


Application of Tea Buffer Zones for Prevention of Forest Encroachment and Livelihood Improvement in Forest Reserves: Case Study of Kakamega Forest

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Abstract

Forest encroachment in indigenous natural forests in Kenya has been one of the major contributors to forest deforestation. Kenya lost about 50% of its forest covering about 300,000 hectares between 1980 and 2000 due to extensive logging, charcoal burning, and extensive clearing of forested regions for food crops plantations. Various strategies have been employed to stop and reverse this negative trend, Forest buffer zones using tea crop has been one of the approaches implemented over the years through the Nyayo Tea Zones Development Corporation. This study investigated the effectiveness of the 100-meter tea buffer zones as a management strategy for the prevention of forest encroachment and livelihood improvement in Kakamega forest reserve Kenya. Geographical Information Systems (GIS) was used to map the extent of protection attributed to the tea buffer zones for the period 1985-2022. The household survey and Focus Group Discussions were conducted among 108 forest-adjacent communities to obtain their views on the importance of the tea buffer zones and their perception of forest conservation. The results from GIS indicate that with the introduction of the tea buffer zones, a 0.7% of forest ecosystem recovery was realized between 2005 and 2015 before a decline of 4.9% between 2015 and 2022 mainly due settlement. Socioeconomic results indicate that 30% of the forest adjacent communities were employed on the buffers tea farms, additionally, the communities rated the forest as a very important natural resource (69.7%) as it provided them with key benefits including the source of food and medicine (31.2%), provision of firewood (24.8%), environment conservation (14.7%) and preservation of cultural sites (7.3%). Based on their opinions the communities rated the forest buffer contribution to forest

conservation moderately at 43.1%. These outcomes show a perfect association between forest conservation strategies and livelihood improvement. The decision to place tea buffers along the forest reserves proved to be an effective tool in preventing forest encroachment and improving the livelihoods of the forest-adjacent communities through the provision of alternative income.

Keywords

Forest Condition, Buffer Zone, Conservation, Livelihood and Encroachment

1. Introduction

Forests constitute one of the world's most valuable natural resources and play a pivotal role in maintaining global ecological balance. However, these resources are increasingly degraded and depleted worldwide, with severe consequences for both ecological stability and socioeconomic development. Declining forest cover not only threatens biodiversity but also undermines agricultural sustainability, carbon storage, and national economies (Mawa et al., 2022; Sisay & Gitima, 2020; Torahi & Rai, 2011). Human pressure on forest ecosystems is now greater than ever before (Haq et al., 2023), making global land cover change—particularly forest loss—one of the most pressing concerns in environmental research (Ichami et al., 2020; Torahi & Rai, 2011).

Predicting the future of forests is vital for understanding climate change dynamics, carbon sequestration potential, deforestation trends, and ecosystem services such as water purification and storage. Buffer zones, defined as peripheral areas adjacent to forests, national parks, or reserves where restrictions on resource use or development measures are implemented, have been widely recognized as an effective conservation strategy (Wambui Kariuki, 2012). Because protected areas are often open socioecological systems, buffer zones serve as both bridging and buffering strategies that protect reserves from external threats while offering alternative livelihood options to surrounding communities (Mehring & Stoll-Kleemann, 2011).

Tropical forests, in particular, face intense anthropogenic pressures from communities highly dependent on forest resources for their livelihoods (Maua et al., 2020). Buffer Zone Regimes (BZR) have therefore become an integral component of conservation planning. Studies in Europe and Australia highlight their role in safeguarding reserves with limited open-edge habitats that are otherwise highly vulnerable to degradation (Namasaka, 2021; Saalu et al., 2020). In agricultural landscapes such as the Midwest USA, riparian forest buffers have been crucial in maintaining ecological integrity despite over 85% of land being devoted to row crop agriculture or intensive grazing (Mehring & Stoll-Kleemann, 2011). These challenges are echoed across Africa, where population growth, urban expansion, illicit logging, overgrazing, and recurrent forest fires are accelerating the conversion of green cover to degraded lands.

