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Contribution of Community-Managed Sal-Based Forest in Climate Change Adaptation and Mitigation: A Case from Nepal

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Abstract: Forests are viable tools in combating the impacts of climate change, as they are capable of sequestering atmospheric carbon and storing it in different pools. This study aimed to examine the carbon sequestration potential of community-managed *Shorea robusta* (Sal) forest and assess the practices that have the potential to reduce adverse climate change impacts, thereby improving the livelihoods of forest-based communities. For this, we obtained forest inventory-derived carbon data from 11 sample plots of *Shorea robusta* (Sal) forest, analyzed them using allometric equations, and estimated the carbon storage and climate change mitigation potential of these forests, while focus group discussions and desk review of secondary information were employed to investigate the adaptation potential. The results show that the estimated biomass density of the selected forest is 352.46 ± 63.79 t/ha, whereas the carbon stock density is 165.66 ± 29.98 t/ha and the CO_2 equivalent is 598.07 ± 110.48 t/ha. The study further revealed that community forest management, as a successful model of participatory forest management and community forest user group (CFUG) as a resourceful local institution, has been playing an important role in the diversification of livelihoods and income opportunities, social cohesion and thus climate change adaptation through collective actions. The adaptation and mitigation of climate change impacts have been prioritized in the operational plans of the CFUGs. Through the promotion and prioritization of alternative energy, agroforestry and enhanced livelihood options, the CFUGs are committed to the sustainable management of forest resources and to enhancing the livelihoods of local communities. This study indicates the relevance of community forests as a priority institution for the implementation of Local Adaptation Plans for Action (LAPA) and support National Adaptation Program of Action (NAPA) to combat climatic impacts, providing important information for planners and policy makers in Nepal and elsewhere.

Keywords: climate change adaptation and mitigation; community forest; carbon stock; livelihoods

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1. Introduction

According to an Intergovernmental Panel on Climate Change (IPCC) special report (2018), the global world temperature has increased by around 1 °C since the pre-industrial era and various anthropogenic emissions are contributing to additional warming of around 0.2 °C on average per decade. If the same trend of anthropogenic emissions continues, it is projected that global warming will increase by 1.5 °C during 2030–2050 [1]. South Asia is one of the regions witnessing rising temperature and increased intensity and frequency of extreme weather events, which are projected to be observed across all regions, including the Tibetan Plateau [2]. In terms of the South Asian country Nepal, greenhouse gas (GHG) emissions globally account for only 0.027% [3]; however, the country has witnessed the harsh impacts of climate-induced disasters [4]. Nepal is one of the most vulnerable countries to floods, landslides, erratic rainfall, or glacial lake outburst floods (GLOF), and ranks fourth based on the climate change vulnerability index [5]. The average annual temperature has been increasing gradually (by 0.056 °C during 1971–2014) and is predicted to continue to increase (by 0.9–1.1 °C during 2016–2045), while monsoonal precipitation is predicted to increase by 15–20% [6].

Such increases in temperature from the local to global level affect vegetation structure [7], natural forest [8] and socio-economic systems around the world [9]. Some evidences of global climate change are provided by the reduction in snow/ice cover, enlarged glacial lakes, sea-level rise, increased climate-induced natural hazards and remarkable increase in subsequent losses and damage to lives and properties [10,11]. Natural forest cover experiences frequent occurrence of forest fires, pest and disease outbreaks, and invasive alien species. Meanwhile, winds, storms and droughts destroy branches, cause crown loss, and even damage standing trunks. Furthermore, the deterioration in forest quality reduces forest biodiversity, non-timber forest products (NTFP), and the aesthetic and recreational value of forests, posing a challenge for soil and watershed management [12]. The impacts of climate change on forests and biodiversity in Nepal have been observed as (i) the upward shifting of vegetation and species range in the northern mountains; (ii) changes in phenological cycles, such as flowering, fruiting and leaf shedding of plant and tree species; and (iii) changes in the availability and regeneration patterns of forests and NTFPs [13]. Since the harsh impacts of climate change are increasing alarmingly along with the changes in global climate, exploring potential strategies to mitigate GHG emissions has become imperative to minimizing the risks of further damage [14].

Since 2008, Nepal has participated in strategies to reduce emissions deforestation and the forest degradation plus (REDD+) program to minimize deforestation and forest degradation, sustainably managing forests resources while conserving and enhancing forest-based carbon stocks [15]; here, community forests (CF) are prioritized as a crucial component. REDD+ is a program moderated by the United Nations Framework Convention on Climate Change (UNFCCC) [16], wherein the utilization of market mechanisms to reduce GHG and thus forest damage and degradation is emphasized, and countries can get benefit through the carbon market [17,18]. The Government of Nepal and the World Bank's Forest Carbon Partnership facilities (FCPA) signed an agreement to provide USD 45 million to Nepal by 2025 to facilitate the reduction of 9 million tons of carbon through forest conservation [19]. Meanwhile, to adapt to the impacts of climate change and establish institutional arrangements, the Government of Nepal introduced the National Adaptation Program of Action (NAPA) [20], the Local Adaptation Plans for Action (LAPA) [21], and the Climate Policy, 2019 [22]. These plans and policies also emphasize the preservation and sustainable management of forest resources to combat the climate change impacts [23]. Community forest user groups (CFUGs) are prioritized as the local institutions that can play a vital role in the adaptation and mitigation of climate change impacts [24].

