest (110.2 t/ha) probably due to the optimum conditions favourable for the SOC stock. Generally, temperate ecosystem has minimum temperature from around freezing to 3.6 °C, and maximum around 29.3 °C to 29.3 °C (Yadav *et al.* 2017;Mahato *et al.* 2016). The annual rainfall in the temperate climate varies from 1387 to 3000 mm (Mahato *et al.*2016;Bhatt *et al.* 2018). Soils of the temperate forests are generally sandy-loam to sandy-clay-loamy. Such type of soil texture has high potential to hold moisture (Mahato *et al.* 2016;Yam *et al.* 2019,). Thus, optimal moisture and moderate temperature in the temperate forest promote high SOC stock. Singh and Singh (1987) reported that temperate forests occasionally have temperature around 28°C, and have arboreal species like of*Quercus*with large canopy, high growth and productivity that result in significant litter production (Sheikh *et al.* 2009). The low-lying temperate forests (altitude 1550-2000 m) comprised mainly of broad-leaf arboreal species like *Populous deltoides, Ulmusvillosa, Salix sp., Juglans regia,* etc. (Dar *et al.* 2015). According to Singh *et al.* (2011), the SOC stock in temperate forest is high because of the low soil temperature, soil moisture, accelerated root proliferation, high vegetation and increased rate of organic matter decomposition. The decomposed litter gets trapped by forming aggregates with clay complexes and soil particles. Sub-tropical climatic forest types have lower SOC stock than the temperate forest types possibly because of the low annual precipitation than in the temperate region. The sub-tropical region experiences temperature from minimum 8.0 °C to maximum up to 42 °C in summer (Singh *et al.* 2011;Lungmnana *et al.* 2018) and annual rainfall round 200-250 cm (Baishya *et al.* 2011;Lungmnana *et al.* 2018) that may reach upto 400 cm in the North-Eastern states. Sub-tropical forest has generally dark yellowish brown to yellowish brown soil (Lungmnana *et al.* 2018). The high temperature of soil causes SOC oxidation at fast rate (Pandey *et al.*2010). Tropical lowlands lose SOC content due to high temperatures and insufficient precipitation, (Melillo *et al.* 2011). Another factor for low values in sub-tropical forests could be the high rate of forest degradation and disturbance caused by substantial conversion of forest area to non-forest landuses, viz., agriculture and tea plantations (Devi *et al.* 2019). Alpine and temperate forests limit human access to the forest, protect it, and result in higher carbon storage at higher elevations (Sparcklen and Righelato 2014; Ahirwal *et al.* 2021).

The sub-alpine forests recorded the lowest SOC stock (35.4 t/ha) having the lowest soil temperature (Table 1.12). This could probably be because of the snowfall instead of wet precipitation that restrict the vegetation growth. Lower and upper alpines experience significant snowfall for five months in winters, and also in the early summers (Singh *et al.* 2011). Such prolonged snow and permafrost conditions cause physiological (dry conditions) stress in the soil that reducesseed germination, vegetation growth and litter production, also influencing activity of microbes, and formation of the soil organic carbon complexes (Parry 1992). The slopes in alpines are deep and steeper than the temperate environment (Singh *et al.* 2011). In the summer, the melting of snow and permafrost drain down the hill towards the low-lying areas through slopes, resulting in lower SOC due to loss by runoff (Singh *et al.* 2011)

Thus, in spite of low temperature, the SOC is reduced due to soil erosion in alpines (Singh *et al.* 2011). *Betula utilis* dominates the high altitudes (2800-3250 m) in most of the regions (Dar *et al.* 2015).