Forest-adjacent communities often rely heavily on forest resources, with poverty levels in rural areas exacerbating this dependence. Human interference at forest peripheries leads to degradation as communities seek firewood, medicinal plants, timber, fodder, mushrooms, and cultural sites for rituals (Sekhar et al., 2024). As resources diminish, encroachment into core forest areas increases, further reducing forest health and cover. Buffer zones play a key role in reducing such conflicts by redirecting resource dependence, providing alternative livelihood opportunities, and reducing pressure on core reserves (Nyongesa & Vacik, 2019).

In Kenya, forests are central to biodiversity conservation, climate change mitigation, and provision of raw materials (Maua et al., 2020; McWilliam et al., 2012). The Nyayo Tea Zones (NTZ) were introduced as a unique buffer regime around all gazetted forests, designed to reduce encroachment while generating economic benefits. A critical example is Kakamega Forest, the only remnant of the Guineo-Congolian tropical rainforest in Kenya, which is surrounded by NTZ plantations. This forest is ecologically and economically significant, supporting rich biodiversity, particularly endemic bird and butterfly species while also serving as an ecotourism hotspot (Saalu et al., 2020). Despite its importance, Kakamega Forest has faced persistent threats including agricultural expansion, infrastructure development, uncontrolled timber extraction, and livestock grazing. By the early 1990s, forest loss had escalated to an estimated 5000 ha per year (Everlyne et al., 2020; Kamweti et al., 2009), underscoring the urgent need for effective management interventions such as buffer zone regimes.

2. Materials and Methods

2.1. Study Area

Kakamega forest is located in Kakamega East in Kakamega county western Kenya (Figure 1). It lies between latitudes 0° 09' 00" N and 0° 25' 00" N and longitudes 34° 49' E 00", and 34° 57' 00" E at an altitude of about 1500 to 1700m above sea level. Rainfall averages 2000 mm y⁻¹ and daily temperatures range from 11°C to 26°C (Saalu et al., 2020). January-March are the hottest months while April-July receive the most rainfall (Saalu et al., 2020). "Kakamega Forest" is used to refer to both the main forest block (8600 ha) and its two satellite fragments, Nandi North Forest also known as Kurgung (200 ha) and South Nandi Forest also known as Kobujoi (400 ha). The forest has high biodiversity and host indigenous tree species such as *Elgon teak*, *Prunus africanus*, *Croton megalocarpus*, *Albinzia gummifera*, *Bosquie aphoberos*, *Fantuma elastic*, *Annigera altissima*. There is also shrub-land, grassland and cultivated areas. It has a closed canopy and indigenous forest cover 60% of the forest, exotic trees such as eucalyptus have also been planted in the forest. The Forest consists of a wide variety of underlying rocks which include basalt, phenollites and ancient gneiss which are nerved with quartz. The main soil types include Rhodic Ferralsols (well drained, moderately to very deep, clay soils) and Ferralic Cambisols (well drained, moderately deep, loamy clay soils to support

forest plant trees (Ichami et al., 2020).