In this context, forest cover itself can be a viable option to combat climate change impacts and minimize the losses and damages [25]. The estimated carbon stock in global forests is 861$\pm$ 66 Pg C, whereas forest degradation and deforestation account for significant GHG emissions [26]. Forests play an important role in carbon cycle [27] due to the contribution of 70–90% of the terrestrial above ground biomass (AGB) and belowground biomass (BGB) [27,28]. Hence, the conservation of forest resources through reforestation and regeneration has been widely recognized as a global priority to maintain a sustainable environment [29]. The UN Environment's sixth Global Outlook has also prioritized the sustainability of forest resources and combating climate change impacts. Of the 17 Sustainable Development Goals (SDGs) adopted by the United Nations in 2015, Goal 15 is to 'sustainably manage forest, combat desertification, halt and reverse land degradation and halt biodiversity loss', while Goal 13 aims to 'take urgent action to combat climate change and its impacts' [30]. Since the Bonn Challenge, initiated in 2011 (www.bonnchallenge.org accessed on 2 December 2021), forest landscape restoration (FLR) has been part of the global agenda. As per the New York Declaration 2014, various countries have committed to restore 150 million ha of deforested and degraded land into forest cover by 2020 and to reach 500 million ha by 2030 [31]. Similarly, CF is a participatory forest management model that is designed to sustainably manage forest resources and enhance forest-based local livelihoods through CFUGs [32]. On the basis of operational plans (legal documents with legitimized provisions for forest management), CFUGs are involved in protection-oriented programs such as forest fire control, combating encroachment and the illegal logging of forest products, regular monitoring and raising awareness, as well as sustainable silvicultural practices to ensure the sustainable utilization of the forest resources [33,34]. Nepal is one of the pioneering countries of CF, with several success stories [35,36] of improving the forest conditions, practicing democratic decision-making processes, and promoting local development activities [37,38]. The program provides a wide range of socio-economic and environmental benefits, including ecological, institutional, financial, and social services and safety nets. In Nepal, as of May 2020, there are 22,266 CFUGs managing 2.24 m ha (35% of total) of the country's forest resources directly benefiting 2.91 m households (around 33% of total) population of the country [39].

Forest cover not only offers several socioeconomic benefits and ecosystem services [36] but also plays a pivotal role particularly in mitigating the adverse impacts of climate change [40] due to its ability to sustain its own carbon stock in several pools, such as standing trees, roots, leaf, litter, and soil, and to remove additional atmospheric carbon [14]. In order to mitigate the climate change impacts globally and provide adaptation strategies locally, methods for accurately estimating the forest carbon in trees and strategies for its management must be explored [41]. Studies have assessed aboveground carbon [42], species-wise carbon [43–45], forest-type-wise carbon [46], and carbon in different land use types [47]. These studies are limited to carbon stock estimation at the local or regional level [44,48–51]. There exists some prior literature on the interactions between climate change and the forestry sector in Nepal. Firstly, a number of studies has analyzed temperature and rainfall trends [52,53]. The second category of studies focuses on assessing the impacts of climate change on the forestry sector [54,55]. The third area is policy initiatives [15,56,57]. However, an important issue that has been largely ignored in the literature is whether community forest management is a viable option for climate change mitigation and adaptation, and we aim to address this gap. The objectives of this study are to examine the carbon sequestration potential of CF, assess the practices that have adaptation potential, and reduce adverse climate change impacts, thereby improving the livelihoods of forest-based communities using forest inventory-derived carbon data, focus group discussion (FGD), and secondary sources. We hypothesize that CF has become a suitable option in adapting to and mitigating the harsh impacts of climate change. The conceptual framework of the research is presented in Figure 1.

This study is therefore timely in providing information that can assist policymakers and CFUG members in promoting climate-smart forest management strategies through the involvement of the local community. As Nepal is implementing local and national climate change adaptation interventions, the results achieved through the novel concept can be a baseline for the planners and policymakers to analyze the relevance of CF.

