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Terrestrial Carbon Stock Potential in Selected Forest in Bhutan, India and Nepal

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Authors' contributions

All of the writers worked together to complete this paper. Author KC wrote the initial draft of the paper and managed the literature searches. Authors BS and PC managed and reviewed the paper. All authors read and approved the final manuscript.

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ABSTRACT

Forests are natural carbon reservoirs that play an important role in the global carbon cycle for storing large quantities of carbon in vegetation and soils. Carbon stored in pool helps in mitigating climate change by carbon sequestration. The vulnerable countries to changing climate such as Bhutan, Nepal, and India require a full understanding of carbon dynamics as well as baseline data on carbon stock potential to mitigate anticipated risks and vulnerabilities (RVs) through climate change. The scope of such RVs are trans boundary in nature, however, the comparative studies at regional scale are still scanty. Therefore, the aim of this review is to assess the carbon stock potentials of selected forest types in the eastern Himalayan area, with an emphasis on Bhutan, India, and Nepal. This review paper is based on published articles, information from websites and considerable data from National forestry reports of India and Bhutan; emphasizing on aboveground biomass and soil organic carbon stock.

The review showed that carbon stock potential is highly dependent on stand density, above-ground biomass, species richness and forest types. The sub-tropical forest was found to have larger carbon capacity and sequestration potential. SOC concentration and tree biomass stocks were significantly higher at the high altitude where there is less human disturbance. In general, forest coverage has increased compare to previous year in Bhutan, India and Nepal which ultimately

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leads to higher carbon stock potential. It is mainly due to strong policies and different strategies for conservation of forest management have reduced mass destruction despite a growing population. Despite the rules, deforestation continues to occur at various scales. However, it can be stated that the government and citizens are working hard to increase carbon stock potential, mostly through afforestation and community forest creation. In addition, it is recommended to practice sustainable forest management, regulated and planned cutting of trees and proper forest products utilization.

Keywords: Biomass; species richness; carbon capacity; sequestration potential; elevation; human encroachment.

1. INTRODUCTION

Carbon (C) occurs mostly as carbon dioxide (CO_2) in the atmosphere of the planet [1,2]. It makes up (0.04%) of the air we breathe and serve an important role in keeping life on the planet alive [3,4]. Forests, the ocean, and soil, including wetlands, are the principal natural carbon sinks [5,6]. Plants receive CO_2 from the atmosphere, convert it to carbohydrates, and release oxygen into the atmosphere during photosynthesis, which is a well-known phenomenon [7,8]. Carbon accumulated in these dead plants or trees is released back into the atmosphere when they are burned [9,10]. When plants die and degrade, some of this carbon is transported to the soil. From the beginning of soil's phytogeographical history, a dynamic balance between organic and inorganic processes has preserved and managed this carbon cycle process [11,12].

As a result of long historical patterns, forest depletion in the Himalayan area is complicated and differs from one local context to another [13]. The Himalayan region's natural resources are normally less affected during pre-industrialization, but the commencement of industrialization is distinguished by enormous forest destruction to acquire land for industry, and the rest is influenced by land reclamation and agricultural land expansion [14,15]. The first phase of extensive deforestation in the Himalayas occurred in the 1850s and 1860s when India was controlled by two British troops [13].

Furthermore, human impacts on the forest/soil can change CO_2 sources and sinks, as well as the movement of carbon [16]. Anthropogenic causes, particularly population expansion, have been identified as primary drivers of deforestation all over the world [17]. People were driven to penetrate the forest border and clear land to offer an additional place for cultivation and shelter as agriculturally-based population density increased in and around wooded regions [18]. Apart from forest disturbance, greater infrastructural development and urban growth also affect soil organic carbon [19,20]. The CO_2 content in the earth's atmosphere has risen from roughly 280 ppm during the pre-industrial period to 409.8 0.1 ppm in 2019 [21,22] and approximately 417.64 0.1 ppm in year 2020 [23,24]. Fossil fuel consumption (about 80-85 percent) and deforestation throughout the world are to blame for rising CO_2 levels in the atmosphere [25,26]. Deforestation is reducing global forest cover at a pace of about 9.4 million hectares per year [27,28]. Forest's total carbon stock is influenced by factors such as species richness, density, and altitude, as well as, and management strategies. As a result, it's critical to comprehend the dynamics of carbon stocks in connection to the fundamental components for sustainable management of forest carbon sinks. Furthermore, as vulnerable countries to changing climate, Bhutan, Nepal, and India require a full understanding of carbon dynamics as well as baseline data on carbon stock. In addition, only a few studies on carbon stock have been conducted in Bhutan. Furthermore, no such study comparative study on carbon stocks has been conducted in Bhutan yet. Therefore the objective of this article is to study the status of carbon stock potential in selected forest types in the eastern Himalayan area, with an emphasis on northeast Bhutan, India, and Nepal.