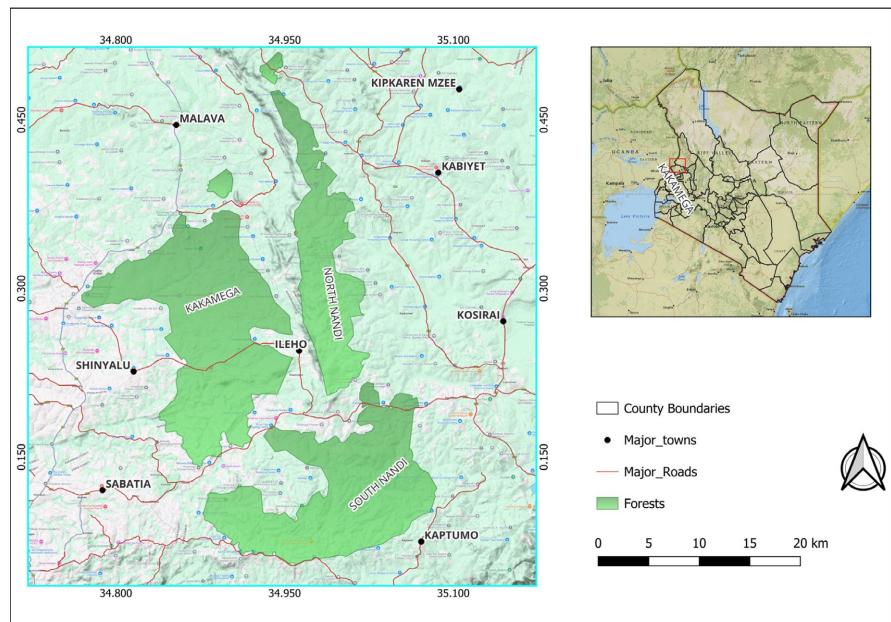


Figure 1. Showing fragments of Kakamega forest.

2.2. Research Design and Sampling

The respondents included people of all age groups bordering forest ecosystem near the Nyayo Tea Zones established. The study targeted the general community groups benefiting from the forest goods and services. Forest resources, rain-fed agriculture and livestock are key to the livelihoods of the majority of Kakamega-Nandi Forest Complex (KNFC) dwellers. The study targeted households living within 6 km from the forest margin, as they are the largest consumers of the forest's resources.

The study employed cross-sectional research design approach with mixed research method, using both qualitative and quantitative techniques. Simple stratified random sampling was used to categorize households. This technique was considered supreme as the target population is heterogeneous and not widely spread out geographically. Relative to simple random sampling, selection of units using a stratified procedure improves representation of particular strata (groups) within the population. Primary data was gathered through structured household questionnaires, focused group discussions (FGDs), key informant interviews (KII), desk research and observations. Generally, the questionnaire administered to household heads captured the socio-economic activities in Kakamega and Nandi areas, knowledge of use of buffer zone regimes to improve forest conditions and main sources of livelihoods. FGDs were organized in both blocks with an average of eight participants in each. FGDs created a forum for interaction and discussions on use of the buffer and how it impacts the forest condition and the communities adjacent to the forests. A considerable sample of 203 was arrived at through Yamane (1967) formula.

2.3. Image Pre-Processing and Classification

Satellite imagery was obtained from the United States Geological Survey (USGS) Earth Explorer platform (<https://earthexplorer.usgs.gov/>). Landsat scenes for the years 1985, 2005, 2015, and 2022 were selected, each comprising seven spectral bands with a spatial resolution of 30 meters for Bands 1 - 5. All images were referenced to the World Geodetic System 1984 (WGS84) datum and projected to the Universal Transverse Mercator (UTM) Zone 37 N. Pre-processing involved geometric and radiometric corrections to ensure consistency across temporal datasets. A supervised multispectral classification was subsequently performed using ArcGIS 10.5 to distinguish six land-use/land-cover (LULC) categories. The classification employed the Maximum Likelihood Classifier (MLC) algorithm, which assumes normal distribution of class signatures and calculates the probability of each pixel belonging to a specific class. Accuracy assessment was carried out by constructing error matrices from reference data. From these, overall accuracy, user's accuracy, and producer's accuracy were derived to evaluate classification reliability. In addition, the Kappa statistic was calculated to measure classification performance beyond chance agreement, as it incorporates off-diagonal elements of the error matrix representing misclassification.

3. Results and Discussions

3.1. Demographics of the Population

The majority of the household heads in households adjacent to Kakamega forest, at least 75% were farmers by occupation (**Table 1**). Only 11.9% were semi-skilled workers. This indicates they are heavily dependent on the forest for livelihood support; the major being through Plantation Establishment for Livelihood Improvement Scheme (PELIS) and also the need for forest to provide resources for staking on the farmlands. The data show that farming is the dominant occupation among household heads in both South Nandi (Kurgung) and North Nandi (Kobujoi). In South Nandi, an overwhelming majority (92.3%) of respondents are farmers, compared to 59.6% in North Nandi. When combined, three-quarters (75.2%) of all households in the study area rely on farming as their main livelihood (**Table 1**).

Table 1. Occupation of household main respondents/head residing near Nyayo Tea Zones.