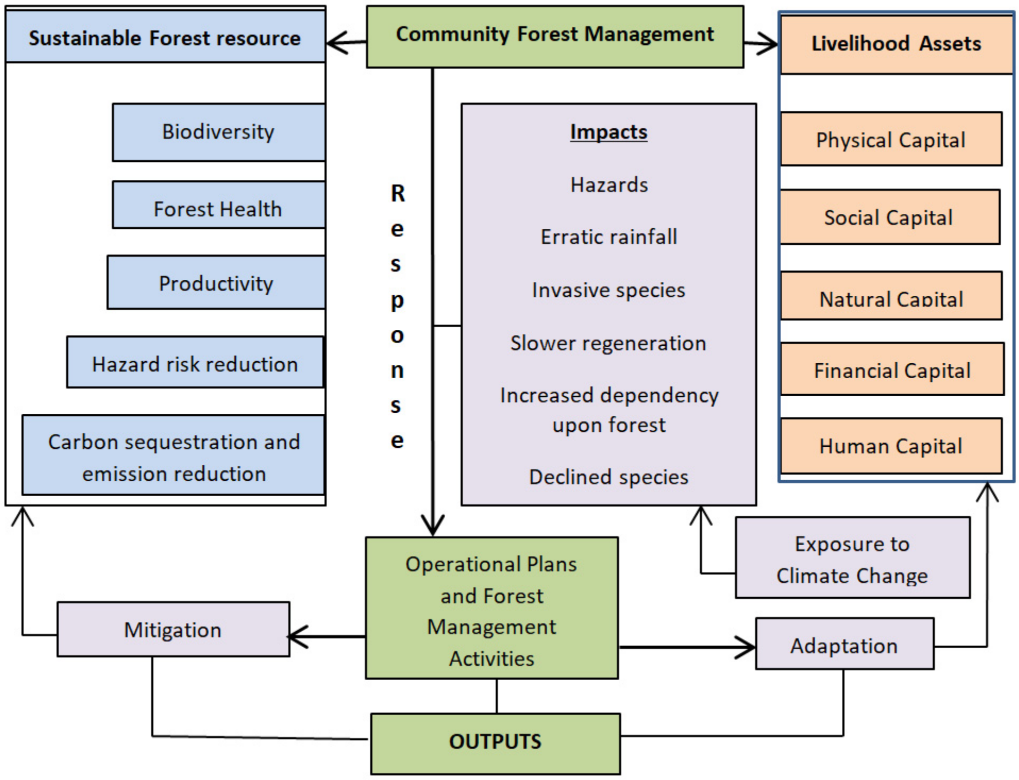

Figure 1. Conceptual framework showing the linkage of community forest management and climate change.

2. Materials and Methods

2.1. Study Area

We selected a *Shorea robusta*-based plot within the Kalika Community Forest (KCF) of Jhapa district, Eastern Nepal, for the case study. The case study area is geographically located within 88°3′40′′ E to 88°4′43′′ E longitude and 26°39′53′′ N to 26°41′23′′ N latitude, covering an area of 199 ha (of the total 212 ha area of KCF). The elevation ranges between 125 and 155 m above sea level. We chose the KCF for the case study because (a) it represents the *Shorea robusta* forest, a highly commercially valued timber species dominant in the (sub-)tropical region of Nepal, and (b) the region has experienced changes in climatic and precipitation patterns over the past few decades. According to the precipitation and temperature statistics of Nepal, the average annual temperature has been rising gradually and the annual precipitation shows a trend of increase that is projected to continue. The mean annual temperature is predicted to increase by 1.2 °C during 2030, 1.7 °C by 2050, and 3 °C by 2100 [58]. In terms of the study area, the maximum average temperature at a nearby station (Gaida Kankai station) was recorded as 29.72 °C in 1989 and had increased to 31.4 °C in 2016, while the minimum temperature increased from 17.54 °C in 1989 to 18.49 °C during 2015. Meanwhile, the average annual rainfall (in the nearby Damak station) showed a declining trend from 277.5 mm in 1988 to 152.75 mm during 2015 [59] (Appendix A, Figure A1: a–c). The research outputs of the selected case study area can replicate the role of CF and its management practices to adapt to the harsh impacts of climate change as well as demonstrating the carbon sequestration potential of the subtropical *Shorea robusta* forest of Nepal to mitigate the climate change impacts. We collected biophysical data during April 2021 from a total of 133 *Shorea robusta* trees from 11 randomly selected samples within the KCF (Figure 2).

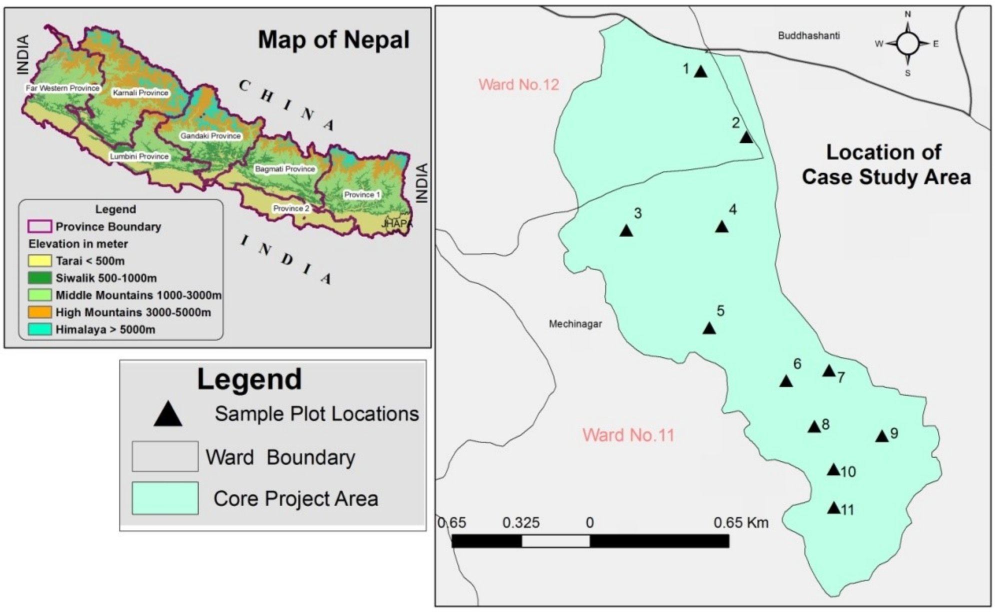

Figure 2. Location map of the case study area.