SOC IN THE IHR AND THE HINDU KUSH HIMALAYA, NEPAL

The Indian Central Himalaya state Uttarakhand is bordered on the east by Nepal and on the west by Himachal Pradesh with the northern boundary extending up to Tibet/China, and the southern boundary extending into the Indo-Gangetic plains. Snow cover/glaciers and steep slopes cover around 20.03 per cent of the overall geographical area of Uttarakhand. Natural forests account for 42 per cent of land use in Nepal, followed by agriculture including non-cultivated areas (27 per cent), natural grassland (12 per cent), and others (19 per

Table 1.12. Variation in SOC (t/ha) under major forest types in IHR

Forest type	Altitude (m)	Species	Study area	SOC (t / ha)	Source (s)
Moist tropical evergreen (Dense)	500 - 1000	*Aesculus indica, Bamboo sp., Bombax ceiba, Dalbergia sissoo, Neolamarchia-cadam, Micheliachampaca*	Upper Assam; Lower slopes of Eastern Himalaya (NE); Naga Hills; Meghalaya; Mizoram and Manipur	64.00	Bhadwal and Singh 2002, Krishnan *et al.* 2007
Moist tropical evergreen (Disturbed)	500 - 1000	*Aesculus indica, Bamboo sp., Bombax ceiba, Dalbergia sissoo, Neolamarchia-cadam, Micheliachampaca*	Upper Assam; Lower slopes of Eastern Himalaya (NE); Naga Hills; Meghalaya; Mizoram and Manipur	63.20	Bhadwal and Singh 2002, Krishnan *et al.* 2007
Montane moistsub–tropicaldeciduous (Broadleaf)	1000 – 1500	*Bauhinia* spp., *Castanopsis sp., Schima sp., Shorearobusta, Terminalia* spp.	Assam; Nagaland; Mizoram; Meghalaya; Arunachal Pradesh and Jammu	73.10	Bhadwal and Singh 2002, Krishnan *et al.* 2007
Montane drysub-tropical deciduous (Boadleaf)	1000 - 1500	*Nerium oleander, Olea cuspidate, Punica granatum, Shorearobusta, Terminalia* spp.	Assam; Nagaland; Mizoram; Meghalaya; Arunachal Pradesh and Jammu	65.00	Bhadwal and Singh 2002, Krishnan *et al.* 2007
Montane sub-tropical evergreen	1500 - 2000	*Pinus roxburghii, Rhododendron arboreum*	Uttarakhand; Himachal; Middle North-East Himalaya	95.90	Shaheen *et al.* 2016
Montane wet temperate	2000 – 2500	*Cedrus deodara, Cupressus sp., Pinus sp., Quercus* spp., *Rhododendron arboreum*	Arunachal Pradesh; Himachal; Uttarakhand; Kashmir	110.20	Bhadwal and Singh 2002
Sub-alpine	2500 – 3500	*Betula utilis* and*Pinuswallichiana*	Himachal; Uttarakhand; Kashmir; Arunachal Pradesh; Sikkim and Darjeeling	35.40	Bhat *et al.* 2012

cent) (UNCD 1992). Natural forest land also includes shrub land with a crown cover of <10 per cent. The hill region accounts for 35 per cent of total natural forestland, whereas the mountainous area accounts merely for one-third. A quarter of the agricultural land is uncultivated in the rain-fed hills. The mountains contain almost 80 per cent of natural grassland. The proportion of land used varies greatly between regions. Paddy terraces and upland maize and millet fields are the two main types of agricultural land in the hills.

The SOC in soil of different land uses in the IHR and Nepal is reported in Table 1.13 and Fig. 1.15 indicate that accumulation of SOC has been higher in the IHR, compared to Nepal (HKH) among different land uses. The soil under natural forest land containshigher SOC than the cultivated land and degraded land in both the regions. The total SOC followed the order as: NaturalForest> natural grassland > horticulture > agriculture > wasteland >agri-silviculture >silvopastoral. Almost similar pattern has been observed in both the regions since geographically both share similar environmental conditions.

