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Harnessing REDD+ for Community Involvement and Equitable Benefit Distribution: Insights from Dhankuta District, Nepal

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Abstract: The complex interplay between fuelwood consumption, deforestation, and land-use transformation in the Dhankuta district of Nepal is scrutinized in this investigation, concurrently shedding light on the feasibility of securing carbon finance via REDD+ mechanisms. Data derived from household surveys and remote sensing ascertained fuelwood as the primary energy recourse for the majority of households, leading to substantial deforestation, forest degradation, and carbon emissions. In a surprising revelation, a 12.4% augmentation in forest cover was discerned over 21 years, attributable to outmigration and conversion of fallow agricultural lands into forests. The investigation established that households involved in agriculture, particularly those with lower income, demonstrated higher dependence on fuelwood, consequently contributing to forest degradation and deforestation that further resulted in the emission of greenhouse gases. Potential avenues for the district to secure carbon finance include the introduction of clean cookstoves, reducing dependency on fuelwood, and greening barren areas. For effective realization of this potential, it is crucial to formulate a benefit-sharing plan that ensures the provision of suitable incentives for forest-dependent communities that are also responsible for forest conservation. By adopting the result-based payment system of REDD+ and promoting sustainable forest management, the district can mitigate carbon emissions, advocate for forest restoration, and qualify for carbon payments.

Keywords: REDD+ benefit sharing; Fuelwood, Carbon emissions; Incentives; Community forest

1 Introduction

In recognition of the urgency to address climate change and its grave impacts on the world's ecosystems, particularly forests, the REDD+ mechanism ('REDD' stands for 'Reducing emissions from deforestation and forest degradation in developing countries. The '+' stands for additional forest-related activities that protect the climate, namely sustainable management of forests and the conservation and enhancement of forest carbon stocks) has been developed [1]. The significance of deforestation and forest degradation as substantial contributors to greenhouse gas emissions underlines the dire need for emission reduction to mitigate climate change effects. A response to this need, REDD+, is designed to incentivize developing countries to lessen these emissions through financial and technical support [2, 3]. Moreover, the mechanism also promotes biodiversity conservation and sustainable forest management practices.

The REDD+ mechanism was established following international discussions under the United Nations Framework Convention on Climate Change (UNFCCC) [2]. Its primary target is to reduce emissions originating from deforestation and forest degradation, rather than concentrating on other emission reduction measures such as promoting renewable energy. Notably, the mechanism emphasizes local community involvement in conservation efforts and ensures their benefit from the initiative's outcomes [4].

To effectively participate in the REDD+ process, it is mandatory for governments to formulate four guiding documents: a National Strategy or Action Plan, a National Forest Monitoring System, a Forest Reference Emission Level, and a Safeguard Information System. This process, divided into three stages: preparedness, implementation, and result-based payments, progresses toward benefit availability, with the first two stages often overlapping [5, 6].

The success of REDD+ implementation hinges upon local populations' cooperation and involvement, who depend on forests for their sustenance. This approach promotes sustainable development and aligns with the international commitment to fight climate change by reducing emissions from deforestation and forest degradation. In addition to climate change mitigation, REDD+ holds potential for numerous benefits, such as biodiversity preservation, improved local livelihoods, and the promotion of sustainable forest management techniques.

However, the effectiveness of REDD+ is strongly contingent upon its successful implementation and the active participation of local populations in conservation activities. Although REDD+ has been implemented in several countries, the outcomes have varied widely. Numerous factors, including inadequate funding, poor governance, and limited community engagement, have hindered its effectiveness in several instances. Consequently, continuous research and evaluation of REDD+ efforts are essential to fully comprehend their potential benefits and limitations.

Despite over 14 years of involvement in REDD+ and significant progress towards accessing result-based payments through the emission reduction program in the Tarai Arc Landscape, Nepal has largely overlooked the carbon benefits of mountain regions. The focus of this study is on the hilly Nepalese district of Dhankuta. It aims to elucidate how benefits can be offered and provide suggestions for the successful local implementation of REDD+ activities. This study's findings offer explicit recommendations for conducting REDD+ projects with a focus on the benefit-sharing mechanism. These suggestions could serve as a significant aid to the Nepalese government and other carbon projects.

2 Literature Review

The indispensable role of effective benefit sharing mechanisms in achieving successful REDD+ initiatives has been affirmed, as these mechanisms ensure that local communities, which rely heavily on forests, obtain direct benefits from conservation endeavors [7–10]. Notably, the context-specific nature of benefit sharing elicits a resistance against adopting a universal approach, since its implementation heavily depends on factors such as socioeconomic circumstances, triggers of deforestation, and institutional structures [11–13].

The variety in the form of these mechanisms is highlighted by methods such as direct payments, non-monetary benefits, and co-management agreements. Direct payments serve as financial rewards, thereby incentivizing the involvement of local communities in forest preservation, whereas non-monetary benefits include the provision of access to essential services. Co-management agreements are characterized by the shared decision-making process between the communities and the governing authorities with regards to the management of forest resources [13–15].

It is observed that the promotion of community participation and engagement in REDD+ projects is facilitated by effective benefit sharing, which allows for the addressal of underlying triggers of deforestation and degradation of forests [16]. Essential aspects such as equity, transparency, and the encouragement of meaningful participation are underscored during the design and implementation of these mechanisms [5]. Beyond the direct benefits provided to local communities, these mechanisms also align with broader developmental objectives, including poverty reduction, gender equality, and conservation of biodiversity.

Diverse country-specific strategies have been illustrated, with Brazil adopting a Payment for Ecosystem Services (PES) approach, wherein communities are rewarded for the conservation or restoration of forests providing essential ecosystem services like carbon storage and watershed protection [17]. Indonesia emphasizes on community forestry, providing legal rights to local communities for forest management, thus enabling their access to forest-related goods and services [18, 19]. Regional equity and local project investments are prioritized in Chile's approach to foster sustainable economic and environmental sectors [20, 21]. In Ghana, a focus on non-financial benefits is observed, with efforts directed towards strengthening local institutions and the agricultural industry to curb forest encroachment [22].

A dedicated benefit-sharing system has been established across 13 districts within Nepal's Tarai Arc Landscape. The system largely revolves around financial compensation provided to forest communities and governmental agencies [23]. A portion of the REDD+ funds, comprising 5%, is allocated explicitly for poverty reduction, supporting households reliant on forest resources. Performance-based national funding, which constitutes 75% of the total, is distributed considering land management and the execution of sustainable plans [23, 24]. This financial support is directed towards various sectors, including forest improvement, poverty reduction, women's empowerment, and the growth of forest-based enterprises. Therefore, for the effectiveness of REDD+ projects, it becomes imperative to prioritize equitable benefit distribution, stakeholder engagement, and robust governance structures [23].

Despite the existence of unique benefit-sharing systems across different countries, the question of household willingness to participate in REDD+ programs continues to prevail [25]. Significantly, a considerable number of households in developing nations continue to depend on fuelwood as their primary energy source. The utilization of benefit sharing mechanisms has been identified as a vital factor for the success of REDD+ initiatives, as these mechanisms promote the active participation and engagement of local communities while addressing the root causes of deforestation and forest degradation [12]. In doing so, these mechanisms can foster sustainable development while simultaneously mitigating climate change.

2.1 Challenges of Fuelwood Consumption for REDD+

One of the primary obstacles in the successful implementation of REDD+ mechanisms and achievement of carbon sequestration targets is the reliance on fuelwood consumption. Forest degradation in developing countries has been predominantly attributed to fuelwood extraction [26–29]. In Nepal, fuelwood and timber are essential for daily activities, such as cooking, heating, and construction, primarily due to the country's hilly terrain and abundant forest resources. Such a situation is not exclusive to Nepal; approximately 2.9 billion people in many developing countries continue to depend on fuelwood for cooking or heating [30, 31]. Biomass, mostly in the form of fuelwood and charcoal, serves as the primary cooking fuel for over 40% of the global population. Nevertheless, charcoal production and fuelwood combustion contribute significantly to greenhouse gas (GHG) emissions [32, 33]. The industry accounts for approximately $2 - 7\%$ of global anthropogenic emissions, releasing nearly 1-2.4 gigatons of carbon dioxide equivalent (CO_2e) each year into the atmosphere [34].