Variable	Categories	Forest blocks					
		South Nandi (Kurgung)		North Nandi (Kobujoi)		Subtotal	
		Number of respondents	Percent (%)	Number of respondents	Percent (%)	Number of respondents	Percent (%)
Distance of household from forest edge	Less than 1 km	34	65.4	18	31.6	52	47.7
	Between 1 - 4 km	18	34.6	35	61.4	53	48.6
	5 km and above	0	0.0	4	7.0	4	3.7

Other occupations are less common. Business activities account for 5.5% overall, though they are more prevalent in North Nandi (8.8%) than in South Nandi (1.9%). Semi-skilled work is absent in South Nandi but makes up a significant share (22.8%) in North Nandi, suggesting more occupational diversity there. Skilled work is relatively low in both areas, with 3.8% in South Nandi and 7.0% in North Nandi. The “Others” category is minimal (1.8% overall).

The findings indicate that agriculture remains the backbone of household livelihoods, especially in South Nandi, where dependency is nearly exclusive. In contrast, North Nandi exhibits a more diverse occupational structure, with notable proportions of semi-skilled and skilled workers, and more engagement in business. This variation may reflect differences in proximity to markets, education levels, or access to non-farm employment opportunities.

Most households in South Nandi (Kurgung) live very close to the forest, with about two-thirds (65.4%) residing within 1 km of the edge. In contrast, in North Nandi (Kobujoi), the majority (61.4%) are located between 1 - 4 km from the forest, and only a small proportion (7%) live more than 5 km away (Table 2). Overall, nearly half of the households (47.7%) live within 1 km of the forest, another 48.6% are 1 - 4 km away, and only 3.7% live beyond 5 km. This indicates that households in South Nandi are generally closer to the forest, suggesting higher direct dependence and pressure on forest resources compared to those in North Nandi. Migration patterns show that most settlers arrived between 1981 and 2000, primarily from neighboring western counties, coinciding with the establishment of Nyayo Tea Zones.

Table 2. Distance of households from the Nyayo Tea Zones.

Household head main occupation	Forest blocks					
	South Nandi (Kurgung)		North Nandi (Kobujoi)		Total	
	Number of respondents	Percent (%)	Number of respondents	Percent (%)	Number of respondents	Percent (%)
Farmer	48	92.3	34	59.6	82	75.2
Business	1	1.9	5	8.8	6	5.5
Semi-skilled worker	0	0.0	13	22.8	13	11.9
Skilled worker	2	3.8	4	7.0	6	5.5
Others	1	1.9	1	1.8	2	1.8

3.2. Analysis of Change Patterns

The forest cover has decreased from 26,467 ha in 1995 to currently 22,720 ha in 2022 as estimated from Landsat classification method. In the year 2015 there was a slight increase in the forest cover from 2005 while Nyayo tea zone buffers has decreased from the original size of 1593 ha in 2005 to the current state in the year 2022 of 655 ha within the two forest blocks covered of Nandi North and Nandi South.

The analysis of land cover changes between 1985 and 2022 reveals significant transformations in the landscape. Between 2005 and 2022, forest cover showed mixed recovery trends but did not return to 1985 levels. In 2005, forest area stood at 23,724 ha, increasing slightly to 23,887 ha by 2015. This modest gain of 163 ha (0.7%) over a decade suggests localized reforestation, natural regeneration, or stricter forest protection during that period. However, after 2015 the trend reversed, with forest area declining again to 22,720 ha in 2022, representing a net loss of 1167 ha (4.9%) in just seven years. Overall, from 2005 to 2022, forests declined by 1004 ha (4.2%), meaning that the recovery observed between 2005 and 2015 was short-lived and insufficient to offset subsequent losses (**Table 3**). This indicates that while there may have been positive interventions such as afforestation programs or improved management in the early 2010s, these gains were eroded by renewed pressures such as agricultural expansion, settlement growth (which rose sharply after 2015), and possible illegal logging.

Table 3. Summary of Landsat classification area statistics 1985, 2005, 2015 and 2022.