When the biomass is more, the SOC is high. However, SOC content is influenced by a number of factors. Another significant factor is the temperature of the location, because the lower the temperature, the higher the SOC sequestration. The temperature in the alpine region is extremely low, which inhibits microbial activity. There is less breakdown and release of nutrients essential for plant growth due to low microbial activity. Plant growth is limited as a result of a lack of necessary nutrients, and the plants are unable to utilise the carbon in the soil. In absence of natural forest, the SOC in the alpine region is higher than in other regions that are viable sinks of atmospheric carbon. The low SOC in the HKH region may be owing to the region's sensitivity to high rate of soil erosion caused by variables, such as, steep slope, current and previous glaciations, high rainfall intensities caused by orographic influences, and a restricted vegetal cover. In addition to significant erosion rates, mountain erosion is thought to have severe downstream impacts. Accelerated anthropogenic activities further add to the decline of the SOC in certain regions

Comparison of SOC in the Forest Ecosystem of the IHR and Hindu

Kush Himalaya,Nepal

As the IHR and Nepal Himalaya share similar geographical characteristics,such comparison could help

Table 1.13. SOC (t/ha) in diverse land uses in the IHR and Hindu Kush Himalaya, Nepal

Region	Land use	SOC (t/ha)	Source
India	Agriculture	92.00	Meena *et al.* (2018)
Nepal		22.60	Ghimire *et al.*(2018)
India	Horticulture	105.20 (2000-2500 m asl)	Gupta and Sharma(2011)
Nepal		Data not available	
India	Agri-silviculture	54.90 (800-2250 m asl)	Yadav *et al.* (2019)
Nepal		19.55 (1000 m asl)	Magar *et al.*(2020)
India	Silvopastoral	51.00	Singh *et al.* (2019)
Nepal		30.25	Magar *et al.*(2020)
India	Wasteland	92 (900-1800 m asl)	Meena *et al.* (2018)
Nepal		18.60	Ghimire *et al.* (2018)
India	Natural grassland	134.00	Meena *et al.*(2018)
Nepal		71.97 (1500-2000 m asl)	Shrestha (2016)
India	Natural forest	161.00	Meena *et al.* (2018)
Nepal		81.36	Dhakal *et al.* (2010)

to understand the difference in the SOC sequestration in both the nations separated by political boundaries.Table1.14 and Fig. 1.16 illustrate SOC content under major forest types of Uttarakhand and Nepal at varying altitudes. At 500-1000 m asl, the value of the SOC in Indian Himalayan forests is 83.82 t/ha under *Populus deltoides,* and 49.30 (t/ha) in Nepal under *Shorearobusta* forest. At 1000-1500 m asl in India and Nepal, the SOC stock valuein *Pinus roxburghii*forest is 33.20 (t/ha) and 53.4 (t/ha), respectively. At 1500-2000 m asl, in mixed forest type, the SOC stock is recorded to be 122 (t/ha) in India and 81.3 (t/ha) in Nepal. At higher altitudes (2000-3000 m asl), the SOC under *Rhododendron sp.* and *Quercus sp.* is 23.20 t/ha for the IHR and 31.00 t/ha for Nepal, Hindukush, Himalaya. This reveals that the SOC stock values at similar altitude under different forestsare nearly thesame. The HKH (Nepal) is potentially susceptible to high soil erosion because of factors like non-seasonal high rainfall cover and glaciations in past and present, extreme human-induced disasterslike floods and landslides, and low vegetation cover (Upadhyay *et al.* 2005). Also, these factors are responsible for the land degradation which is a cumulative impact of increasing human population and tourism, forest fires, floods, improper soil management, inappropriate land uses and unplanned developmental activities

Recall that, Nepal and India are neighbouring countries sharing similar geographical and climatic attributes resulting in nearby similar vegetation types, both countries have different forest protection policies and laws (Choden *et al.* 2021). Despite the fact that Nepal had faced wide destruction of forest in the past, the Nepal government is working for its conservation (Choden *et al.* 2021). In India, the forest cover has increased accountably compared to past (FSI 2019), thus could result in carbon sequestration progressively.