Population growth exacerbates the demand for fuelwood and timber, resulting in unsustainable harvesting practices such as illegal logging and unregulated fuelwood collection. These practices contribute to deforestation and forest degradation, negatively impacting forest productivity, biodiversity, and ecosystem services. Consequently, the livelihoods of local communities and the ecological health of the area are adversely affected. Addressing these challenges is crucial for the success of REDD+ mechanisms and can be achieved through tailored incentives provided to forest-dependent communities.

Efforts have been made by governments to tackle unsustainable fuelwood and timber harvesting through initiatives such as community-based forest management, sustainable forest harvesting, and the promotion of alternative energy sources. These initiatives have encouraged local forest dwellers to conserve and manage forests more effectively. However, the outcomes of these conservation efforts have not been adequately incentivized, particularly through the allocation of REDD+ funds. In the absence of proper incentives, tangible improvements in forest conservation and management might not be realized.

In summary, this section has highlighted the challenges posed by fuelwood consumption to the successful implementation of REDD+ mechanisms and achieving carbon sequestration targets. It has emphasized the importance of tailored incentives for forest-dependent communities and the necessity for governments to support initiatives that encourage sustainable forest management. To ensure the effectiveness of REDD+ mechanisms, it is essential to address these challenges and provide adequate incentives for conservation efforts.

2.2 Conceptual Framework

Community forests (CF) hold substantial importance in Nepal, serving as the primary approach to managing a considerable portion of the country's forests while aligning with long-standing traditions. The CF model has been instrumental in restoring degraded and barren areas in Nepal. Furthermore, local communities' heavy reliance on forest resources for subsistence has fostered collaborative efforts in forest management. Shifting livelihood strategies, such as transitioning from agriculture to migration/remittances and the service sector, necessitate a more in-depth understanding [35]. Presently, 22,266 CF user groups benefit approximately 14.45 million people from 2.9 million households [36]. The success of CF in Nepal can be ascribed to the active participation of local forest users in managing and conserving forests.

Several factors motivate local communities' engagement in forest management, including livelihood support, benefits derived from forest resources, and capacity development. The degree of involvement in forest management is directly linked to the benefits communities receive from the forest, ultimately enhancing their livelihoods. Consequently, the relationship between people and forests depends on the support forests provide for their sustenance. Given the notable success of community forests (CF) in conservation, management, governance, benefits, and resource utilization, comprehending the key issues and stakeholders involved is essential. It should be noted that CF communities primarily rely on forests for fuelwood consumption [37].

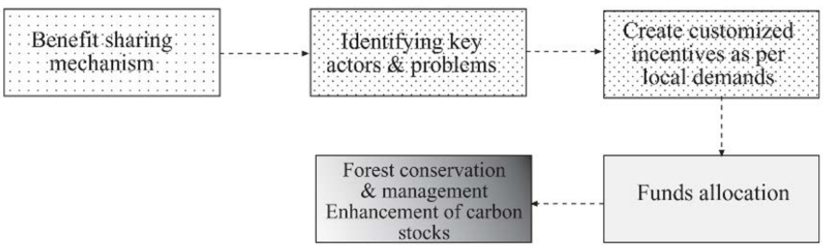

Figure 1. Conceptual framework for REDD+ benefit-sharing mechanism

In Nepal, the prevalent dependence on fuelwood by households for cooking and heating poses a significant challenge, leading to considerable carbon emissions. Fuelwood collection contributes not only to forest degradation but also to increased carbon emissions when burned. Ensuring that CF users are adequately rewarded for their conservation efforts is vital for the success of the REDD+ mechanism. CF communities play a pivotal role in reducing carbon emissions and mitigating the adverse impacts of fuelwood combustion. As such, designing appropriate incentives for these communities is crucial to ensure the successful implementation of REDD+ programs (as shown in Figure 1).

3 Materials and Methods

3.1 Study Area

Located within the Koshi Zone, Dhankuta district forms an integral part of eastern Nepal, as indicated in Figure 2. This district spans an area of 891 square kilometers and is divided into eight municipalities, including two sub-metropolitan cities, three urban municipalities, and three rural municipalities. Dhankuta town, serving as the district headquarters, is also recognized as the district's largest city.

Geographically positioned between 26°52′ to 27°19′ north latitude and 87°18′ to 87°50′ east longitude, Dhankuta is surrounded by Bhojpur district in the east, Terhathum district in the west, Morang and Jhapa districts in the south, while its northern border aligns with China.

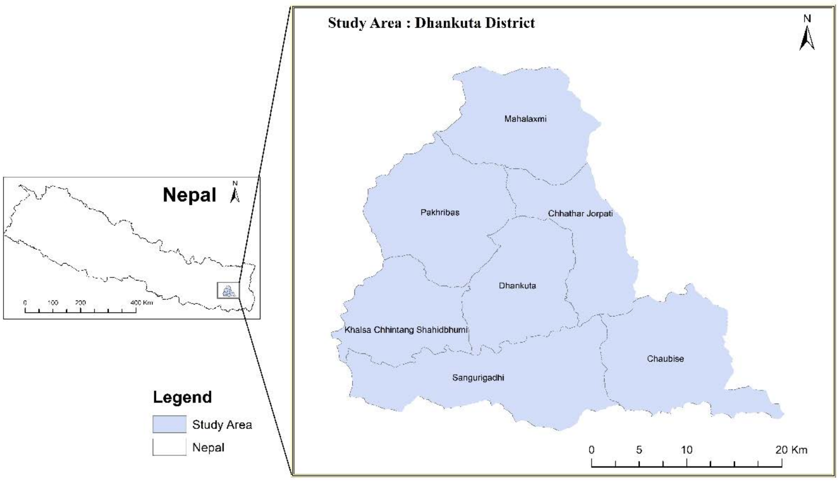

Figure 2. The geographical delineation of Dhankuta district, Nepal

Dhankuta exhibits a topographical variation that ranges from the Koshi river basin's lowlands to the formidable heights of the Himalayan mountains. Altitudes within the district extend from 300 meters to a formidable 7,144 meters above sea level. Parallel to each other, the Mahabharat Range and the Himalayan Range form significant topographical features in the district, with the Arun River threading its path between them.

In line with altitude variations, the region's climate also presents a spectrum from tropical conditions characterized by high temperatures and humidity in the lowlands to a cooler climate at the elevated areas. The monsoon season from June to September brings substantial rainfall, adding to the district's climatic diversity.

The predominant rural population of Dhankuta is primarily engaged in agriculture, with principal crops including rice, maize, wheat, and millet. Additionally, Dhankuta, often referred to as the capital of avocado, also cultivates significant quantities of avocados, oranges, and tea.

A variety of ethnic groups, namely Brahmin, Chhetri, Rai, Limbu, Tamang, and Newar, enrich the district's demographic diversity. With regards to education, the district's literacy rate surpasses many other districts within Nepal.

The aesthetic appeal of Dhankuta is heightened by its scenic beauty and cultural heritage. It hosts several revered temples, including the Bishnupaduka Temple, the Chhintang Devi Temple, and the Panchkanya Temple. Additionally, it offers numerous trekking trails, including the widely renowned Makalu Base Camp trek.

The convergence of unique topography, climate, and diverse population characterizes Dhankuta as a compelling area of study for researchers across various fields. Its unique environmental conditions, climatic variations, topography, and forest cover can potentially serve as a model for the development of carbon projects in other hilly districts of Nepal.