Categories	Years classification			
	2022	2015	2005	1985
Forest	22,720	23,887	23,724	26,467
Grass	2974	2546	4507	1050
Tea zone	655	588	1593	–
Settlements	1413	151	–	–
Fallow	2840	3374	816	2985
Water	175	231	137	275
Total	30,777	30,777	30,777	30,777

Grasslands expanded markedly from 1050 ha in 1985 to 4507 ha in 2005, before declining to 2546 ha in 2015 and slightly recovering to 2974 ha in 2022. This fluctuation suggests cycles of forest clearing, temporary grass cover, and subsequent conversion to other land uses. Similarly, fallow land showed dynamic changes, decreasing sharply from 2985 ha in 1985 to 816 ha in 2005, but later increasing again to 2840 ha by 2022, an indication of shifting cultivation and land abandonment. The tea zone, which was absent in 1985, expanded rapidly to 1593 ha by 2005, but then declined to 655 ha in 2022. This reflects both the expansion of commercial agriculture and its later displacement by settlements or other land uses. Settlements emerged only after 2005, expanding dramatically from 151 ha in 2015 to 1413 ha in 2022. This rapid growth highlights population increase, urbanization, and rising demand for land for both agriculture and infrastructure. Water bodies, on the other hand, decreased from 275 ha in 1985 to 175 ha in 2022, a decline of 36% (Mitchell et al., 2006). Although there were minor recoveries in some years, the overall trend points to environmental stress likely linked to deforestation, climate variability, and watershed degradation (Langat et al., 2021).

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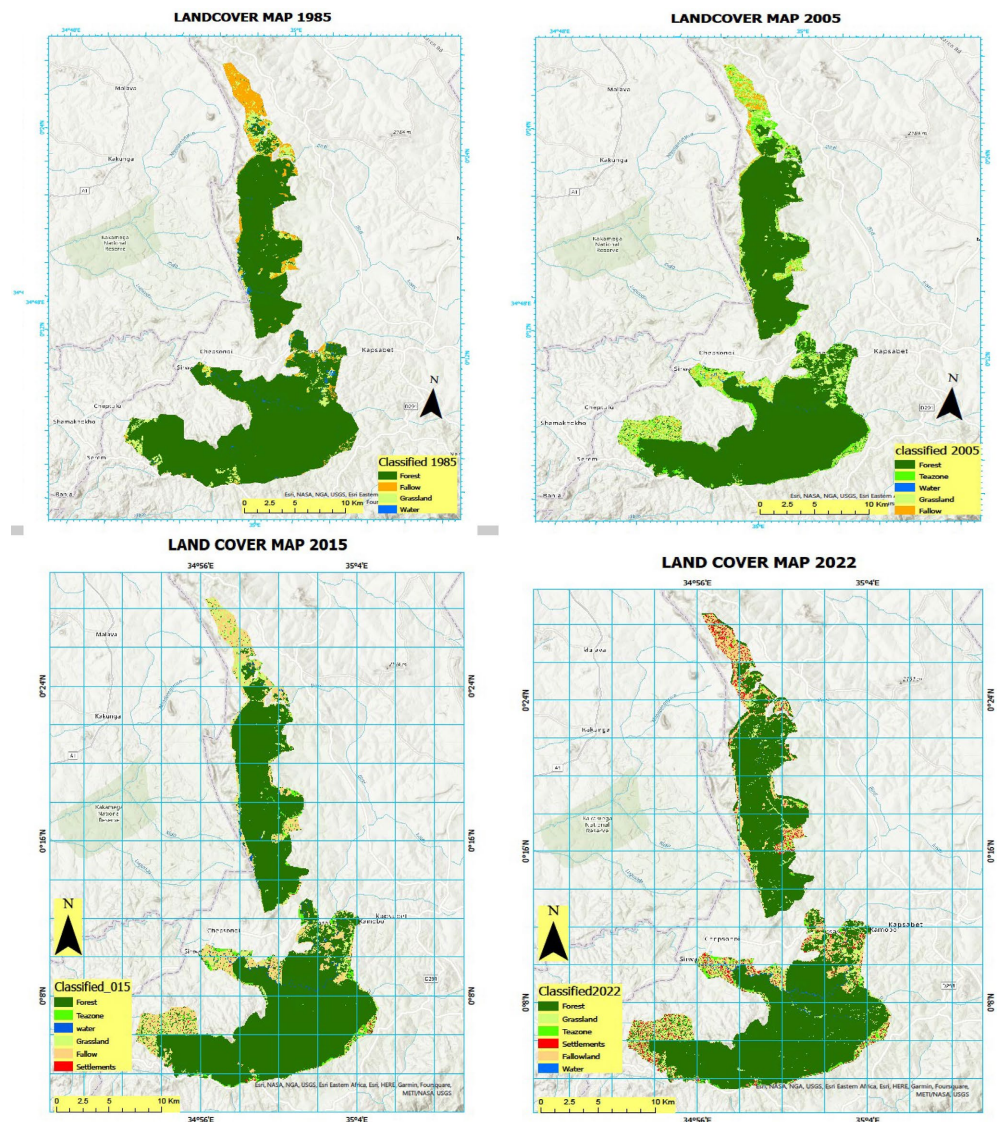