2. METHODS

This review study is based on peer-reviewed studies, information from websites, and statistics from national reports (India and Bhutan) that focus on aboveground biomass and soil organic carbon. Information from contemporary articles that describe carbon stock potential as well as earlier literatures on historical perspectives on forest conservation also included.

3. LITERATURE REVIEW

3.1 General Description of Study Area

Nepal, India, and Bhutan are all located in the Himalayan area, with certain valleys are highly being affected by climate change. Furthermore, they are neighboring countries sharing a similar biological zone and are confronted with comparable issues or negative effects as a result of climate change. About 240 million people who dwell amidst its crags and peaks have already had their lives affected by the changes [29] Developmental activities continue in these three countries, resulting in an annual rise in carbon concentration. Since all three nations are developing, forest and soil sequestration is the most cost-effective technique for carbon sequestration. As a result, baseline information of the carbon reservoir in vulnerable nations is critical. Furthermore, these three countries have similar views on forest protection and the importance of forest sequestration carbon which helps in reducing climate change. Moreover, these three countries have a similar forest type, which makes this study more effective and accurate.

Although these three nearby nations have comparable geographical circumstances and impacts, their forest protection policies and laws differ. Furthermore, each forest has its history and natural characteristics. Bhutan is a hilly and impoverished nation with natural forests that are less affected by human activity. Moreover, there is a strong policy for forest protection and conservation, thus country's forest covering stays stable.

However, Nepal saw widespread forest destruction in the past, but people started working on replanting, and Nepal currently has a better forest coverage. India's forest coverage is increasing as a result of new laws and policies. However, certain parts of India continue to lose forests.

3.2 Forest Conservation in Bhutan

Bhutan now has a forest cover of 72.5 percent [30] which is backed up by a constitutional obligation that a minimum of 60 percent of the country's entire area shall be covered in the forest at all times [31]. Bhutan's forest management planning was formalized in the 1950s, with the establishment of the Forest Department in the year 1952 [32]. Previously, individuals had unrestricted access to forest assets, resulting in forest degradation [33].

However, enactment of a legal framework for forest management planning in 1969 (Bhutan Forest Act), now known as the Forest and Nature Conservation Act 1995, states that management plans for all forests, including protected areas, must be prepared before any first activities begin, and it also allows active public participation in the conservation and management of forests [34].

Since the government was concerned about the rapid depletion of forests in some regions of the nation and their long-term viability, contemporary laws gradually limited people's rights to use forest resources [33]. The current forest management program's five-year strategy emphasizes sustainable management with a focus on traditional community forest usage [32]. Despite the various benefits, there are a few obstacles and limitations, such as human-wildlife conflict, forest fires, pastureland, and deforestation [35,30].

3.2.1 Forest conservation and trend line of carbon stock and density in India

In the early 1960s and 1970s, India experienced tremendous forest degradation, and through the years, various laws and regulations were enacted by the country. By the 1980s, India had nationalized the majority of the forest wood and non-wood forest products industries [36,37]. The Conservation Act of 1980 established that to pursue sustainable agroforestry in a forest region, central approval is necessary, followed by the National Forest Policy of 1988 [38]. Following that, forest covering has continuously expanded, resulting in increasing carbon stock. The shift in the country's carbon stock from 1880 to 1980 revealed a significant reduction (Table 1). Even though the wooded area has risen; there has been no change in forest carbon stock over time from year 1980 to 2007. The decrease in carbon stock might be related to the loss of high-density growing forest, whereas newly planted forest has a lower carbon density while expanding wooded area [39]. Despite an increase in the country's population, fast urbanization, and great strain on resources such as forests, India's forest, and tree cover rose by 5, 081 sq km between 2015 (7044 MT) and 2019 (7124.6 MT) in (Table 1), increasing to just 80.6 Mt of carbon stock [40,41].