3.2 Analysis of Changes in Land Cover

Driven principally by anthropogenic influence, alterations in land cover bear significant implications for ecosystems, biodiversity, and climate change. Approximately 35% of atmospheric carbon emissions are attributed directly to human activities post-industrial revolution [38]. Therefore, land cover change analysis, with a particular emphasis on fluctuations in forest areas correlated to carbon levels, is deemed critical in this study.

To monitor these transitions, the Regional Land Cover Monitoring System (RLCMS) was developed through a collaboration between ICIMOD and other organizations, such as the SERVIR-Mekong at Asian Disaster Preparedness Center, Afghanistan's Ministry of Agriculture, Irrigation and Livestock, and the Global Land Analysis and Discovery laboratory at the University of Maryland [39]. This system harnesses advanced remote sensing technology on the Google Earth Engine and a standard data source set, yielding high-quality land cover data at both regional and national scales.

Through a collective effort with partner organizations, land cover classes were defined, reference data were compiled, and validation of the resultant data was executed. The RLCMS also facilitated the production of land cover maps for the HKH region from 2000 to 2021 as part of the ICIMOD's SERVIR-HKH Initiative. These maps, offering a resolution of 30m, classify land use into nine distinct categories.

The area under study was subsequently selected, and changes in land use, specifically transitions between forest and non-forest areas, were scrutinized. This scrutiny was performed using ArcMap 10.8.1 software, and by cross-referencing the pre-established land use maps from 2000 and 2010, land use change extent was computed. Discerning patterns of land cover change becomes invaluable, as it offers critical insights for planning and executing various activities, such as the REDD+ initiative.

3.3 Household Survey

For a robust data collection process, a questionnaire was curated, drawing from preliminary surveys and an exhaustive review of pertinent secondary literature. The intention behind this questionnaire was to accrue information on a range of aspects germane to the research topic, inclusive of household demographics, land use patterns, and perceptions on land management practices.

Pre-testing was undertaken before the commencement of the household surveys to ascertain the questionnaire's clarity, relevance, and effectiveness. The final version of the questionnaire was subsequently uploaded to the Kobocollect tool for streamlined survey administration.

A random sampling method was employed at each local level within the district to gather a representative sample of households. To collect a diverse range of information, sampling was executed in every municipality or rural municipality, including their wards. The 2021 Nepal census data was used to ensure representation across distinct income and occupation sectors. Local administration validation and support were also secured to expedite the survey and select suitable households for inclusion.

The survey encompassed a total of 247 households, with distribution across different municipalities and rural municipalities. Prior to the survey, training was provided to the enumerators on the use of the Kobocollect tool to ensure their competence in managing the questionnaire and adeptly addressing any potential issues or respondent queries.

Upon survey completion, data were downloaded and analyzed using Microsoft Excel. Descriptive statistics were applied to summarize the data, and pertinent charts were created for visual representation of the results. Further testing and validation of the obtained results were performed through linear regression analysis, enabling the identification of substantial relationships between variables and providing a deeper understanding of the research findings.

4 Results

4.1 Land Use and Land Cover Change

The analysis of land use change in the study area over the past two decades has demonstrated significant transformations in cropland (as shown in Figure 3). Approximately 130 square kilometers of cropland were converted, primarily into forested areas, resulting in a 13% decrease in cropland extent. Concurrently, the forest area in the study sites experienced an estimated increase of 12.4% during the same period. This increase can primarily be ascribed to the conversion of cropland, with a minor contribution observed from grassland conversion. Furthermore, changes in grassland cover within the district were noted, indicating an overall increase of 1.9% in grassland extent between 2000 and 2021 (as shown in Figure 4). Several factors contribute to this increase, including the shrinking and drying of water bodies and the conversion of cropland into barren land. These changes were particularly noticeable as grassland cover expanded within the study area. The land use analysis within the district highlighted three main land classes: forest, cropland, and riverbed, which underwent the most significant changes during the study period.

Notably, the conversion of forested areas to other land uses was most pronounced in urban areas and riverbanks, while remote areas of the district experienced an increase in forest cover, largely due to migration.

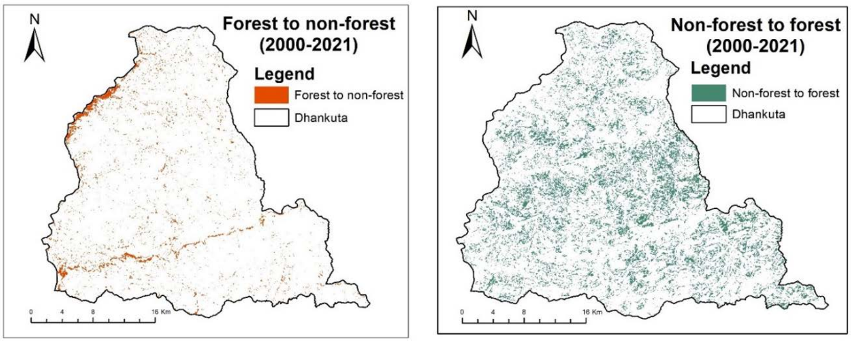

Figure 3. Map showing forest to non-forest and non-forest to forest locations

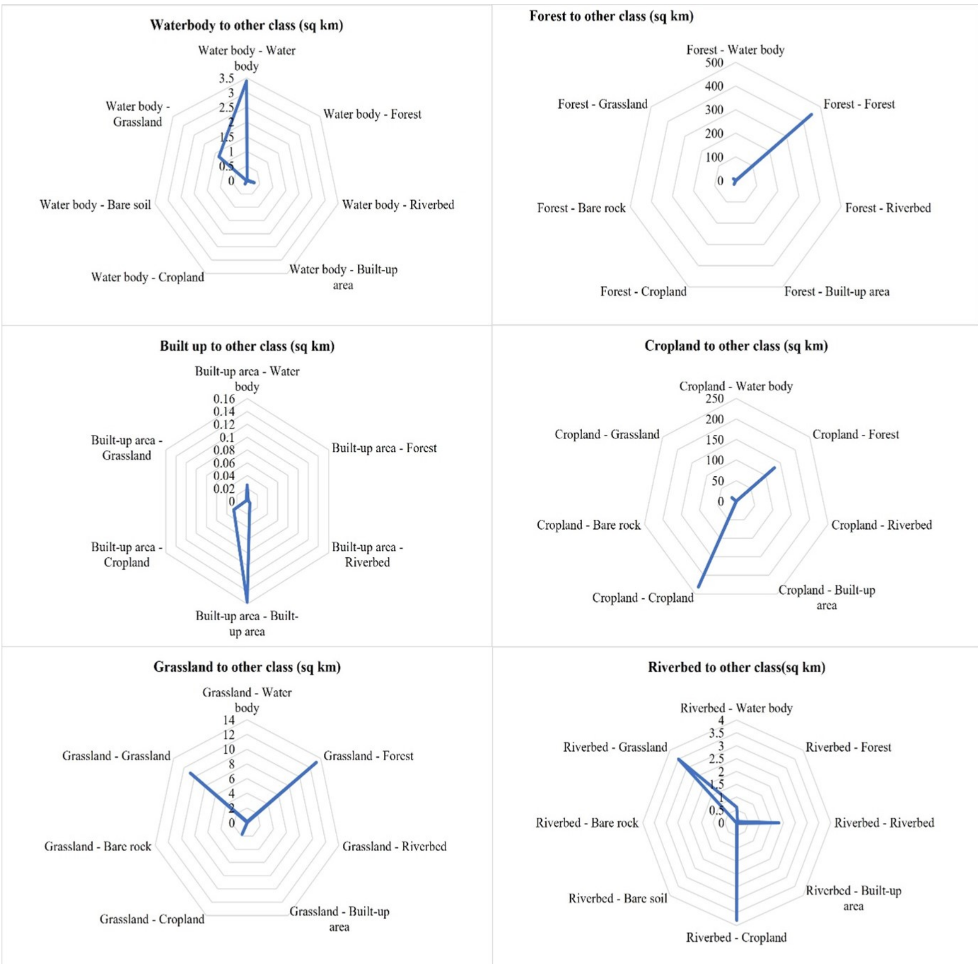

Figure 4. Land use change from 2000-2021

Although the primary focus of this study was on the major land cover changes, it is essential to mention that minor alterations in other land classes were also observed. Over the 21-year timeframe, water bodies decreased by approximately one square kilometer, primarily affecting grassland areas. Additionally, small changes in the riverbed were observed, with conversions mainly occurring to cropland and grasslands. The built-up area experienced some growth, but the increase was not significant.