Figure 2. Land-use/cover change Nyayo Tea Zones next to the Forest: 1985-2005-2015 and 2022.

3.3. The Impact of Buffer on Households and Forest Conservation

The forest plays a central role in supporting household livelihoods, serving as the primary source of essential goods and ecosystem services. Residents reported that the forest provides food and medicine (31.2%), timber and firewood (24.8%), rainfall regulation (22.0%), environmental conservation (14.7%), and preservation of cultural sites (7.3%). In terms of perceived importance, the majority of households rated the forest as important (69.7%), with 12.8% considering it most important, 12.8% somewhat important, and only 4.6% classifying it as least important. This distribution highlights the forest's high value in both ecological and socio-economic dimensions.

A comparison of resource use between 2012 and 2022 shows significant changes in extraction patterns. The proportion of households extracting firewood increased from 37.6% to 47.7%, while grass collection rose from 13.8% to 24.8%. In contrast, extraction of timber declined sharply from 20.2% in 2012 to only 2.8% in 2022, suggesting reduced logging pressure, possibly due to conservation measures, stricter regulations, or availability of alternatives. The collection of poles and fittos also dropped from 13.8% to 7.3%, while extraction of grass more than doubled from 13.8% to 24.8%, reflecting growing demand for livestock fodder (Table 4). Similarly, extraction of fruits and medicinal plants rose from 7.3% to 11.0%, and food items such as mushrooms increased modestly from 2.8% to 4.6%, highlighting the role of forests in supporting household nutrition and traditional healthcare (Ojunga et al., 2023, Osewe et al., 2025). Resources classified as others declined slightly from 4.6% to 1.8%. These shifts indicate a transition from extractive timber-based uses toward diversified subsistence resources, aligning with changing household needs and broader conservation goals.

Table 4. Proportion of Households extracting and consuming forest resources in 2012-2022.

Forest resources	Extraction trend in 2022		Extraction trend in 2012	
	Number of respondents	Percent (%)	Number of respondents	Percent (%)
Firewood	52	47.7	41	37.6
Poles and fittos	8	7.3	15	13.8
Timber	3	2.8	22	20.2
Grass	27	24.8	15	13.8
Fruits and medicine	12	11.0	8	7.3
Food and mushroom	5	4.6	3	2.8
Others	2	1.8	5	4.6

The establishment of the Nyayo Tea buffer zone has been instrumental in reducing pressure on the forest. By providing alternative livelihood options and creating a physical barrier against encroachment, the buffer zone has contributed to a decline in logging activities. Moreover, community attitudes toward forest con-

ervation have become increasingly positive, with residents recognizing the broader benefits of sustainable forest management. In addition to firewood and poles, households now derive value from honey, mushrooms, herbs, and other non-timber products, reinforcing their commitment to forest stewardship.