2.2. Data Collection

2.2.1. Carbon Pool Inventory

As a large fraction of biomass and carbon are stored in tree stems, accurately estimating their volumes is essential [60]. Therefore, we collected biophysical data through the forest inventory, and the data collection process was based on the guidelines prepared by the Asia Network for Sustainable Agriculture and Bioresources (ANSAB), Federation of Community Forestry Users, Nepal (FECOFUN), and International Centre for Integrated Mountain Development (ICIMOD) [61]. The CFUG boundary was obtained through a global positioning system (GPS)-based field survey with the involvement of forest experts and executive committee members. Due to species homogeneity, the forest was randomly sampled as different plots using GPS for the inventory (Figure 2); a stratum of rubber species and an ecotourism area were excluded. A total of 11 temporary circular plots were generated. Predetermined sample points were navigated using GPS. The plot sizes were determined as per the parameters of MacDicken [62]. Each plot was generated with a radius of 8.92 m (to measure tree poles above 5 cm in diameter at breast height (DBH)), and subplot of 5.64 m radius (to measure saplings) (Figure 3). Central points of the plot were marked with a rod and, from the center of each plot, 4 permanent reference plots were prepared around the center. Individual tree and saplings within the respective plots were measured using a diameter tape, clinometer, and linear tape, and recorded in the datasheet.

2.2.2. Data Collection for Climate Change Adaptation

Essential data to investigate the adaptation roles of CFUGs were obtained from primary and secondary sources. For the primary information, an FGD with semi-structured questions was conducted in the CFUG during the field visit in April 2020. The FGD aimed to explore the (a) resource management practices of CFUG and (b) adaptation strategies to enhance the livelihoods of the users' households, thereby sustainably managing the resources in relation to climate change scenarios. A total of 9 people among the executive committee members participated in the discussion, as the FGD was focused on the plans, policy provisions, and activities of the CFUG with regard to adaptation and mitigation. The objective of the study was not to explore the local people's perceptions regarding the adaptation and mitigation potential of CFUG and, therefore, we limited the discussion with the executive committee members. Acquired information was reported with note-keeping techniques. Secondary literature was inclusive of the operational plans, official records, and annual reports collected from the CFUG office.

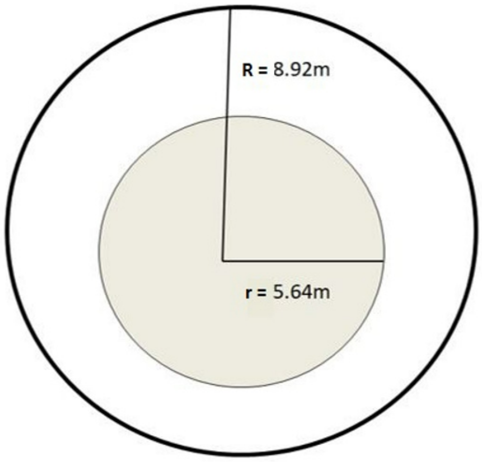

Figure 3. Sample plot layout. Note: R = radius plot for AGTB, r = radius plot for AGSB.

2.3. Data Analysis

2.3.1. Analysis of Biomass and Carbon Content

Estimation of Aboveground Tree Biomass (AGTB)

The inventory guideline suggests the allometric equations (models) developed by Chave et al. [63] as the best choice in estimating AGTB on the basis of climate and forest stand types [61]. Since our study site was situated in a moist region receiving between 1500 and 4000 mm rainfall annually, we used the following equation to estimate AGTB [64]:

$$AGTB = 0.0509 \times pD^2H \quad (1)$$

where AGTB = aboveground tree biomass (kg), p = wood specific gravity (g cm^{-3}), D = tree diameter at breast height (cm) and H = tree height (m).

For the estimation of aboveground sapling biomass, the following equation was used [62],

$$\ln (AGSB) = a + b\ln (D) \quad (2)$$

where AGSB = above ground sapling biomass, ln = natural logarithm, a = intercept of allometric relationship for saplings (dimensionless), b = slope allometric relationship for saplings (dimensionless), D = over bark diameter at breast height (cm) (measured at 1.3 m above ground).

The obtained value of each individual tree (in kg) was summed up and then divided by the sampling plot area (250 m^2 for trees and 100 m^2 for the saplings). This biomass estimate in kg/m^2 was converted into t/ha by multiplying by 10.

For *Shorea robusta*, the wood-specific gravity used here is 0.88 as its specific gravity value ranges within 0.83–0.93 g/cm^3 [65]. The aboveground total biomass was calculated by adding together the biomasses in standing trees and in saplings.

Below Ground Biomass (BGB)

For the estimation of BGB, the guidelines recommended by MacDicken [62] were taken into consideration, which consider a 1:5 root: shoot ratio (20%) (BGTB = AGTB × 0.2) of the aboveground biomass to estimate the BGB of a tree. This has been used by various prior studies [66,67].

Total Biomass and Net Carbon Content

Total biomass refers to the sum of AGB and BGB. After acquiring the biomass per ha, it was multiplied by a default carbon fraction of 0.47, as recommended by IPCC 2006 guidelines [68], to acquire the net carbon content (carbon stock density per ha), which was then multiplied by 3.67 (44/12) for conversion to tons of CO_2 equivalent. The main limitation of this study is that we excluded the carbon content in regeneration, dead wood, leaf, litter, and soil organic carbon.