A particularly interesting finding is the significant increase in forest area within the district over the 21-year period. The forest area expanded by approximately 112 square kilometers, representing a remarkable 12.5% increase in forest cover (as shown in Table 1).

Table 1. Change in forest to non-forest and non-forest to forest area (in sq km)

Forest to non-forest		Non-forest to forest	
Forest - Water body	0.11	Water body - Forest	0.03
Forest - Riverbed	0.00	Riverbed - Forest	0.07
Forest - Built-up area	0.15	Built-up area - Forest	0.00
Forest - Cropland	17.85	Cropland - Forest	129.94
Forest - Grassland	13.29	Grassland - Forest	13.15
Total area (sq km)	**31.40**	**Total area (sq km)**	**143.19**

4.2 Fuelwood Consumption and Income Linkage

The study offers an intriguing perspective on the diverse range of professions within the population of the study area. The local economy is predominantly based on agriculture, with a significant proportion of the community actively engaged in farming practices. The region is known for cultivating various crops, including paddy rice, maize, millet, vegetables, and fruits. A survey conducted on a representative sample of households revealed that 46% of respondents identified agriculture as their primary profession. The survey included individuals from different age groups, with approximately 15% of participants reporting either being unemployed or in the student phase of their lives (as shown in Figure 5).

Interestingly, it was observed that a majority of households with agriculture as their primary profession did not engage in a secondary profession. However, a few respondents indicated simultaneous involvement in both agriculture and either business or service, suggesting concurrent engagement in multiple professions. This observation emphasizes the predominantly agricultural nature of the Dhankuta district. In urban areas, a significant number of respondents reported business or service as their primary profession while maintaining agriculture as a prominent secondary occupation. This finding underscores the enduring significance of agriculture, even in urban settings, as a supplementary source of livelihood for numerous individuals.

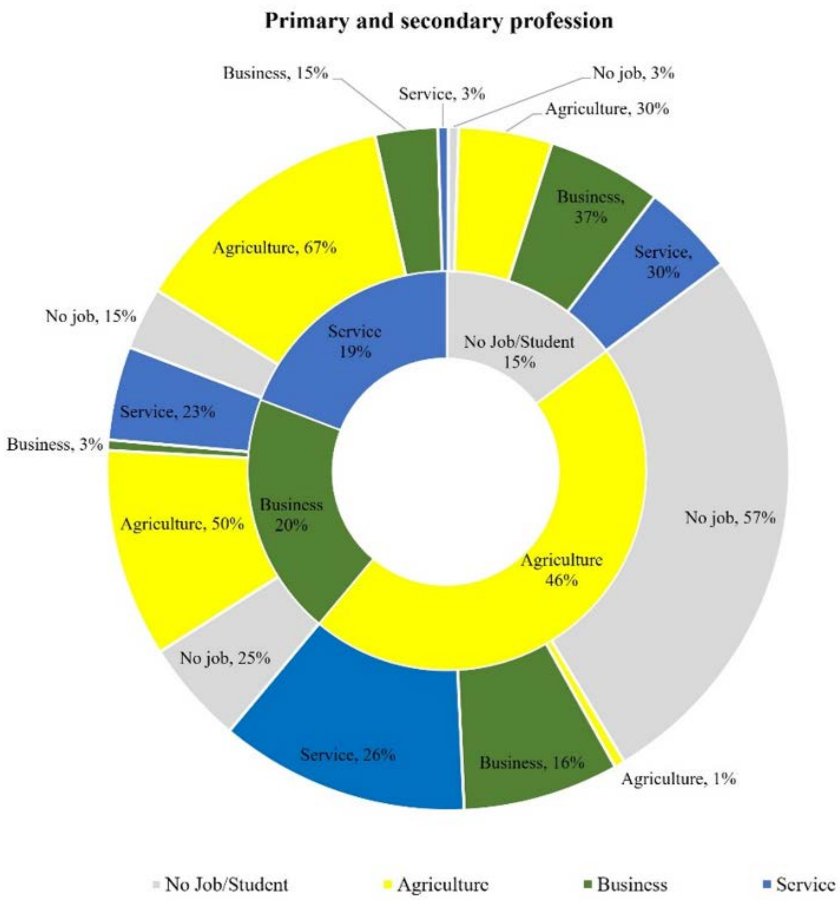

Figure 5. Primary and secondary profession

This study examines the relationship between individuals' occupations and their energy sources. It was found that a majority of households primarily depend on fuelwood as their main energy source. To further analyze the relationship between fuelwood usage, income, and occupation, the data were plotted. When examining the overall income class and fuelwood usage trend, a downward trend was observed (refer to subgraph (A) of Figure 6). However, a different pattern emerged when the data were segregated based on income levels below 300,000 (see subgraph (B) of Figure 6) and 500,000 or above (see subgraph (C) of Figure 6). Figure 6 illustrates that households with annual incomes below USD 2300 (Nepalese rupee 300,000) predominantly rely on fuelwood as their primary energy source. In contrast, households with annual incomes exceeding USD 3800 (Nepalese rupee 500,000) primarily utilize LPG as their main energy source, with only a minority still using fuelwood and an even smaller fraction adopting clean cookstoves.