Table 1. Forest conservation and trend line of carbon stock and density in India

Year	Approach	Stock(Mt)	Density (t/ha)	References
1980	Degradation mode	3426	53	(Global Environment Facility, 1999) [42]
2007	Based on GS data by FSI as per IPCC guidelines	3261.71	41.08	(Sheikh et al., 2012) [39]
2015	India State of Forest Report	7044	-	(India State of Forest, 2015) [43]
2019	India state of forest report	7124.6	-	(Indian State of Forest, 2020) [38]

3.2.2 Forest conservation status in Nepal

Nepal's forest management began in the year 1880 [44] and the country now has a total forest covering of 5.96 million hectares (40.36 percent) [45]. Between the years 1960 and 1994, Nepal's wooded area shrank at a rate of 1.7 percent per year, while forest and shrubland shrank at a rate of 0.5 percent per year [46,47]. Following severe deforestation in the 1970s, Nepal's forest resources were managed through community forestry. Local Community Forest User Groups currently administer almost a quarter of Nepal's forests [48].

Nepal has joined the United Nations Framework Convention on Climate Change (UNFCCC) on June 12, 1992, and the Reducing Emissions from Deforestation and Forest Degradation (REDD) on June 12, 1993, pledging to act against the planet's climate regime and deforestation [49,50]. As of March 2007, the protected area covered around 19.7% of the total land area of the country, and it is expected to remain stable until the year 2020 [37,51]. Nepal is now concentrating its efforts on forest extension, although particular data on the carbon stock is unavailable.

3.2.3 Comparisons of carbon stock of three himalayan countries (Nepal, Bhutan, and India)

The Eastern Himalayas ecoregion ranges from eastern Nepal to Bhutan, passing via northeast India [52].

The montane cloud forest at 2000-3300 meters and tropical rainforest on the lower slopes up to 900 meters in the foothills are the most diversified [52]. The assessment of carbon stock inside the diverse forest types along the altitudinal gradient in these three nations is based on the biomass and carbon pool in each country's distinct forests. Currently, India, Bhutan, and Nepal have extensive forest coverage and carbon sequestration capability; nevertheless, the eastern Himalayan conifer forest, which is the main forest, is vulnerable to human disturbance and degradation.

The tree biomass carbon stock of the subtropical forest was improved to 144.96 t/ha, but the carbon stock of the tropical forest (80.47 t/ha) was smaller. Findings were similar to [48] for Terai forest (76 t/ha) and Hill forest (37 ton /ha) (Table 2) [53].

Also said that wet tropical forests are significant and have a higher capacity for carbon sequestration than subtropical forests. Conifer forest provides less (38.7 t/ha) than tropical and subtropical forest (Table 2), which is attributable to the lower coverage of conifer forest in the study area. This discovery is similar to [54] who found a carbon stock of 51.27 t/ha in Nepal's Makawanpur area [55] found that biomass and carbon stock differed among conifer forest ranges. In the Khasadrapchu forest range, the Thimphu forest had the highest biomass, at 62.306 t/ha. Pinus wallichiana has the largest average basal area, which means it contributes the most carbon. The study also found a favorable association between basal area, biomass, and carbon stock [56]. According to Torres and Marshall [57] trees with greater basal areas have more carbon potential storage when compared to trees with smaller basal areas since carbon storage and basal area have a positive correlation.