A *t*-test was used to identify significant differences in tree height and DBH among plots, with a significance level of 95%. Homogeneity of variance was used to verify the assumption of homogeneity of variance prior to conducting the t-test. The normality test was performed using the Kolmogorov–Smirnov test.

2.3.2. Social Data Analysis

The acquired primary and secondary data were intensively desk-reviewed. The thematic analysis method was used to analyze the data acquired from the FGD and reports, and the data were categorized under five themes referring to climate change adaptation and mitigation strategies: (a) carbon sequestration and minimization of GHG emissions; (b) climate-sensitive resource management options; (c) social cohesion, bonding, and collective action; (d) sustainable utilization of resources (forest, soil, and wetland management), and (e) diversification of livelihoods and income opportunities. For the data analysis, the analytical framework developed by Rijal et al. [23] was modified and used. The workflow chart of the research is presented in Figure 4.

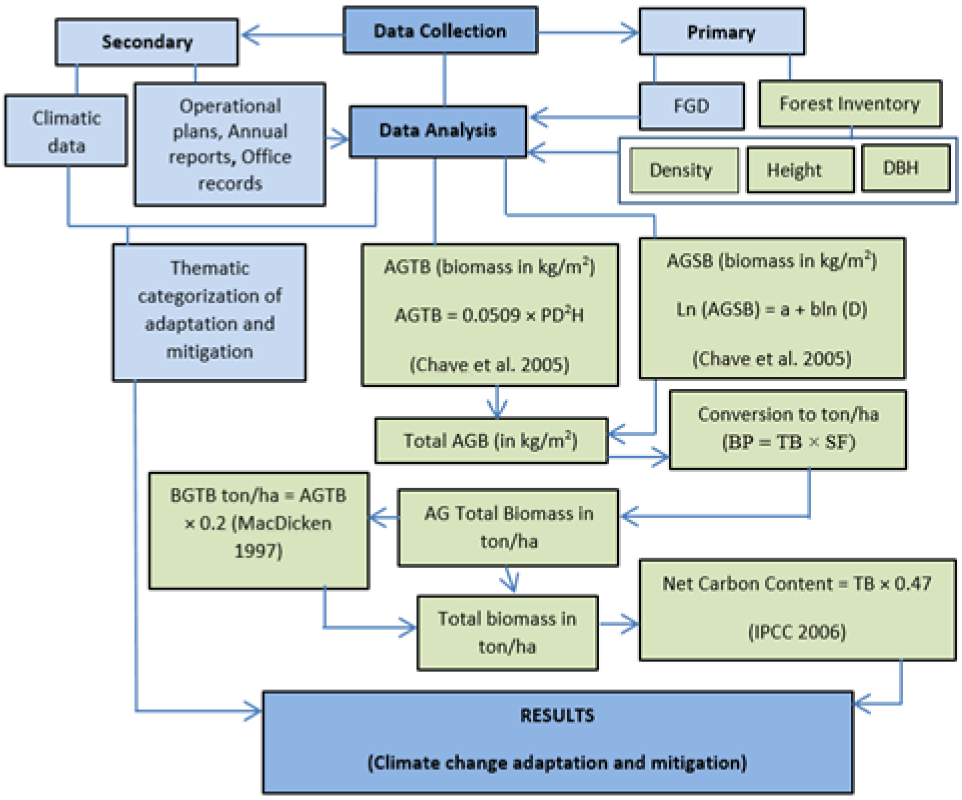

Figure 4. Work flowchart.

3. Results

3.1. Estimated Forest Carbon in the Selected CF

Within the 11 selected plots, the total number of standing trees was 113. The average height of standing trees ranges between 14.4 and 22.7 m, whereas the average DBH was between 16.6 and 62.5 cm (Table 1). There was no significant difference in tree height among plots ($p > 0.05$), but we found noticeable differences in the DBH of trees among different plots ($p < 0.05$) (Table 1).

According to the analysis, the biomass stock density of the forest was 352.46 ± 63.79 t/ha. As the forest was composed of matured as well as newly growing standing trees, the biomass and carbon storage also largely varied among plots. Of the total, plot 1, which consists of only four standing trees with the largest DBH (average 196.25 ± 49.50 cm), had the highest biomass density (885.3 t/ha) while plot 10 had the lowest biomass stock density per ha (85.9 t/ha). Similarly, the analysis showed that the average carbon storage was 165.66 ± 29.98 t/ha. Meanwhile, the forest stored 598.07 ± 110.48 CO_2 t/ha and 598.07 ± 110.48 tons of CO_2 equivalent (Table 1).

Table 1. Biomass and carbon in individual plot; data are represented as means ± SE.