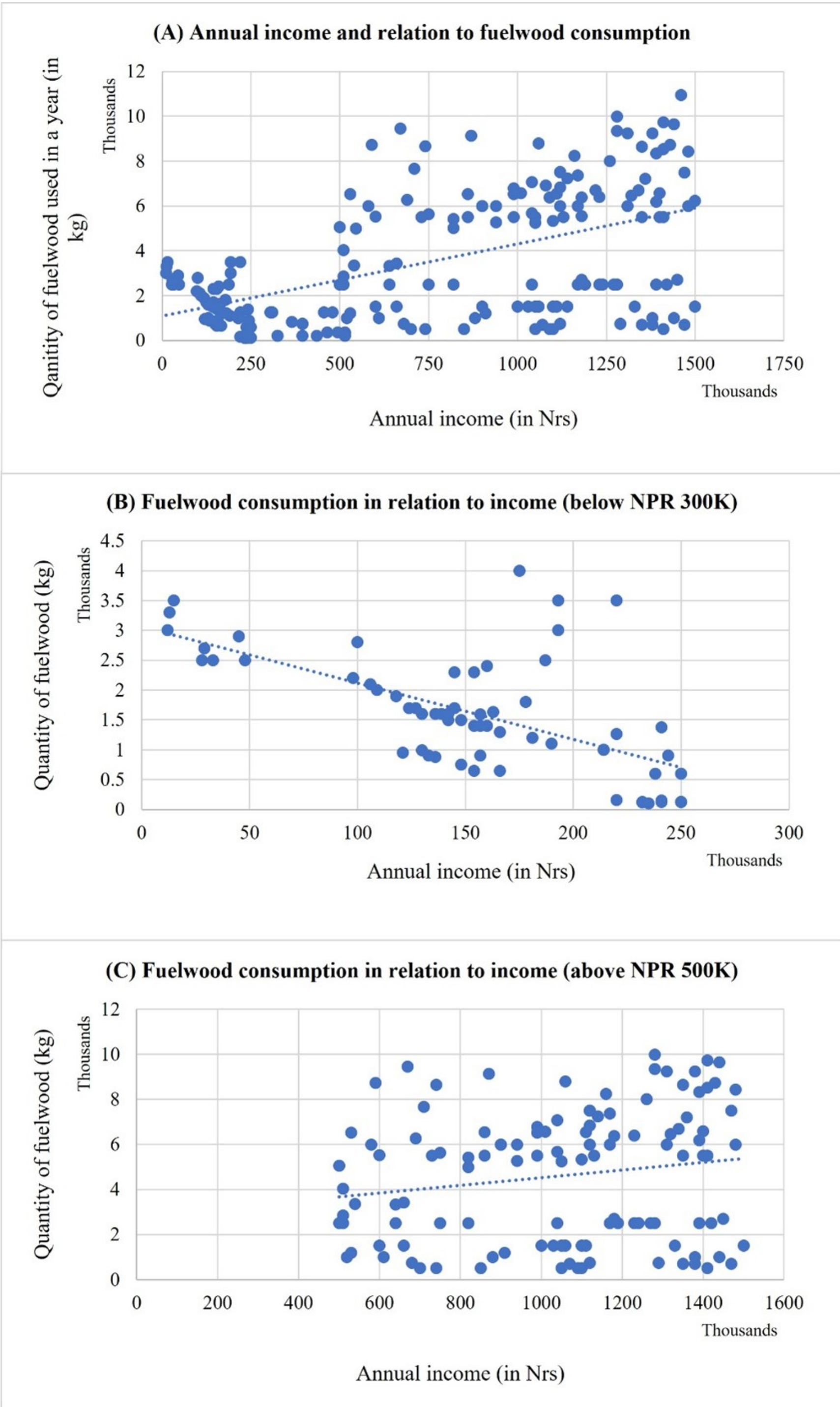

Figure 6. Fuelwood consumption trend in relation to annual income

5 Discussion

5.1 Changes in Land Use and Land Cover

The primary impetus for alterations in land use and cover is attributed to migratory patterns within the nation, a process influenced by both internal migration and outmigration [40]. This migration is predominantly directed towards urban areas within districts, or to low-lying regions with superior facilities. In areas facing water scarcity, the local population is often compelled to relocate, subsequently leaving agricultural lands deserted. These deserted areas are subject to conversion to forests, bushy areas, grasslands, or construction sites [41–43].

The conversion of agricultural land has emerged as a nationwide concern, with national records indicating a 2.1% reduction in cropland, equivalent to 8,053 hectares, in 2019 compared to 2000 [44]. Proposed solutions to this pressing issue include the implementation of incentives such as carbon finance to encourage agricultural practices like agroforestry and horticulture [45–48]. Households receiving remittances can meet their needs through market resources rather than relying exclusively on agriculture. Moreover, farmers are faced with difficulties in obtaining high-quality seeds and fertilizers, in addition to locating reliable markets for their produce [49].

Agriculture's reliance on water for irrigation, combined with dwindling water supplies and sources, drives the conversion of agricultural lands into barren areas, construction sites or forested areas [50, 51]. Population growth coupled with increasing demands exacerbates these challenges, with family fragmentation leading to either cropland or forest utilization for housing construction [52]. In regions with prevalent water scarcity, residents situated near rivers expand their cropland onto the riverbed, thereby accessing a reliable water source for irrigation [53, 54]. Such demands increase in parallel with population growth, posing significant challenges intensified by the effects of climate change.

Between 2000 and 2019, the forest area of Nepal expanded by 1.7% on a national scale, while agricultural land diminished by 2.1% due to the expansion of built-up areas [55]. The Forest Survey of Nepal, conducted in 2019, reported that the district comprises a total forest area of 60,631 hectares, amounting to 55.9% of its total land area. Although the district's forest cover displayed a minor increase between 2000 and 2016, with an annual forest cover change rate of 0.16%, the area remains susceptible to deforestation and forest degradation.

In rural areas, local communities heavily depend on forest resources for their daily subsistence. This reliance has resulted in significant disruption in forest conservation and management efforts. The main contributors to deforestation and forest degradation in the study area include illegal logging and fuelwood collection, unregulated extraction of non-timber forest products, and forest fires. The region's challenging topography and terrain impede the control of illegal activities, such as logging and hunting. Multiple initiatives have been implemented to tackle these challenges, including community-based forest management, forest conservation, and sustainable livelihood programs.

The REDD+ mechanism presents a promising solution for regions grappling with these challenges, offering incentives and support to communities experiencing forest area expansion [56]. This method encourages effective forest management and conservation, consequently leading to increased carbon sequestration [57, 58]. The observed patterns of land use change underline the complex interplay between socioeconomic factors, environmental challenges, and the pressing need for sustainable methods. Active engagement with relevant stakeholders and beneficiaries is necessary for effectively addressing these issues, promoting a collaborative and inclusive framework, and providing incentives to the forest-dependent communities, ensuring the long-term sustainability of interventions.

5.2 Profession and Fuelwood Dependency Relationship

This study investigates the relationship between individuals' occupations and their energy sources, specifically focusing on the Dhankuta district in Nepal. The findings reveal that a majority of households primarily depend on fuelwood as their main energy source, corroborating previous research conducted in the district or region by the studies [59–61]. Despite the use of liquefied petroleum gas (LPG) having doubled over the past decade, more than half of Nepali households still utilize firewood for cooking purposes [62]. According to the National Statistical Office (NSO) report of 2023, out of the total 6.66 million households in Nepal, 51% utilize firewood, while 44.3% use LPG in their kitchens [62]. The combustion of biomass, such as fuelwood, contributes to air pollution, resulting in a wide range of detrimental health effects [63].

Although the government of Nepal provides LPG subsidies, concerns regarding affordability and accessibility persist, leading local communities to rely on fuelwood. This dependence can be attributed to the high demand for cooking substantial quantities of food for domestic animals, requiring a strong flame, as well as the necessity of heating during the winter season. Consequently, these households significantly contribute to carbon emissions. The burning of 1 kilogram of fuelwood is estimated to emit approximately 1.65 to 1.80 kilograms of CO_2 [64]. The NSO [62] reports a total of 6,666,937 households in the Dhankuta District. Based on the average fuelwood consumption observed in the surveyed households, an approximate annual fuelwood usage of 3,500 kilograms per family is obtained. If this average is extrapolated to the entire district, the estimated annual CO_2 emissions range from approximately 6.4 to 6.9 metric tons per household, resulting in an overall emission estimate of around 42 to 46 million metric tons of CO_2 per year for the district. However, it should be noted that these figures serve as references, as the carbon emissions from fuelwood burning depend on factors such as wood type, species, and cookstove characteristics [65, 66].

The heavy reliance on fuelwood for cooking and heating purposes in many communities not only leads to deforestation and forest degradation but also significantly contributes to carbon emissions. Urgent action is required to address the impact of climate change in the Dhankuta district. The provision of sustainable alternatives to fuelwood is crucial to promote carbon sequestration and mitigate the adverse effects of deforestation. These findings align with previous studies highlighting the challenges of forest conservation and management in rural areas of developing countries [67–69]. Addressing fuelwood dependency is a critical step towards achieving sustainable forest management in the district. Strategies such as promoting cleaner energy sources like electric cookstoves, biogas, and improved cookstoves, as well as advocating for sustainable forest management practices that benefit local communities, can contribute to forest conservation and sustainable utilization [23, 70]. Clean cookstoves, in particular, hold promise for reducing emissions [71].

To effect meaningful change, it is essential to identify households that are heavily reliant on fuelwood and provide them with subsidies or incentives. Moreover, the REDD+ mechanism should identify suitable beneficiaries who currently collect fuelwood from the forest, as they play a role in both deforestation and forest conservation efforts. Effective conservation and management can be facilitated by incentivizing forest users through various means, including monetary rewards, non-monetary incentives, and capacity development opportunities [13, 72, 73].

