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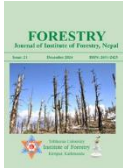

Carbon Sequestration Potential in Piple Pokhara Community Forest: Implications for Climate Change Mitigation

Nitesh Rai[1*], Rima Kumari Budhamagar[2], Manish Bidari[1] and Kedar Paudel[1]

[1] *College of Natural Resource Management (CNRM), Agriculture and Forestry University, Katari, Udayapur, Nepal*

[2] *Purbanchal University, College of Environment and Forestry, Gothgaun, Morang, Nepal*

KEYWORDS

Carbon sequestration
Carbon stock
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Community forest management

ABSTRACT

Forests are considered a cost-effective way to reduce global CO_2 emissions, yet the viability of community forest management for climate change mitigation remains underexplored. This study evaluates the carbon sequestration potential of the Piple Pokhara Community Forest, which spans 209.09 hectares and contains diverse tree species like *Shorea robusta* and *Schima wallichii*. Using stratified random sampling, 42 circular plots were established for carbon pool measurements. The findings reveal significant carbon stocks, with a total of 138.94 tons per hectare. Converted to CO_2 equivalent, the forest sequesters 509.91 tons of CO_2 per hectare. *Shorea robusta* is the dominant species, contributing 75.93% of the total carbon stock. The highest carbon reserves were in trees with a diameter at breast height (DBH) over 30 cm and heights between 15.1 and 20 meters. This study underscores the Piple Pokhara Community Forest's considerable carbon sequestration potential and suggests economic benefits through carbon trading. It highlights the forest's role in climate change mitigation and its benefits for both forest conservation and community well-being.

INTRODUCTION

Climate change is one of the most pressing global challenges of the 21st century, with far-reaching consequences on ecological processes, biodiversity, food production, economic stability, and human health (IPCC, 2021). The increasing concentration of greenhouse gases (GHGs), particularly carbon dioxide (CO_2), in the atmosphere is a key driver of climate change, primarily due to anthropogenic activities such as deforestation, industrialization, and fossil fuel combustion (Friedlingstein et al., 2022). Addressing this challenge requires a multifaceted approach that includes reducing carbon emissions and enhancing natural carbon sinks. Carbon sequestration, which refers to the process of capturing and storing atmospheric CO_2 in biomass and soil, has gained significant attention as a viable strategy for mitigating climate change (Griscom et al., 2017).

*Corresponding author
Email: niteshr763@gmail.com
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Forests play a crucial role in the global carbon cycle by acting as major carbon sinks, absorbing and storing large amounts of atmospheric CO_2 (Bastin et al., 2019). The carbon sequestration potential of a forest depends on various factors, including tree species composition, forest management practices, and growth rates (Pan et al., 2017). Among the different forest management approaches, Community Forestry (CF) has emerged as an effective model in developing countries, promoting conservation, biodiversity enhancement, and sustainable livelihoods (Bayrak & Marafa, 2016). Community-managed forests have been recognized for their ability to improve carbon sequestration while simultaneously providing economic and social benefits to local populations (Thapa et al., 2018).

Nepal has been a global pioneer in community forestry, with over 22,000 community forests covering approximately 2.2 million hectares and involving millions of local users in forest management (Pokharel et al., 2019). The Piple Pokhara Community Forest, located in the Mid-Hill region of Nepal, represents an ideal case study to assess the carbon sequestration potential of community-managed forests. Community forests in Nepal have been shown to have enhanced biomass accumulation, prevented deforestation, and contributed to climate change mitigation through participatory management (Shrestha et al., 2020).

In recent years, international climate mitigation initiatives such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) have underscored the importance of community forests in global carbon trading and emission reduction strategies (West et al., 2020). Accurate estimations of forest carbon stocks are essential for the successful implementation of such programs, enabling policymakers to design effective climate policies and financial mechanisms to support sustainable forest management (Dangal et al., 2017; Pandey et al., 2021). However, despite growing recognition, the carbon sequestration potential and economic valuation of community forests remain underexplored in scientific literature (Regmi et al., 2022).