Plots	Number of Standing Tree	Average Tree Height (m)	Average DBH (cm)	Biomass Stock Density (t/ha)	Carbon Stock Density (t/ha)	Tons of CO_2 Equivalent
1	4	19.25 ± 1.55	196.25 ± 49.50 [a]	885.3	416.1	1527.0
2	5	14.42 ± 2.03	136.80 ± 24.39 [b]	369.6	173.7	637.5
3	18	17.31 ± 0.63	54.78 ± 1.99 [c]	211.8	99.6	365.4
4	8	22.69 ± 0.67	101.33 ± 7.56 [bc]	433.2	203.6	747.3
5	12	22.02 ± 9.20	52.15 ± 4.36 [c]	173.1	81.4	289.6
6	13	17.42 ± 0.64	83.11 ± 4.29 [bc]	362.4	170.3	525.1
7	9	15.89 ± 0.96	92.72 ± 19.83 [bc]	434.7	204.3	749.8
8	11	15.91 ± 0.85	70.00 ± 3.91 [c]	200.5	94.2	345.9
9	12	14.42 ± 1.10	68.28 ± 16.40 [c]	403.8	189.8	696.6
10	6	14.83 ± 0.42	64.90 ± 5.37 [c]	85.9	40.4	148.2
11	15	16.55 ± 0.65	74.19 ± 4.22 [c]	316.8	148.9	546.4
mean ± SE	**10.27 ± 1.31**			**352.46 ± 63.79**	**165.66 ± 29.98**	**598.07 ± 110.48**

[a, b], and [c] indicate significant differences among plots.

3.2. Community Forest Management in Adapting with Climate Change Impacts

The review of the operational plans, office records, reports, and FGD reveals that the CFUG has been performing as an active local institution to ensure forest conservation and carbon sequestration and the reduction of GHG emissions. Operational plans have incorporated the monitoring, management, and utilization of the forest resources. Meanwhile, CFUG is an important platform contributing to the physical, financial, social, natural, and human dimensions of the local communities and thereby combat the adverse impacts of climate change, particularly through several provisions.

Carbon sequestration and minimization of GHG emission has been a focus of CF. In order to minimize the dependency of the local people on forest resources, alternative energy and agroforestry are prioritized, while forest management and silvicultural activities are regularly undertaken to maintain forest health. The participants of the FGD reported that, regarding alternative energy use, the user households receive financial and required infrastructural support to install biogas plants, solar panels and improved stoves. Meanwhile, in terms of agroforestry, seedlings of various fodder plants, timber, and fruit were distributed. For improved and healthy forest, afforestation and reforestation, regular silvicultural activities, such as thinning, pruning, singling, clearing, and the removal of invasive species, bushes, thrones, dry leaves, and litter were carried out. According to the financial report of the KCF, the CF annually spent, on average, USD 19,960.4 during fiscal years 2016/017–2019/020 for the management and development of forest resources [36]. The extraction of forest products is based on systematic procedures and schedules. The harvesting of dry wood and timber instead of standing live trees is prioritized. The management of forest is more conservation-oriented, which has resulted in the conversion of previous shrub lands, grasslands, and bushes into healthy forests. For example, in the KCF, within the reforestation and afforestation program, *Khayar* (*Acacia catechu*), plants in the riverbanks and seedlings of various species were planted in areas of barren land, shrub, and grasslands.

The resource management activities are sensitive to the adverse impacts of climate change. Activities that might result in soil loss, the use of pesticides, sand and gravel extraction and the construction of private infrastructure are restricted [69]. To prevent the overexploitation of the resources, operational plans have defined the extraction criteria for firewood timber and grass on the basis of forest quality. Forests are regularly patrolled by CFUG members, watchmen, and overseeing committees to monitor fire hazards, encroachment, and illegal logging. The FGD revealed that anti-forest activities such as smuggling, activities harming biodiversity, forest products, and encroachment are strongly discouraged through the implementation of punishments and penalty provisions in operational plans. For fire hazard prevention, piped fire lines and roads have been constructed across the forests. Leaf, litter, and fodder on the fire lines are regularly cleared and fire-inducing activities are strictly prohibited.

Social cohesion, bonding and collective action is an integral aspect of resilience and adaptation and the CFUG has been functioning as a social institution for collective action. The members of user groups collectively perform the silvicultural activities, hazard control and social activities, which has strengthened the social bonding and interaction.

CF management activities are sensitive to sustainable resource utilization and management particularly in terms of forest, soil and wetland. Strict silvicultural activities and prohibition of deforestation and grazing, technical consultations regarding disease and pest exposure, and the conservation of water resources are prioritized. Participants of the FGD reported that KCF has restricted forest product collection within 10 m from the water source and maintains a green belt around the source. To combat the flood hazards and soil erosion, river embankment via bioengineering techniques such as wire nets and bamboo plantations has been implemented. In the operational plan of the KCF, the preservation of endangered species, punishment mechanisms to dissuade from disturbance, harm, and the illegal extraction and felling of plants, and the hunting of animal species are integrated. *Dalbergia latifolia, Dalbergia oojeinensis Roxb., Alstonia scholaris,* and *Terminalia chebula* are the most commercially important species, and there is focus on their regeneration. CF has also contributed to biodiversity, and also has developed a mini zoo within the forest premises as an ecotourism attraction [69]. The FGD with the executive committee members also revealed the role of CF in biodiversity conservation.

CF has played an important role in the diversification of livelihoods and income opportunities. From the FGD, we found that diversification of livelihoods and income is one of the strategies adopted to adapt to climate change impacts; the institutional support of CFUGs aims to enhance the socio-economic conditions of the community members during periods of financial hardships by providing financial support and incentives for various income-generating activities. Low-income and marginalized users receive discount-priced-timber and firewood, scholarships, health insurance packages, as well as agricultural inputs. CF has allocated 35% of the total budget to poverty alleviation. Additionally, to develop skilled and semi-skilled manpower, user group members are provided with training and services focused on forest management, skill development, exposure visits, vegetable farming, market management, and livestock. For instance, the KCF annually spent USD 75,445.8 on social and infrastructural development and USD 9504.03 on poverty alleviation and other initiatives during 2016/017–2019/020 (Table 2). Meanwhile, the inclusive representation in the executive committee has ensured the mainstreaming of marginalized groups and minorities. Similarly, forest cover is used for the production of NTFPs, and, through the reforestation and afforestation activities, shrub land, barren land, and grass land are converted into forest cover. Management of forest cover, its recreational attributes, and NTFP are important sources for revenue collection and employment.