6 Conclusions

In the investigation conducted, an established reliance on fuelwood was noted within the Dhankuta district, contributing to forest degradation, deforestation, and increased carbon emissions. An unexpected rise in forest coverage was recorded over 21 years, an increase of 12.4%, which can be attributed to factors such as the conversion of fallow agricultural lands into forests and outmigration. A greater dependence on fuelwood was observed among lower-income households and those involved in agriculture, which intensified the issues of forest degradation and deforestation.

These findings hold significance for broader comprehension of the intricate interplay between fuelwood consumption, deforestation, and shifts in land use in analogous settings. The potential for accessing carbon finance is highlighted through the implementation of interventions like the promotion of clean cookstoves, afforestation, and sustainable forest management practices. For a successful engagement with carbon finance, it is proposed that a benefit-sharing plan be adopted to convert carbon finance into tangible incentives for local communities. REDD+ as a mechanism for result-based payments can encourage a decrease in fuelwood consumption and by supporting sustainable forest management practices, it can alleviate the strain on forests, decrease carbon emissions, and qualify for carbon payments.

Future research directions could encompass evaluating the efficacy of different interventions to diminish fuelwood consumption, scrutinizing the role of local institutions in forest resources management, or analyzing the effect of demographic changes on land use and forest coverage in the region. The success of REDD+ mechanisms is contingent on the benefits reaching local beneficiaries, as an insufficient reach of incentives to local forest-dependent communities has led to the failure of numerous REDD+ programs. By addressing these challenges, the Dhankuta district has the potential to leverage carbon finance to support sustainable development and contribute to global efforts aimed at climate change mitigation.

On a final note, the researchers emphasize that the district's carbon emissions reduction, land management strategies, and sustainable energy sources must be in harmony with local livelihoods, traditional customs, and the wellbeing of the local ecosystem. This approach ensures the long-term viability of these strategies and promotes the region's development in an ecologically sensitive manner. This aligns with the global trend toward holistic land management practices that take into account both human and environmental needs.

Author Contributions

Conceptualization, N.B., T.W., and B.S.K.; methodology, N.B., and R.A.; software, N.B., R.A. and R.B.T.; validation, N.B., B.S.K., W.T., R.V and R.B.T.; formal analysis, N.B.; investigation, N.B., B.S.K., and R.B.T.; resources, N.B., and R.B.T.; data curation, N.B.; writing—original draft preparation, N.B.; writing—review and editing, N.B., W.T., R.A., B.S.K., and R.B.T.; visualization, N.B., B.S.K.; supervision, W.T., R.A., B.S.K. and R.B.T.; project administration, N.B., W.T.; funding acquisition, N.B., W.T., B.S.K. All authors have read and agreed to the published version of the manuscript. The relevant terms are explained at the CRediT taxonomy.

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Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Roshani, H. Sajjad, P. Kumar, M. Masroor, M. H. Rahaman, S. Rehman, R. Ahmed, and M. Sahana, "Forest vulnerability to climate change: A review for future research framework," *Forests*, vol. 13, no. 6, p. 917, 2022. https://doi.org/10.3390/f13060917

[2] K. Morita and K. I. Matsumoto, "Challenges and lessons learned for REDD+ finance and its governance," *C. Balance Manag.*, vol. 18, no. 1, p. 8, 2023. https://doi.org/10.1186/s13021-023-00228-y

[3] C. Gueiros, S. Jodoin, and C. L. McDermott, "Jurisdictional approaches to reducing emissions from deforestation and forest degradation in Brazil: Why do states adopt jurisdictional policies?" *Land Use Policy*, vol. 127, p. 106582, 2023.

[4] A. C. Collins, M. N. Grote, T. Caro, A. Ghosh, J. Thorne, J. Salerno, and M. B. Mulder, "How community forest management performs when REDD+ payments fail," *Environ. Res. Lett.*, vol. 17, no. 3, p. 034019, 2022. https://doi.org/10.1088/1748-9326/ac4b54

[5] N. Bhattarai, B. S. Karky, R. Avtar, R. B. Thapa, and T. Watanabe, "Are countries ready for REDD+ payments? REDD+ readiness in Bhutan, India, Myanmar, and Nepal," *Sustainability*, vol. 15, no. 7, p. 6078, 2023. https://doi.org/10.3390/su15076078

[6] "REDD+ web platform," 2023. https://redd.unfccc.int/submissions.html?country=np

[7] S. Manda and N. Mukanda, "Can REDD+ projects deliver livelihood benefits in private tenure arrangements? Experiences from rural Zambia," *Forest Policy Econ.*, vol. 150, p. 102952, 2023. https://doi.org/10.1016/j.forpol.2023.102952

[8] M. Pauly and J. Tosteson, "Safeguarding natural forests through the voluntary REDD+ scheme," *Nat. Plants*, vol. 8, no. 8, pp. 861–866, 2007. https://doi.org/10.1038/s41477-022-01208-9

[9] G. Wong, P. T. Thuy, I. Valencia, and et al., "Designing REDD+ benefit-sharing mechanisms," *Center for International Forestry Research (CIFOR)*, 2022.

[10] G. Wong, A. Angelsen, M. Brockhaus, and et al., "Results-based payments for REDD+: Lessons on finance, performance, and non-carbon benefits," *Center for International Forestry Research (CIFOR)*, vol. 138, 2016.

[11] G. Y. Wong, C. Luttrell, L. Loft, A. Yang, T. T. Pham, D. Naito, S. Assembe-Mvondo, and M. Brockhaus, "Narratives in REDD+ benefit sharing: Examining evidence within and beyond the forest sector," *Clim. Policy*, vol. 19, no. 8, pp. 1038–1051, 2019. https://doi.org/10.1080/14693062.2019.1618786

[12] T. Dunlop and E. Corbera, "Incentivizing REDD+: How developing countries are laying the groundwork for benefit-sharing," *Environ. Sci. Policy*, vol. 63, pp. 44–54, 2016. https://doi.org/10.1016/j.envsci.2016.04.018

[13] T. T. Pham, M. Moeliono, B. Dwisatrio, J. Yuwono, and S. Atmadja, "REDD+ benefit sharing in Ethiopia: Policy and stakeholder perceptions analysis," *Int. For. Rev.*, vol. 23, no. 4, pp. 476–491, 2021. https://doi.org/10.1505/146554821834777170

[14] J. Costenbader, "REDD+ benefit sharing: A comparative assessment of three national policy approaches," *For. Carbon Partn. Facil. UN-REDD Programme*, 2011.

[15] B. H. Poudyal, T. Maraseni, G. Cockfield, and B. Bhattarai, "Recognition of historical contribution of indigenous peoples and local communities through benefit sharing plans (BSPs) in REDD+," *Environ. Sci. Policy*, vol. 106, pp. 111–114, 2020. https://doi.org/10.1016/j.envsci.2020.01.022

[16] J. Andoh, K. A. Oduro, J. Park, and Y. Lee, "Towards REDD+ implementation: Deforestation and forest degradation drivers, REDD+ financing, and readiness activities in participant countries," *Front. For. Glob. Chang.*, vol. 5, 2022. http://dx.doi.org/10.3389/ffgc.2022.957550

[17] E. A. Morgan, A. Buckwell, C. Guidi, B. Garcia, L. Rimmer, T. Cadman, and B. Mackey, "Capturing multiple forest ecosystem services for just benefit sharing: The basket of benefits approach," *Ecosyst. Serv.*, vol. 55, p. 101421, 2022. https://doi.org/10.1016/j.ecoser.2022.101421

[18] S. Kane, A. Dhiaulhaq, L. M. Sapkota, and D. Gritten, "Transforming forest landscape conflicts: The promises and perils of global forest management initiatives such as REDD+," *Forest Soc.*, vol. 2, no. 1, pp. 1–17, 2018.