CONCLUSION

The present study is an attempt on the organic carbon in the soil (SOC) at different altitude in diverse land uses, under different forest types in the IHR. The study offers an insight into the role of forest ecosystem in maintainingSOC in the IHR. Climate, moisture, temperature, and soil type all influence the organic carbon content in soil. Both land usage and soil depth have a major impact on the SOC stock. Natural forest and natural grassland are the greater contributors to the SOC than the other land uses. Leaf and root litter inputs have a crucial influence in natural forest soil carbon dynamics. The SOC stock was found to be substantially within the same land use profile higher in the top soil than in other depths. The SOC content declines as the depth of the soil increases. Thus, besides land use, soil depth also influences the availability of the SOC. The SOC is quite high at higher altitudes though there is no uniformity in the trend. In natural environment, factors like altitude, latitude, precipitation, temperature, etc. affect the SOC. Besides soil type, terrain adds to the governing factors. There is a cumulative impact of various factors onthe SOC. Reversing soil loss and improving soil quality require minimising erosion, which usually entails leaving plant leftovers on the surface or growing a cover crops. Low-tillage, legume-based, or manure-applied agriculture are examples of land use practices that can improve soil C storage. As a result, the most important treatments for increasing SOC storage capacity in different land use systems in the IHR would be an appropriate land use strategy and long-term soil management planning. While comparing the SOC in the IHR with that of Hindu Kush region (Nepal), it is evident that there exists just political differentiation and no such bio-geographical boundaries exist between the

Table 1.14. SOC (t/ha) stock in the forests of the IHR and Nepal Himalaya

Altitude (m)	Location	SOC (t/ha)	Forest type Species	Source
500-1000	India	83.82	*Populus deltoides*	Arora *et al.*(2014)
	Nepal	49.30	*Shorearobusta*	Ghimire *et al.* (2018)
1000-1500	India	33.20	*Pinus roxburghii*	Kumar *et al.* (2012)
	Nepal	53.40	*Pinus roxburghii, Schimaspp.,Castanopsis spp.*	Khanal *et al.* (2010)
1500-2000	India	122.00	*Quercus leucotrichophora, Rhododendron arboreum,Pinus roxburghii*	Sharma *et al.*(2011)
	Nepal	81.36	*Schimaspp., Castonopsisspp., Pinus roxburghii* and *Quercus sp.*	Dhakal *et al.*(2010)
2000-3000	India	23.20	*Rhododendron sp.* and *Quercus sp.*	Bhat *et al.*(2012)
	Nepal	31.00	*Rhododendron arboreum* and *Quercus sp.*	Suwal *et al.*(2014)

two regions. The SOC is higher in some parts of IHR as compared to the Nepal. This is possibly because of the forest management approaches of both countries and approach towards and utilization of forest resources vary. The reduced values of soil carbon in most of the region is due to the extensive anthropogenic pressure on the forests.

The focus in this contribution is on soil carbon reservoir because it contains twice as much carbon as the atmosphere, and thrice as much carbon as the terrestrial plants, and it is clearly addressable since forest soil carbon behaves as both a sink and a source of carbon. Hence, sustainable management and conservation of forests could not only reduce carbon emission but also act as the sink to sequester more atmospheric carbon, which enhances carbon stock consequently. Additionally, REDD+ and CDM play a role in restoration of degraded forests. This study is helpful in adding value in providing a database for SOC in the IHR.

ACKNOWLEDGEMENTS

We gratefully acknowledge the contributions of various authors cited in this review to come to a meaningful conclusion.

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How to Cite this Article: Melkania N.P., Arunachalam A., Mehrotra S., Pachauri A., Shailja S., Ramanan S S.. (2026). Soil Organic Carbon Across Diverse Land Use and Forest Types in the Indian Himalayan Region: A Review. *Indian Journal of Agroforestry*, ***28***(2), 1-17. https://doi.org/10.48165/ija.2026.28.02.01