However, it failed to account for the biomass of smaller species in the plots, including hemlock (*Tsuga dumosa*), *willow (Salix spp.),* and other woody shrubs, which would have increased overall carbon storage [58]. The total of above-ground biomass and carbon in conifer forests with a diameter of (60-80) was typically high in India, with 85.4 t/ha (Table 3). It was further supported by data provided by [59] in the Nainital area of Uttarakhand, where research was conducted on the entire biomass of tree species and the highest carbon stock was reported to have been shared by conifer forest. In chir pine or conifer forest, the presence of Quercus species has provided more carbon [60,61] on the other hand, found that tree density and diameter did not affect the aboveground carbon stock of diverse tree species in the Cachar forest [62].

Physical elements like temperature, geology, aspects, forest disturbing effect, and forest management techniques might, nevertheless, clarify the inconstancy.

3.2.4 Carbon stock in disturbed and undisturbed forest based on Nepal

Table 3 shows that carbon stock in Nepal's *Pinus roxburghii* forest, both undisturbed and damaged, in similar ecological settings. Between 900 and 1950 meters, *Pinus roxburghii* is the most abundant conifer species in Nepal. Okhe Community Woodland is a *Pinus roxburghii* forest located between 900 and 1600 meters above sea level (Table 3). Table 3 shows that the total carbon stock in the *Pinus roxburghii* forest is 140.56 t/ha, with soil organic carbon at 45.35 t/ha. The amount of organic carbon in the soil dropped as depth increased, with 1.64 times more in the 0-20 cm soil depth than in the 20-40 cm soil depth [63] found that in three Nepalese protected forests, the largest quantity of soil organic carbon was recovered in the 0-10 cm layer when compared to other levels.

Another research in the Kusumdanda community forest, which is in the same biological zone as Nepal's Okhe community forest, found similar carbon inventory levels in Pine species [54]. Furthermore, research from Nepal's Makawanpur forest found 144.96 t/ha of *Pinus roxburghii* forest and 43.94 t/ha of soil carbon (Table 3). These results are more in line with the value. Carbon sequestration rates in the degraded forests of central Himalaya forests have been reported by [64,65,66]. Similar findings have been reported from Kumaum, India's central Himalaya, where they found 112.0 t/ha in a protected forest and 10.0 t/ha in an open field.

Table 2. Comparisons of Carbon stock of three Himalayan countries (Nepal, Bhutan, and India)

Country	Forest types	DBH range (cm)	CS (t/ha)	References
Nepal	Tropical forest	123 to 29.49	80.47	(Barral et al., 2009) [67]
	Subtropical	68.00 32.97	144.96	(Ghimire et al., 2018) [68]
	Coniferous	46 to 31.17	38.7	(Barral et al., 2009) [67]
Bhutan	Broad-leaved	-	341	(National Inventory forest,2017) [69]
	Coniferous	35.86 to 17.984	95.15	(Tshering, 2019) [55]
India	Tropical forest	-	70.55	(State forest of India, 2017) [70]
	Subtropical forest	-	37.34	(State forest of India, 2017) [70]
	Coniferous		85.4	(Kikim & Yadava, 2001) [71]

Table 3. Carbon stock in disturbed and undisturbed forest based in Nepal

Site status	Site name	Dominant species	Carbon stock(t/ha)	References
Undisturbed	Kailakhan	*Pinus roxburghii*	112	(Pant & Tewari , 2014) [72]
Undistrubed	Okhe CF	*Quercus leucotrichophora*	140.56	(Ghimire, 2019) [54]
		Pinus rouxburghii		
Undisturbed	Makawanpur	*Pinus rouxburghii*	144.96	(Ghimire et al.,2018) [68]
Disturbed	BaliyaNala	*Pinus rouxburghii* *Quercus leucotrichophora* *Cupressustorulosa*	14.7	(Pant & Tewari , 2014) [72]

3.2.5 Carbon concentration and density of tree species in the different forest zone

According to [73] there is no substantial association between carbon stock and the density of tree species. [29] Found similar results in tropical forests in India, as well as a negative association in community forests in Nepal. However, in India's Chitteri protected forest [74], a considerable positive relationship between carbon stock and density was discovered [75]. The diameter of a tree species has a significant impact on its carbon stock in the forest [76].