[19] S. De Royer, M. Van Noordwijk, and J. M. Roshetko, "Does community-based forest management in Indonesia devolve social justice or social costs?" *Int. For. Rev.*, vol. 20, no. 2, pp. 167–180, 2018. https://doi.org/10.1505/146554818823767609

[20] A. M. Cisneros-Montemayor, M. Moreno-Báez, M. Voyer, and et al., "Social equity and benefits as the nexus of a transformative Blue Economy: A sectoral review of implications," *Mar. Policy*, vol. 109, p. 103702, 2019. https://doi.org/10.1016/j.marpol.2019.103702

[21] C. Streck, "REDD+ and leakage: Debunking myths and promoting integrated solutions," *Clim. Policy*, vol. 21, no. 6, pp. 843–852, 2021.

[22] I. Soliev, I. Theesfeld, E. Abert, and W. Schramm, "Benefit sharing and conflict transformation: Insights for and from REDD+ forest governance in sub-Saharan Africa," *Forest Policy Econ.*, vol. 133, p. 102623, 2021. https://doi.org/10.1016/j.forpol.2021.102623

[23] S. Adhikari and H. Baral, "Emission reductions program for addressing drivers of deforestation and forest degradation: An insight from the Terai Arc landscape in southern Nepal," *For. Dyn. Conserv.: Sci., Innov. Pol.*, pp. 419–437, 2022. https://doi.org/10.1007/978-981-19-0071-6_20

[24] A. Parajuli, S. A. Manzoor, and M. Lukac, "Areas of the Terai Arc landscape in Nepal at risk of forest fire identified by fuzzy analytic hierarchy process," *Environ. Dev.*, vol. 45, p. 100810, 2023.

[25] Q. Van Khuc, L. Pham, M. Tran, T. Nguyen, B. Q. Tran, T. Hoang, T. Ngo, and T. D. Tran, "Understanding vietnamese farmers' perception toward forest importance and perceived willingness-to-participate in REDD+ program: A case study in Nghe An province," *Forests*, vol. 12, no. 5, p. 521, 2021. https://doi.org/10.3390/f12050521

[26] M. J. Specht, S. R. R. Pinto, U. P. Albuquerque, M. Tabarelli, and F. P. Melo, "Burning biodiversity: Fuelwood harvesting causes forest degradation in human-dominated tropical landscapes," *Glob. Ecol. Conserv.*, vol. 3, pp. 200–209, 2015. https://doi.org/10.1016/j.gecco.2014.12.002

[27] R. A. Houghton, "Carbon emissions and the drivers of deforestation and forest degradation in the tropics," *Curr. Opin. Environ. Sustain.*, vol. 4, no. 6, pp. 597–603, 2012. https://doi.org/10.1016/j.cosust.2012.06.006

[28] N. Hosonuma, M. Herold, V. De Sy, R. S. De Fries, M. Brockhaus, L. Verchot, A. Angelsen, and E. Romijn, "An assessment of deforestation and forest degradation drivers in developing countries," *Environ. Res. Lett.*, vol. 7, no. 4, p. 044009, 2012. https://doi.org/10.1088/1748-9326/7/4/044009

[29] M. Richards, B. S. Karky, N. Bhattarai, T. Basnett, K. Windhorst, M. Richards, and N. Bhattarai, "The drivers of deforestation and forest degradation in the himalayan region: A literature review," *ICIMOD*, 2022. https://doi.org/10.53055/ICIMOD.1012

[30] A. Ifegbesan and T. Makonese, "Energy preferences for household cooking in Burundi," *Soc. Health Sci.*, vol. 20, no. 1 and 2, p. 044009, 2022.

[31] P. Adhikari, M. Buddhacharya, N. Jha, and D. K. Yadav, "Prevalence of biomass use and its effect on the respiratory health of women residing in eastern Terai region of Nepal," *Annapurna J. Health Sci.*, vol. 3, no. 1, pp. 22–27, 2023.

[32] C. A. Ochieng, C. Tonne, and S. Vardoulakis, "A comparison of fuel use between a low cost, improved wood stove and traditional three-stone stove in rural Kenya," *Biomass Bioenerg.*, vol. 58, pp. 258–266, 2013. https://doi.org/10.1016/j.biombioe.2013.07.017

[33] A. Manaye, S. Amaha, Y. Gufi, B. Tesfamariam, A. Worku, and H. Abrha, "Fuelwood use and carbon emission reduction of improved biomass cookstoves: Evidence from kitchen performance tests in Tigray, Ethiopia,"

Energy Sustain. Soc., vol. 12, no. 1, pp. 1–9, 2022. https://doi.org/10.1186/s13705-022-00355-3
[34] J. V. Dam, "The charcoal transition: Greening the charcoal value chain to mitigate climate change and improve local livelihoods," 2017.
[35] N. Shahi, P. Bhusal, G. Paudel, and J. N. Kimengsi, "Forest—People nexus in changing livelihood contexts: Evidence from community forests in Nepal," *Trees For. People*, vol. 8, p. 100223, 2022. https://doi.org/10.1016/j.tfp.2022.100223
[36] P. K. Bhandari, P. Bhusal, G. Paudel, C. P. Upadhyaya, and B. B. Khanal Chhetri, "Importance of community forestry funds for rural development in Nepal," *Resources*, vol. 8, no. 2, p. 85, 2019.
[37] B. S. Karky and M. Skutsch, "The cost of carbon abatement through community forest management in Nepal Himalaya," *Ecol. Econ.*, vol. 69, no. 3, pp. 666–672, 2010. https://doi.org/10.1016/j.ecolecon.2009.10.004
[38] R. A. Houghton, D. L. Skole, C. A. Nobre, J. L. Hackler, K. T. Lawrence, and W. H. Chomentowski, "Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon," *Nature*, vol. 403, no. 6767, pp. 301–304, 2000. https://doi.org/10.1038/35002062
[39] "Regional land cover monitoring system for the Hindu Kush Himalaya," 2023. https://servir.icimod.org/science-applications/regional-land-cover-monitoring-system-for-the-hindu-kush-himalaya/
[40] C. P. Acharya and R. León-González, "The quest for quality education: International remittances and rural–urban migration in Nepal," *Migr. Dev.*, vol. 8, no. 2, pp. 119–154, 2019. https://doi.org/10.1080/21632324.2018.1429834
[41] S. Banerjee, J. Y. Gerlitz, and B. Hoermann, "Labour migration as a response strategy to water hazards in the Hindu Kush-Himalayas," *Int. Cent. Integr. Mt. Dev.*, 2011.
[42] "Migration turning hill villages into ghost towns," 2022. https://kathmandupost.com/national/2022/12/02/migration-turning-hill-villages-into-ghost-towns
[43] R. H. Timilsina, G. P. Ojha, P. B. Nepali, and U. Tiwari, "Agriculture land use in Nepal: Prospects and impacts on food security," *J. Agric. For. Univ.*, vol. 3, pp. 1–9, 2019.
[44] "Forest cover may have increased but agricultural land is shrinking," 2022. https://kathmandupost.com/climate-environment/2022/04/25/forest-cover-may-have-increased-but-agricultural-land-is-shrinking#:~:text=Whiletheforestareaof,MinistryofForestsandEnvironment
[45] G. Rasul, "Ecosystem services and agricultural land-use practices: A case study of the Chittagong Hill Tracts of Bangladesh," *Sustain.: Sci. Pract. Policy*, vol. 5, no. 2, pp. 15–27, 2009. https://doi.org/10.1080/15487733.2009.11908032
[46] I. K. Murthy, M. Gupta, S. Tomar, M. Munsi, R. Tiwari, G. T. Hegde, and N. H. Ravindranath, "Carbon sequestration potential of agroforestry systems in India," *J. Earth Sci. Clim. Change*, vol. 4, no. 1, pp. 1–7, 2013.
[47] N. Bhattarai, L. Joshi, B. S. Karky, K. Windhorst, and W. Ning, "Potential synergies for agroforestry and REDD+ in the Hindu Kush Himalaya," *ICIMOD Work. Pap.*, vol. 11, 2016.
[48] R. Sharma, S. K. Chauhan, and A. M. Tripathi, "Carbon sequestration potential in agroforestry system in India: An analysis for carbon project," *Agrofor. Syst.*, vol. 90, pp. 631–644, 2016. https://doi.org/10.1007/s10457-015-9840-8
[49] A. R. Beshir, M. Mahato, F. M. Qamar, and S. Shrestha, "Managing seeds and agricultural losses in the wake of extreme climate events: Lessons from Nepal," *Centro Interncional de Mejoramiento de Maiz y Trigo*, 2022.
[50] H. Azadi, P. Keramati, F. Taheri, P. Rafiaani, D. Teklemariam, K. Gebrehiwot, G. Hosseininia, S. V. Passel, P. Lebailly, and F. Witlox, "Agricultural land conversion: Reviewing drought impacts and coping strategies," *Int. J. Disaster Risk Reduct.*, vol. 31, pp. 184–195, 2018. https://doi.org/10.1016/j.ijdrr.2018.05.003
[51] B. Rachman, E. Ariningsih, T. Sudaryanto, and et al., "Sustainability status, sensitive and key factors for increasing rice production: A case study in West Java, Indonesia," *PLoS ONE*, vol. 17, no. 12, p. e0274689, 2022. https://doi.org/10.1371/journal.pone.0274689
[52] K. C. Bhawana, T. Wang, and P. Gentle, "Internal migration and land use and land cover changes in the middle mountains of Nepal," *Mt. Res. Dev.*, vol. 37, no. 4, pp. 446–455, 2017.
[53] J. Merz, G. Nakarmi, S. K. Shrestha, B. M. Dahal, P. M. Dangol, M. P. Dhakal, B. S. Dongol, S. Sharma, P. B. Shah, and R. Weingartner, "Water: A scarce resource in rural watersheds of Nepal's middle mountains," *Mt. Res. Dev.*, vol. 23, no. 1, pp. 41–49, 2003. https://doi.org/10.1659/0276-4741(2003)023[0041:WASRIR]2.0.CO;2
[54] A. Gurung, S. Adhikari, R. Chauhan, S. Thakuri, S. Nakarmi, S. Ghale, B. S. Dongol, and D. Rijal, "Water crises in a water-rich country: Case studies from rural watersheds of Nepal's mid-hills," *Water Policy*, vol. 21, no. 4, pp. 826–847, 2019. https://doi.org/10.2166/wp.2019.245
[55] S. Shah, N. P. Gautam, B. P. Dhakal, J. N. Sah, and S. C. Sharma, "Impact of land cover dynamics on ecosystem services value of Siwalik Range of Madhesh province Nepal," *Water Policy*, vol. 21, no. 4, pp. 826–847, 2019.