This study estimates the carbon sequestration potential of the Piple Pokhara Community Forest and evaluates its economic benefits through carbon trading. The findings show that the forest has a substantial capacity to sequester carbon, contributing significantly to climate change mitigation. Moreover, the research highlights the potential for carbon trading to provide a sustainable income for local communities. These results underscore the value of community forestry in supporting both local conservation and global climate goals, offering insights for policymakers in Nepal and similar regions to strengthen forest management strategies and climate policies.

MATERIALS AND METHODS

Study area

The study was conducted in Piple Pokhara Community Forest of Hetauda ward no 5 of Makawanpur district (Figure 1). The total area of the Community Forest is 209.09 ha. The total forest area is divided into five blocks i.e., Block I, Block II, Block III, Block IV and Block V, covering 48.66 ha, 35.71 ha, 57.43 ha, 33.04 ha and 31.42 ha respectively (Community Forest OP, 2018). The climate is mild, and generally warm and temperate. The average temperature ranges from 15 to 25 degrees from November to February and from 30 to 40 degrees from April to June (Accuweather, 2024). This community forest's elevation ranges from 430 to 750 m above mean sea level. Topography is moderately sloping with average slopes ranging from 10 degrees to 35 degrees. Major tree species found in CF are *Shorea robusta*, *Schima wallichi*, *Syzygium cumini*, *Terminalia chebula*, *Terminalia bellirica* (Community Forest OP, 2018).

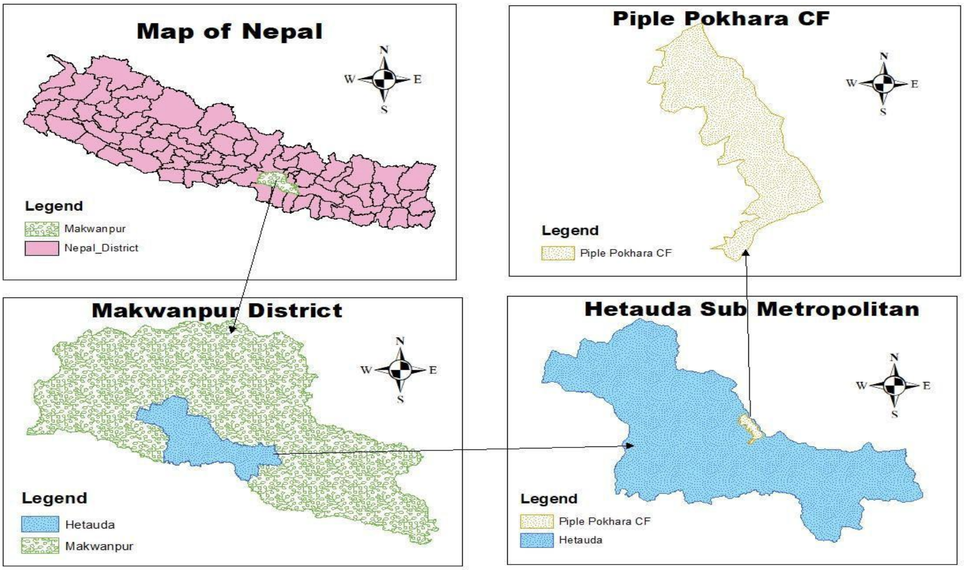

Figure 1: Map of the study area

Sampling design and measurement methods

For biomass and carbon sampling, stratified random sampling method was used. Three main strata namely tree, pole and regeneration based on stage of the plants in the forest were delineated on the map using GPS coordinates. A total of 42 circular plots were laid out from 3 strata in the CF taking sampling intensity of 0.5%. A plot of 8.92 m radius was established for moderately dense woody vegetation and several sub-plots were established within each plot for specific purposes: inside of the 8.92 m radius plot, a sub-plot with a 5.64 m radius was established for saplings and a sub-plot with a 0.56 m radius was established for sampling leaf litter, herbs, and grass (Figure 2).