Reports also showed that, a tree's carbon store is exactly proportionate to its biomass, diameter, and species [77]. Although the majority of the research claims that there is no link between tree density and carbon, various tree species have different carbon storage capabilities. Despite their large above-ground biomass, certain tree species such as *Taxus baccata, Picea spinsulosa,* and *Quercus lanata* were shown to have lower carbon sequestration capability [78]. According to data from Bhutan's National Forest Inventory Report, tree density has a positive relationship with carbon stock (Fig. 1), with evergreen oak and blue pine forests having more carbon stock due to higher tree density [79].

3.2.6 Relationship between carbon stock and elevation gradient

The forest is the world's greatest biomass storehouse and stores more carbon than any other terrestrial ecosystem [80]. The link between species abundance, aboveground biomass, and carbon stock at various elevations can have a critical effect on the management and preservation of carbon [81].

According to research conducted in Manipur, Northeast India, to assess carbon stock along an altitudinal gradient. Where above-ground biomass fluctuated between 100 and 3000 meters, and carbon stock fluctuated in each attitude range in several forest types [82].

Similar findings have been reported for higher altitude forests of the Central Himalaya [83,67] and temperate valley sides of the Garhwal Himalaya, India [83,67,81,29].

Bhutan has a total carbon footprint of 45 million tons. In terms of forest type, broadleaf forests have a higher total biomass stock (726 million tons) than coniferous forests (329 million tons) [69]. In a broadleaf forest, this equates to 341 million tons of carbon, whereas in a conifer forest, it equates to 155 million tons of carbon. The overall biomass stock is highest between 2000 and 3000 meters, with 540 million tons of biomass, and lowest above 4000 meters, with 144 million tonnes of biomass [79]. To summarize, the forest has larger carbon storage in the 2000-3000 m elevation range and less carbon stock above the 4000 m elevation range (Fig. 2).This favorable link might be owing to reduced disturbance and the existence of trees with larger diameters and higher canopy coverage. However, this contradicted the findings of [84] and [85] who found that aboveground biomass dropped with rising altitude because the high altitude was dominated by small trees and shrubs. Furthermore, at lower elevations, logged and standing deadwood led to a greater carbon stock [86].