https://doi.org/10.2166/wp.2019.245

[56] S. Barrett, "Local level climate justice? Adaptation finance and vulnerability reduction," *Glob. Environ. Change*, vol. 23, no. 6, pp. 1819–1829, 2013. https://doi.org/10.1016/j.gloenvcha.2013.07.015

[57] M. Skutsch and M. K. McCall, "The role of community forest management in REDD+," *Unasylva*, vol. 63, no. 239, pp. 51–56, 2012.

[58] S. Shrestha, B. S. Karky, and S. Karki, "Case study report: REDD+ pilot project in community forests in three watersheds of Nepal," *Forests*, vol. 5, no. 10, pp. 2425–2439, 2014. https://doi.org/10.3390/f5102425

[59] B. B. K. Chhetri, F. H. Johnsen, M. Konoshima, and A. Yoshimoto, "Community forestry in the hills of Nepal: Determinants of user participation in forest management," *Forest Policy Econ.*, vol. 30, pp. 6–13, 2013. https://doi.org/10.1016/j.forpol.2013.01.010

[60] B. Pokharel, "Changing pattern of forest consumption: A case study from an eastern hill village in Nepal," *Occas. Pap. Sociol. Anthropol.*, vol. 8, pp. 41–58, 2003.

[61] K. Bhandari and B. Paudel, "Analysis of urban infrastructures and facilities in Pakhribas Municipality, Dhankuta, Nepal," *Geogr. Base*, vol. 8, no. 01, pp. 47–62, 2021. https://doi.org/10.3126/tgb.v8i01.43470

[62] "National population and housing census 2021," 2023. https://censusnepal.cbs.gov.np/results

[63] N. Bhattarai, S. Dahal, S. Thapa, S. Pradhananga, B. S. Karky, R. S. Rawat, and R. Avatar, "Forest fire in the Hindu Kush Himalayas: A major challenge for climate action," *J. Forest Livelihood*, vol. 21, no. 1, 2022.

[64] "How much CO2 is stored in 1kg of wood," 2023. https://www.kaltimber.com/blog/2017/6/19/how-much-co2-is-stored-in-1-kg-of-wood#:~:text=Similarlyburningof1kg,emittedmoreduringitsproduction

[65] M. Baqir, R. Kothari, and R. P. Singh, "Fuel wood consumption, and its influence on forest biomass carbon stock and emission of carbon dioxide. A case study of Kahinaur, district Mau, Uttar Pradesh, India," *Biofuels*, vol. 10, no. 1, pp. 145–154, 2019. https://doi.org/10.1080/17597269.2018.1442666

[66] H. M. Desta and C. S. Ambaye, "Determination of energy properties of fuelwood from five selected tree species in tropical highlands of southeast Ethiopia," *J. Energy*, vol. 2020, pp. 1–7, 2020. https://doi.org/10.1155/2020/3635094

[67] J. A. Fuwape and J. C. ONYEKWELU, "Urban forest development in West Africa: Benefits and challenges," *J. Energy*, 2011.

[68] R. P. Chaudhary, Y. Uprety, and S. K. Rimal, "Deforestation in Nepal: Causes, consequences and responses," *Biol. Environ. Hazards, Risks, Disasters*, pp. 335–372, 2016.

[69] R. Gautam, S. Baral, and S. Herat, "Biogas as a sustainable energy source in Nepal: Present status and future challenges," *Renew. Sustain. Energy Rev.*, vol. 13, no. 1, pp. 248–252, 2009. https://doi.org/10.1016/j.rser.2007.07.006

[70] D. Singh, H. Zerriffi, R. Bailis, and V. LeMay, "Forest, farms and fuelwood: Measuring changes in fuelwood collection and consumption behavior from a clean cooking intervention," *Energy Sustain. Dev.*, vol. 61, pp. 196–205, 2021. https://doi.org/10.1016/j.esd.2021.02.002

[71] R. Piedrahita, M. Johnson, K. R. Bilsback, C. L'Orange, J. K. Kodros, S. R. Eilenberg, and J. Volckens, "Comparing regional stove-usage patterns and using those patterns to model indoor air quality impacts," *Indoor Air*, vol. 30, no. 3, pp. 521–533, 2020. https://doi.org/10.1111/ina.12645

[72] P. Satyal, E. Corbera, N. Dawson, H. Dhungana, and G. Maskey, "Justice-related impacts and social differentiation dynamics in Nepal's REDD+ projects," *Forest Policy Econ.*, vol. 117, p. 102203, 2020.

[73] A. Chhatre and A. Agrawal, "Trade-offs and synergies between carbon storage and livelihood benefits from forest commons," *Proc. Natl. Acad. Sci.*, vol. 106, no. 42, pp. 17 667–17 670, 2009.