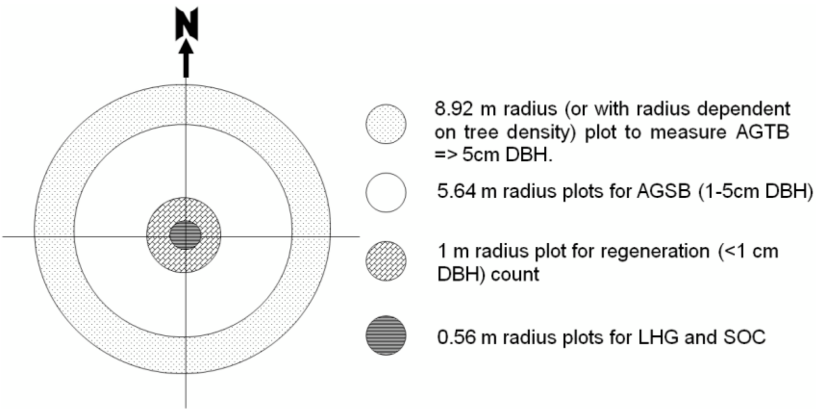

Figure 2: Sample plot layout

Data collection

Both the primary and secondary data collection methods were used for the research. The primary field data were collected between April and May 2023, through forest inventory strictly following Forest Carbon Measurement Guidelines, 2011. For the secondary data collection, published journals, thesis and articles were used as references for literature review. Information regarding floral and faunal diversity, topography, location, community forest map, etc., was extracted from Community Forest OP, 2018. The calculated dry wood density data were taken from Jackson, 1994.

Carbon pools measurement: The carbon pools that were measured for forest carbon estimation along with measurement methods given by forest carbon inventory guidelines, 2067 are as follows.

Above-ground tree biomass (AGTB): The DBH (at 1.3m) and height of individual trees greater than or equal to 5cm DBH were measured in each permanent circular 250m^2 plot that is 8.92m in radius using diameter tape, range finder and linear tape. Trees on the border were included if > 50% of their basal area fell within the plot.

Above-ground sapling biomass and regeneration (AGSB): Saplings with diameters of > 1 cm to < 5 cm were measured at 1.3 m above ground level, while saplings smaller than 1 cm in diameter at 1.3 m above ground level were counted as regeneration.

Below-ground biomass (BB): Below ground biomass was estimated as 20% of above ground tree biomass (MacDicken,1997).

Leaf litter, herbs, and grass (LHG): All the liter (dead leaves, twigs, and so forth) within the 1 m^2 sub-plots (0.56m radius) were collected and weighed. Approximately 100 g of evenly mixed sub-samples were brought to the laboratory to determine moisture content, from which total dry mass was then calculated which was later used to determine the biomass stock density of LHG.

Limitation: This study does not account for carbon reserves in soils and dead wood, both of which are significant in forest carbon storage. Estimating carbon in these components requires time-intensive inventory methods, which were beyond the scope of this study. Excluding soil and dead wood carbon likely leads to an underestimation of the forest's total carbon sequestration potential. Future research should aim to incorporate these carbon pools for a more comprehensive assessment.

Data analysis

Carbon stock estimation

For above ground tree biomass (AGTB): AGTB= 0.0509 * ρD2H (For moist forest stand)

where, ρ = wood specific gravity (g/cm^3)

D = diameter at breast height (cm)

H = tree height (m)

AGTB= above ground tree biomass (kg)

The biomass stock density of the sample plot was then converted to carbon stock densities after multiplication with the default carbon fraction of 0.47 (IPCC, 2006).

For above ground sapling biomass: Log (AGSB) = a + blog(D)

where, log = natural log (dimensionless)

AGSB = above ground sapling biomass (kg)

a = intercept of allometric relationship for saplings (dimensionless)

b = slope allometric relationship for saplings (dimensionless)

D = over bark diameter at breast height (cm)

The biomass stock density of the sample plot was then converted to carbon stock densities after multiplication with the default carbon fraction of 0.47 (IPCC, 2006).

Leaf litter, herb and grassb (LHG) biomass:

$$LHG = \frac{(W\ field)}{A} * \frac{(W\ sub\ sample\ dry)}{(W\ sub\ sample\ wet)} * \frac{1}{10000}$$

where, LHG= biomass of leaf litter, herbs and grass (t/ha)

W field = weight of the fresh field sample of leaf litter, herbs and grass destructively sampled within an area of size A (g)

A = the area (m^2) in which leaf litter, herbs, and grass were collected (ha)

W sub-sample dry = weight of the oven-dry sub-sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content (g)

W sub-sample wet = weight of the fresh sub-sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content (g)

The biomass stock density of the sample plot will be converted to carbon stock densities after multiplication with the default carbon fraction of 0.47 (IPCC, 2006).