Table 2. Budget allocation in different livelihood assets during some recent fiscal years (amounts are in USD) *.

Particulars	Budget Allocation (Amount in USD) *				Remarks
	2016/017	2018/019	2019/020	Average (2016/017–2019/020)	
Forest management and development	23,757.5	28,856.0	7267.672	19,960.4	Fire line and bush cleaning, forest security and monitoring, fencing, plantation, thinning, pruning, technical training, employee salaries, river embankment, exposure visits

Table 2. *Cont.*

Particulars	Budget Allocation (Amount in USD) *				Remarks
	2016/017	2018/019	2019/020	Average (2016/017–2019/020)	
Social and infrastructural development	31,281.8	-	119,609.8	75,445.8	Infrastructural development, sports, education, wildlife control, financial assistance to low-income households, wetland ecotourism management
Poverty alleviation and others	11,197.5	8280.1	9034.5	9504.0	Alternative energy programs and support, skill development trainings, health and COVID-19 relief

* 1 USD = NRS 116. Source: Annual auditor's reports (obtained from KCF office records).

4. Discussion

The study explored the ability of community-managed *Shorea robusta* to adapt to and mitigate climate change impacts. Forests sequester significant amounts of carbon in different pools, which is comparable to the results of various other community forests. For example, the total carbon stock in *Schima-Castonopsis* species in Ghwangkhola Sapaude Babiyabhir CF of Syangja district was 122.3 t/ha, annual carbon sequestration was 0.45%, and CO_2 mitigation potential was 1.6 t/ha [70]. The six selected community forests within the Dolakha district had an average annual carbon increment of 2.2 t/ha, while carbon out-take through timber and fuelwood was limited to 0.25 t/ha, resulting in a net average carbon accumulation of 1.9 t/ha, which is equal to 117.4 t/ha per year [42]. The carbon sequestration of *Shorea robusta* within Chyandada CF of Mahottari was 35.93 t/ha [44]. Among the forests of Tarai, Mahabharat and Middle hill, the highest carbon stock was observed in Tarai forests. The above ground carbon stock per ha ranged from 34.3 to 97.9 t/ha while carbon sequestration rate ranged between 1.3 and 3.2 t/ha/year [46]. In the CHAL region, the carbon value for dense forest was 236.1 t/ha and that for sparse forest was 157.5 t/ha for the study area. The sequestration of CO_2 potential was 2.6 million t/c per year [51]. In the community-managed mid-hill forests of Palpa, the biomass of *Shorea robusta* was 101.7 t/ha, while it was 44.4 t/ha in *Schima-Castanopsis*. Similarly, carbon sequestration in the two species reached 130.8 and 126.1 t/ha, respectively. This indicates that sequestration in *Shorea robusta* is 1.3-fold higher. The total carbon storage of 105 CF of the Khayarkhola watershed, Charnawati watershed, and Ludikhola watershed was quantified as 296.4 t/ha, 228.6 t/ha and 216.3 t/ha, respectively. Meanwhile, the storage in sparse forests in the three respective watersheds was recorded as 256.7, 166.8, and 163 t/ha [49].

In terms of *Shorea robusta* in the Terai Arc landscape under different management regimes, the highest carbon storage was noted in protected areas (291.55 ± 42.51 Mg ha^{-1}), followed by CF (237.15 ± 32.54 Mg ha^{-1}), government-managed forests (189.16 ± 26.46 Mg ha^{-1}), and other forests (126.76 ± 56.36 Mg ha^{-1}) [58]. The estimated carbon storage in a community-managed chir pine (*Pinus roxburghii* Sarg.) forest planted in Kathmandu, in Central Nepal, was 108 ± 5.0 MgC/ha^{-1} [71], while the total carbon stock of an oak forest in the Panchase region was 127.6 Mg/ha^{-1} [72]. The community-managed sparse *Rhododendron*–*Quercus* forest was limited to 48.2 MgC/ha [73].

Nepal has minimal carbon emissions (0.1 metric ton) in comparison to the global average (4.7 metric tons) [74]; however, the forest area, which covers around 40% of the land use of the country, significantly impacts the mitigation of the effects of climate change impacts [75]. CF is regarded as the vehicle for the implementation of REDD+, and Nepal is preparing itself to receive the economic benefits from the associated trading. During the inventory, we observed limited forest regeneration. The average sapling count per plot is only three. Although old trees accumulate relatively more carbon, the removal of large and matured trees releases the stored carbon back to the atmosphere [76], and regeneration has been largely implemented in plots with matured trees with large DBH. As younger trees remove more CO_2 from the atmosphere [77], the harvesting of matured trees has been essential for maintaining forest health [56]. Therefore, an appropriate forest management plan is essential.