3.4. Contribution of Nyayo Tea Buffer to Livelihood Improvement

The establishment of Nyayo Tea Zones emerged as a significant source of employment for local households, thereby reducing direct dependence on forest resources. Survey results indicated that 47.7% of respondents acknowledged deriving benefits from the tea zones, primarily through alternative employment opportunities such as tea picking, weeding, and other manual tasks facilitated by tea factories. Overall, 24.8% of households reported active engagement in tea-related activities, highlighting the role of tea zones in providing supplementary income and mitigating forest over-exploitation (Figure 3).

Despite these opportunities, the majority of residents (73.4%) remained without any formal income-generating activities, underscoring persistent socio-economic vulnerability in the area. A small proportion of respondents, at 0.9% were engaged in managerial roles within Nyayo Tea Zones and affiliated factories, while another 0.9% pursued income from other minor sources. These findings emphasize both the contribution of tea zones to local livelihoods and the continued need for diversified and sustainable economic alternatives to strengthen community resilience.

3.5. Effects of Buffer on Forest Condition Improvement

Nyayo Tea Buffer Zones have generated multiple conservation benefits. The most significant is improved forest condition (35.8%), followed by increased rainfall regulation (20.2%) and biodiversity preservation (15.6%). Other important contributions include soil erosion control (11%), reduced air pollution (10.1%), and climate change mitigation (7.3%) (Figure 4). Overall, tea buffer zones serve as an effective boundary management strategy that protects forests from encroachment while enhancing ecological services. The strongest impacts are seen in forest recovery and microclimate regulation, while biodiversity, climate, and soil benefits provide long-term sustainability gains.

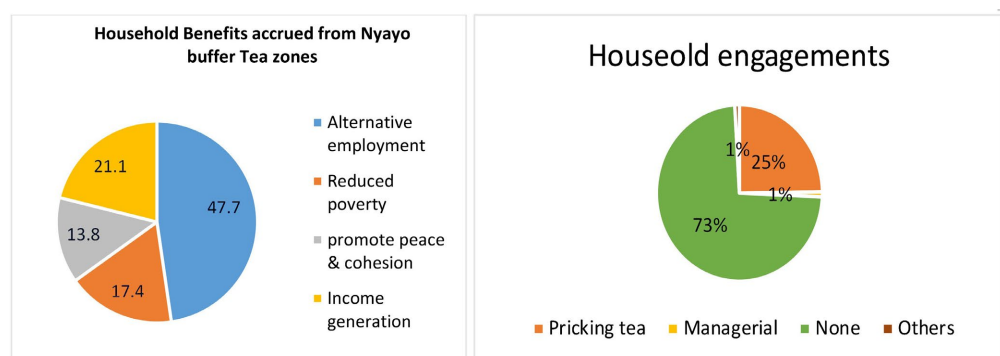


Figure 3. Benefits accrued and the engagements by household from Nyayo Tea Zones.

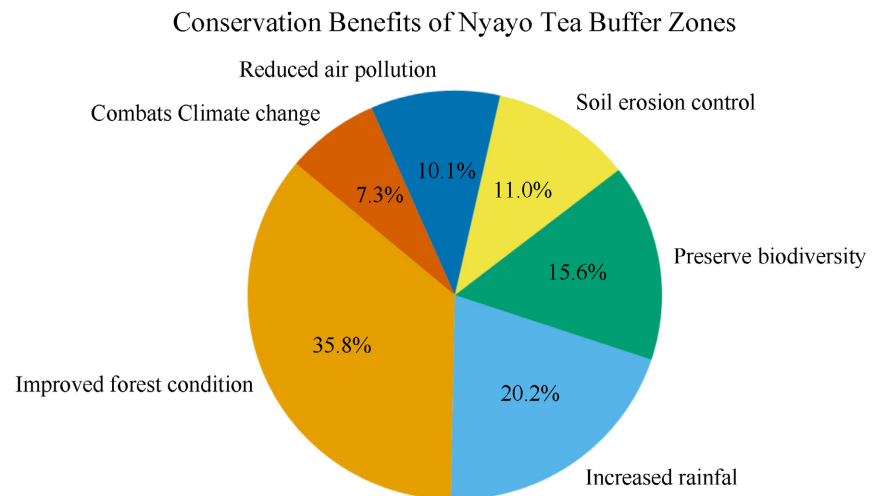


Figure 4. Benefits accrued from the conservation of the forest.