For Below ground biomass: Below ground biomass = 20% of above ground tree biomass (MacDicken, 1997).

The biomass stock density of the sample plot was then converted to carbon stock densities after multiplication with the default carbon fraction of 0.47 (IPCC, 2006).

Total carbon stock density: Total carbon stock = C(AGTB) + C(AGSB) + C(BB) + C(LHG)

where, C(AGTB) = carbon in above-ground tree biomass (tons/ha)

C(AGSB) = carbon in above-ground sapling biomass (tons/ha)

C(BB)= carbon in below-ground biomass (tons/ha)

C(LHG)= carbon in liter, herb & grass (tons/ha)

The total carbon stock was then converted to tons of CO2 equivalent by multiplying it by 44/12, or 3.67 (Pearson et al., 2007).

Statistical analysis: The biomass and carbon stock were calculated using descriptive statistics like means, percentages and summations on the spreadsheet of MS-Excel and the inferential statistics like Pearson correlation test was done using Statistical Package for Social Sciences (SPSS) version 25 to quantify the strength of the relationship between carbon stock and the DBH and height of tree.

RESULTS

Biomass and carbon stock of tree species

Among the fifteen major tree species identified in Piple Pokhara Community Forest, *Shorea robusta* exhibited the highest carbon stock at 96.63 t/ha (75.93%), followed by *Schima wallichii* at 13.91 t/ha (10.93%) (Table 1). This high carbon sequestration is directly linked to their substantial growing stock and biomass density. In contrast, *Mangifera indica* showed the lowest carbon stock of 0.04 t/ha, corresponding with its relatively low growing stock. The variation in species-wise carbon stock clearly reflects differences in biomass accumulation, where species like Sal dominate due to their greater volume and prevalence in the forest stand.

Table 1: Biomass and carbon stock estimation of tree species (t/ha)

Scientific name	Family	TAGB (t/ha)	TBGB (t/ha)	TB (t/ha)	TAGC (t/ha)	TBGC (t/ha)	TC (t/ha)
Shorea robusta	Dipterocarpaceae	171.34	34.27	205.61	80.53	16.11	96.63
Schima wallichii	Theaceae	24.66	4.93	29.59	11.59	2.32	13.91
Dalbergia sissoo	Legiminosae	1.86	0.46	2.32	0.87	0.22	1.09
Eucalyptus grandis	Myrtaceae	7.79	1.56	9.35	3.66	0.73	4.39
Mangifera indica	Anacardiaceae	0.07	0.01	0.08	0.03	0.01	0.04
Pinus roxburghii	Pinaceae	6.87	1.37	8.24	3.23	0.65	3.87
Aegle marmelos	Euphorbiaceae	0.14	0.03	0.16	0.06	0.01	0.08
Syzygium cumini	Myrtaceae	0.83	0.17	1	0.39	0.08	0.47
Syzygium operculatum	Myrtaceae	0.57	0.11	0.68	0.27	0.05	0.32
Choerospondias axilaris	Anacardiaceae	0.22	0.04	0.26	0.10	0.02	0.12
Phyllanthus emblica	Euphorbiaceae	1.08	0.22	1.30	0.51	0.10	0.61
Populus ciliata	Solisaceae	3.60	0.72	4.32	1.69	0.34	2.03
Terminalia chebula	Combretaceae	4.16	0.83	4.99	1.95	0.39	2.34
Terminalia bellirica	Combretaceae	2.14	0.54	2.68	1	0.26	1.26
Bombax ceiba	Bombacaceae	0.14	0.03	0.16	0.06	0.02	0.08
Total		225.47	45.29	270.76	105.94	21.32	127.26

Note: TAGB= Total above-ground biomass; TBGB = Total below-ground biomass; TB= Total biomass; TAGC= Total above-ground carbon; TBGC= Total below-ground carbon; TC= Total carbon

Carbon stock share within DBH classes of tree species

The DBH of the tree species were categorized into six classes i.e. (5.1-10) cm, (10.1-15) cm, (15.1-20) cm, (20.1-25) cm, (25.1-30) cm, and above 30 cm. The highest carbon reserve was found in DBH class of above 30 cm trees (32.86 tons/ha) followed by DBH class of (25.1-30) cm having carbon store of 32.56 tons/ha (Figure 3). The least carbon reserve was found in DBH class (5.1-10) cm trees with 0.36 tons/ha. This finding suggests that mature and large-diameter trees play a disproportionate role in carbon sequestration compared to smaller trees (DBH < 10 cm) which is supported by Pearson correlation test that revealed strongly positive correlation (+0.897) between carbon stock and diameter of tree species at 99% confidence level.