The forest cover of Nepal is capable of creating 400,000 full-time employment opportunities and has the potential to produce 1.66 million cubic meters of forest products each year [78]. However, due to the conservation-oriented management, the supply of timber products from Nepalese forests is limited to 0.5 million cubic meters per year [79], which is very low in terms of the demand. Hence, timber and timber products worth a remarkable amount (estimated as USD 38 million) are imported each year [80]. Against this background, scientific forest management was implemented under a scientific forest management work Procedure, in 2014, to minimize the trade deficit by increasing the national timber production [15]. However, it remained controversial and was often accused of several shortcomings, such as confining the role of CFUGs, and the dominance of technical officials, deforestation, and the failure to address the rights and aspirations of the local stakeholders [81]. As a result, it was scrapped in January 2021 and the management scheme of the community forests has since remained undefined (https://english.khabarhub.com/2021/27/159314/ accessed on 20 November 2021).

Several studies have reported the success of community management in increasing canopy cover, aggressive tree growth, forest density, and overall forest health [35,82,83], resulting in higher biomass accumulation and increased carbon sequestration. The findings of this study regarding carbon indicate that the *Shorea robusta* species under community management has the potential to sequester significant amounts of carbon stock. Interestingly there is a wide range of carbon stock within the plots, indicating that several factors affect the carbon sequestration potential. The findings from the FGD reveal that communities have implemented several forest management strategies such as the regulated harvesting of forest products, regular monitoring to minimize fire risk, and the promotion of alternative energy sources so as to reduce firewood collection from forests, which all contribute to enhancing carbon storage. Furthermore, communities have promoted agroforestry—growing timber and fruit species on agricultural lands, grasslands, and barren lands—to minimize the dependency on the forest. Such strategies can increase forest cover, enhance tree growth, and contribute to the carbon stock, thereby mitigating global climate change effects.

The adoption of planned adaptation strategies is imperative in combating the effects of climate change in the long term [84]. One of the most effective strategies that communities have put in place is fire risk reduction through monitoring and managing fire control lines. Increased forest cover by reducing the dependency on forest for firewood and fodder also consequently minimizes the soil loss due to wind and landslides during strong wind and erratic rainfall. The effectiveness of the strategies is confirmed also by the FGD findings, indicating that community forestry has played an important role in enhancing the adaptation capacity of the local communities to the increased threats of climate change through livelihood diversification, promoting collective actions, and strengthening grass-root-level organizations.

5. Conclusions

Exploring the carbon sequestration potential of forests is a low-cost and reliable method that can serve as a gateway to obtaining financial aid and funds through carbon trading. According to the research results, the estimated biomass density of the forest is 352 t/ha, and the carbon stock density is 165 t/ha. This indicates that this community-managed forest has the potential for carbon trading. The financial benefits acquired from the carbon trade and equitable benefit sharing indicate that this is a viable option to enhance the socio-economic wellbeing and livelihoods of the local communities.

An appropriate management plan for harvesting forest products and for additional investments in the pro-poor livelihood assets through benefit-sharing with the local people can contribute to the adaptability through community forestry. Given the importance of local communities in forest resource management and the mitigation of and adaptation to the adverse impacts of climate change, the findings of this study suggest that policy makers should involve local communities in the design and implementation of future climate change mitigation and adaptation strategies. However, enhancing the carbon sequestration potential and thereby ensuring the adaptation of the local community is associated with multiple challenges, such as maintaining forest health and the supply of forest products, enhancing the awareness of the local people in terms of the carbon trade's benefits for their livelihoods, and equitable benefit sharing

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Appendix A

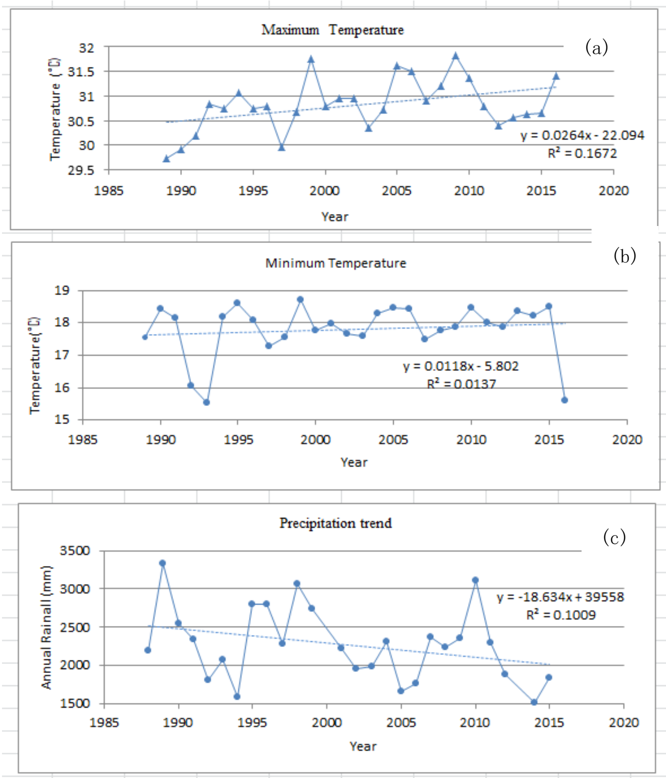

Figure A1. Maximum and minimum temperature (**a**,**b**) (Gaida-Kankai station) trend (1985–2020); Precipitation (Damak station) (**c**).

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