Buffer zones, particularly those employing agroforestry or vegetated systems, have consistently shown strong positive impacts on forest condition. In this study, 35.8% of respondents reported noticeable improvements in forest condition attributed to buffer zones, citing enhanced species diversity and ecosystem restoration. These localized findings are mirrored in broader research: [Namasaka, \(2021\)](#) demonstrated a robust positive relationship between tea buffer zone (NTZ) area and tree species richness in Kakamega Forest ($R^2 = 0.93$, $p < 0.001$), as well as tree density ($R^2 = 0.95$), indicating reduced erosion, runoff, and disturbance in buffer areas.

Agroforestry-based buffers also contribute significantly to biodiversity conservation. [Wekesa et al. \(2019\)](#) reported that in the Taita Hills of Kenya, adjacent cash crop buffer zones exhibited elevated plant biomass and tree species richness. These results align with global findings: agroforestry systems inherently support greater biodiversity than monocrop environments (e.g., alley cropping and silvopastoral enhance microclimate, soil properties, and habitat complexity).

Beyond biodiversity, buffer zones play vital ecological roles by mitigating edge effects and maintaining microclimates. Riparian buffers, for instance, are recognized for preserving stream ecosystems via shading and nutrient retention. Tropical reserves with intact buffer areas have been found less prone to deforestation than their peripheries, suggesting buffers reduce forest leakage and help maintain landscape connectivity.

Together, these studies substantiate the buffered tea zones' contributions to both the ecological resilience through increased species richness and forest regeneration. Moreover the socioeconomic resilience is realized through it offering livelihoods that directly reduce pressure on core forest reserves.

4. Conclusion and Recommendations

Based on these insights, this study recommends the urgent reinstatement and expansion of Nyayo Tea buffer zones in degraded forest peripheries. The recent de-

cline in buffer coverage poses a significant risk to both forest integrity and community livelihoods. Expanding these buffer areas will help re-establish physical and functional barriers against encroachment while offering reliable livelihood alternatives to forest-adjacent populations.

In addition, it is advisable to integrate indigenous tree species within and alongside tea plantations. Indigenous trees not only enhance ecological diversity but also provide culturally significant resources, including medicinal plants, wild fruits, and timber species valued by local communities. A mixed-species buffer system would therefore increase biodiversity, strengthen ecosystem services, and reflect local ecological knowledge systems, thereby reinforcing community support for conservation efforts.

The study also advocates for the development and operationalization of comprehensive Corporate Social Responsibility (CSR) frameworks within Nyayo Tea buffer programs and affiliated enterprises. At present, the benefits derived by local communities are largely limited to employment opportunities, which, while valuable, remain insufficient to address broader social development needs. A robust CSR framework should prioritize access to education, healthcare, water infrastructure, and livelihood diversification projects such as beekeeping, eco-tourism, and tree nursery enterprises. Embedding such social welfare initiatives within conservation programs will secure sustained community participation and cooperation in forest management.

Furthermore, integrating these social investments into the buffer zone strategy would enhance the socio-economic resilience of forest-adjacent communities and reduce illegal forest exploitation driven by poverty and marginalization. The study also recommends scaling up participatory forest management approaches to strengthen local stewardship and ensure inclusive decision-making in the management of forest reserves and buffer zones. Active community involvement in forest governance promotes a sense of ownership and responsibility towards resource protection.

Finally, future research should focus on assessing the long-term socio-economic impacts of buffer zones on household welfare, as well as evaluating the comparative effectiveness of different buffer regimes such as exotic plantations, indigenous forests, and agroforestry systems. Quantifying the ecosystem services generated by buffer-protected forests would provide evidence-based insights to guide policymakers and conservation planners on the most efficient, equitable, and sustainable models for forest conservation.

These combined efforts will not only safeguard critical ecosystems such as Kakamega Forest but also provide a scalable and replicable model for integrated forest conservation and community development in Kenya and other tropical regions facing similar pressures.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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