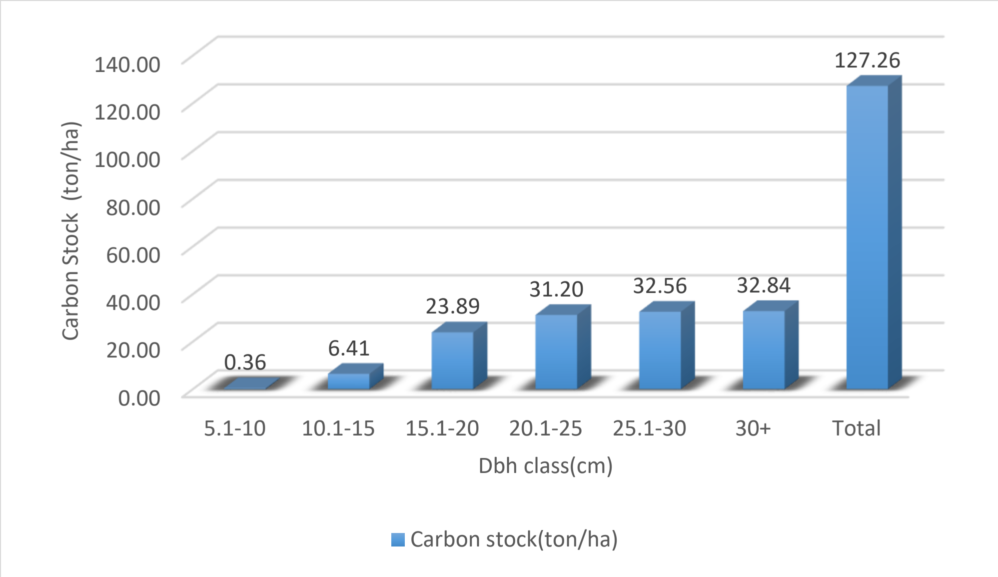

Figure 3: Carbon stock in different DBH classes of CF

Carbon stock share within height classes of tree species

Within five category of height classes, the highest carbon reserves were found in height class of (15.1-20) m with 66.20 tons/ha which is 52.02% of the total tree carbon stock measured in the CF (Figure 4). The lowest carbon stock densities were found in height class of below 5 m with 0.01 tons/ha. The carbon stock value was highly influenced by tree height which was supported by Pearson correlation test that showed moderately positive correlation (+0.653) between tree height and carbon stock at 99% confidence level.

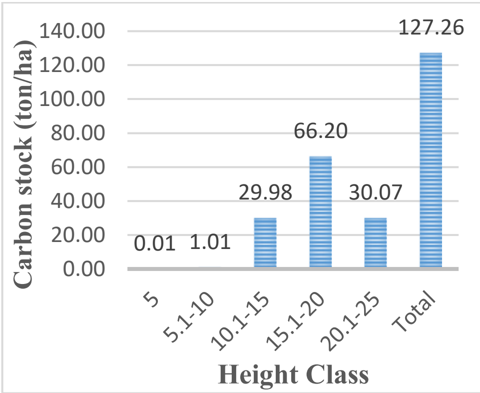

Figure 4: Carbon stock in different height classes of CF

Total carbon stock (tons/ha) in Piple Pokhara CF

Among trees, saplings and LHG's, the highest carbon stock was found in trees with 127.26 tons/ha (91.60%) followed by saplings and LHG's with the corresponding stock density of 9.41 tons/ha (6.77%) and 2.27 tons/ha (1.63%) (Table 2). Altogether, the overall carbon stock in Piple Pokhara CF was measured 138.94 tons/ha.