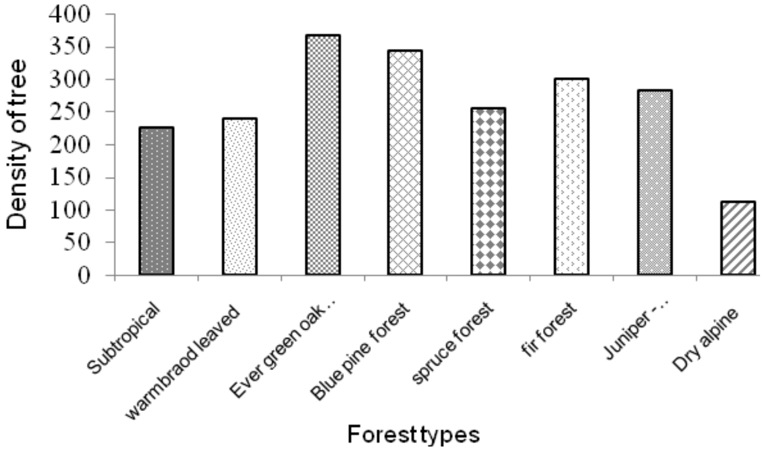

Fig. 1. Forest type and tree density

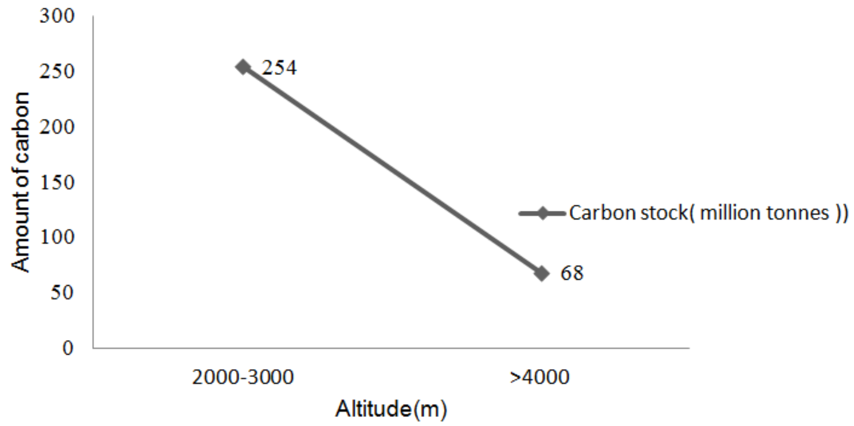

Fig. 2. Carbon stocks along an altitudinal gradient in Bhutan

Another study found that as elevation rises, soil organic carbon capacity decreases, which might be linked to thin stand density and increased canopy coverage [87].

This might be related to the delayed decomposition process, the buildup of litter biomass, and the variety of species [88]. SOC stocks were shown to be diminishing with increasing altitude in temperate forests, according to [89]. [87] observed increased soil organic carbon stock in Darjeeling, Eastern Himalaya, where greater elevation had held the greatest soil organic carbon stock following positive connection. This conclusion is similar to the findings of [90] who observed that SOC stocks altered predictably with elevation.

3.2.7 Estimated Carbon stocks in the past three years in Bhutan, India, and Nepal

Since early 2005, the pace of deforestation has fallen by 1.35 percent each year, and it is still decreasing [83].

For example, it has larger carbon stock in open forest types in the year 2017 [70]. The rise in carbon stock may be explained by the introduction of more conservation practices and policy-related forest resource management. In the past year, India and Nepal have experienced several deforestation difficulties; nonetheless, there is rising concern about forest management in the eastern Himalayas. Data from the Forest Service International (FSI) reveals a 2 million hectare increase in forest cover between the years 2009 and 2017 [91].

Commercial plantings have resulted has increased forest growth under the open forest category in the year 2015 to 2017 which increases the overall forest coverage or carbon stock. However, India continued to lose its moderately dense forest between the years 2017 and 2019 due to settlement and mining projects [92].

The Union Ministry of Environment, Forest and Climate Change (MoEFCC) sent a letter to all states and Union Territories, requesting their land to undertake compensatory afforestation, especially in islands. It is also important to note that the majority of the information in this work comes from publications in which researchers published their findings from community forest studies in India and Nepal.

However, it has been claimed that the forest in the North Eastern States is decreasing. Between 2011 and 2019, the forest covers of six states, excluding Assam, dropped by approximately 18% [93].

The region lost roughly 25,012 sq km of forest cover in a decade. They projected that forest decline would be caused by a lack of rainfall and human devastation [94].

Since there is little literature from Bhutan on carbon stock (3 percent publication), there is no precise data from Bhutan on carbon stock in previous years, as stated by [59] As a result, it is not included in this part.

4. CONCLUSION

This review study attempted to assess the status of carbon stock in selected forest zones in eastern Himalaya, focusing on community forests in Nepal, India, and Bhutan. In particular, the research looked into forest biomass, tree density, carbon stock in the different forest scenes, and this work also compared carbon stock in disturbed and undisturbed forests. Overall, the result shows that trees with larger diameters have the greatest carbon storage capacity; species dominance and forest density are also important factors in determining carbon stock potential. Despite the rising population, forest covering has increased in Nepal and India in recent years, increasing the carbon store potential. Bhutan's forest coverage, on the other hand, remains unaltered, and historical data on carbon stock in Bhutan is limited.

However, the Himalayan region being vulnerable to climate change; it is encouraged to conserve the forest.

Therefore, it is recommended to reduce emissions and increase carbon sequestration through planting trees with diverse species and reforestation activities would be essential. Given its importance, regulated and planned cutting of trees is highly encouraged. Restricting forest clearance for agricultural expansion in the forest as well as proper agriculture techniques and sustainable forest management would be an effective strategy to increase the terrestrial carbon sink.

5. LIMITATIONS

This review paper covers some general information about carbon stock in the Himalayan region which includes three neighboring countries. If a specific study field is chosen and examined based on that, the research outcome will be more comprehensive and informative. However, the goal of this study was to establish baseline information for terrestrial carbon stock in the Himalayan region.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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