Table 2: Biomass and carbon stock densities in different carbon pools of CF

Carbon pools	TAGB (ton/ha)	TBGB (ton/ha)	TB (ton/ha)	TAGC (ton/ha)	TBGC (ton/ha)	TC (ton/ha)
Trees	216.62	54.15	270.77	101.81	25.45	127.26
Saplings			20.02			9.41
LHGs			4.83			2.27
Total			295.62			138.94

Conversion of carbon to carbon-dioxide (CO2)

Carbon thus calculated by different methods can be converted in to CO_2. For carbon trading CO_2 (ton) is calculated and used rather than carbon. Hence, it should be converted in terms of CO_2 for carbon trading. For the conversion, following relation was used (Pearson et. al, 2007).

Carbon-dioxide (CO_2) = Carbon * 3.67

So, the total carbon (ton/ha) obtained in Piple Pokhara CF is also converted in terms of CO_2. Hence, the total carbon sequestration potential of the forest is 509.91 tons/ha.

DISCUSSION

The findings of this study demonstrate that Piple Pokhara Community Forest (CF) plays a significant role in carbon sequestration. The dominance of *Shorea robusta* and *Schima wallichii* in carbon storage aligns with previous studies conducted in Nepalese forests, which indicate that broad-leaved, high-biomass species are key contributors to carbon sequestration (Bhatta et al., 2021; Pandey et al., 2022). The findings align with studies by Kandel et al. (2016) and Gaire et al. (2017), where *Shorea robusta* was also identified as a major carbon sequestering species. However, the carbon density observed in *Shorea robusta* (96.63 t/ha) is higher than values reported in other studies, such as Acharya et al. (2019), likely due to better forest management practices in Piple Pokhara CF. The high carbon density recorded in large-diameter trees (DBH >30 cm) reinforces the well-established relationship between tree size and carbon sequestration capacity (Karki et al., 2018). Similar trends have been observed in other community forests in Nepal, where mature trees store significantly more carbon than younger or smaller-diameter trees (Adhikari et al., 2019).

The positive correlation between carbon stock and both tree DBH and height further confirms the importance of mature trees in carbon sequestration. This is in agreement with studies that highlight the role of older, taller trees in maximizing biomass accumulation and carbon storage (Gautam et al., 2020). However, the comparatively lower carbon stock in saplings and litter, herbs, and grasses (LHGs) suggests that while these components contribute to the overall ecosystem carbon pool, their role in long-term carbon sequestration is relatively limited.

The total carbon stock in Piple Pokhara CF was found to be 138.94 tons/ha, which is higher than values in other community forests in Nepal, where carbon stock ranges from 80 to 120 tons/ha (Sharma et al., 2017). This could be due to the active management and protection of the forest, which enhances its carbon sequestration potential. The total carbon sequestration potential of Piple Pokhara CF was estimated to be 509.91 tons of CO_2 per hectare. This is similar to other community forests in Nepal, as reported by Gaire et al. (2017), showing the significant role of community-managed forests in climate change mitigation.

CONCLUSION

The Piple Pokhara Community Forest (CF) demonstrates significant carbon sequestration potential, with *Shorea robusta* and *Schima wallichii* being the primary contributors to the carbon stock. The total carbon stock in the CF was found to be 138.94 tons/ha, with the majority of this carbon (91.60%) stored in trees. The study indicates that the forest's carbon stock is strongly influenced by tree size, with larger trees (DBH > 30 cm) and taller trees (height class of 15.1–20 m) holding the highest reserves. The results highlight the role of this forest in mitigating climate change by sequestering substantial amounts of carbon dioxide, amounting to 509.91 tons of CO_2 per hectare.

The carbon sequestration capacity of the Piple Pokhara CF has implications for climate change mitigation and offers an opportunity for carbon trading. This potential provides environmental and economic benefits, supporting local efforts to conserve and manage the forest sustainably. Enhancing carbon stock through improved forest management could amplify the CF’s role in global climate efforts while generating income for local communities via carbon credits.

The findings highlight the importance of preserving and expanding community forests in combating climate change. Community-driven conservation, like that in Piple Pokhara, can help achieve national and global climate targets, offering a model for balancing ecological health and socioeconomic development. Investing in carbon storage strategies, such as protecting and restoring natural forests, not only mitigates climate change but also promotes biodiversity, protects watershed, and enhances livelihoods. These insights are valuable for policymakers aiming to integrate carbon sequestration into climate action plans.

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