Biomass Loss and Atmospheric Carbon Emissions from Habitat Conversion in Kahe Forest Reserve, Northern Tanzania

Abstract

This study provides an in-depth analysis of the biomass loss and atmospheric carbon emissions resulting from habitat conversion in Kahe Forest Reserve (KFR), Northern Tanzania, over a 20-year period from 2003 to 2023. Employing the NAFORMA methodology and geospatial analysis, the research quantifies the ecological and economic impacts associated with these changes. The findings indicate a significant biomass loss of approximately 23,019.6 tonnes, alongside carbon emissions totaling 10,819.2 tonnes. The study also estimates a carbon dioxide emission of 39,706.46 tonnes and highlights a corresponding carbon trade loss valued at US$ 158,825.83. These figures underscore the critical environmental challenges facing KFR, exacerbated by a 141.4% increase in the human population in surrounding districts from 1967 to 2022. This demographic surge has intensified the pressure on the Reserve, leading to illegal agricultural encroachment despite existing regulations designed to protect the forest. The study reveals that this encroachment not only threatens the ecological integrity of KFR but also severely hampers its carbon sequestration potential, contributing to habitat degradation and biodiversity loss. In light of these findings, the study calls for urgent action from the government and stakeholders. Key recommendations include strengthening policy enforcement, enhancing community engagement and education, promoting sustainable agricultural practices outside the Reserve, initiating restoration efforts, and integrating KFR into global carbon markets to mitigate further environmental and economic losses. These measures are essential to preserving the Reserve's ecological functions and ensuring the long-term sustainability of the region's natural resources.

Key words: Biomass loss, Carbon emission, Carbon dioxide emission, Carbon trade loss

1. Introduction

The rapid degradation of biodiversity and ecosystem services is a pressing global issue, driven by habitat loss, fragmentation, pollution, overexploitation, and the proliferation of invasive alien species. These threats, compounded by accelerated climate change, jeopardize flora and fauna and disrupt natural systems essential to human welfare. Climate change manifests through increased atmospheric carbon dioxide, rising land and ocean temperatures, altered precipitation patterns, and sea-level rise, all significantly impacting both ecosystems and human communities (World Bank, 2023; UNEP, 2023). Likewise, global warming and climate change have already caused

observable effects on natural ecosystems and species worldwide, altering their distribution, behavior, and reproductive patterns. In Sub-Saharan Africa, these changes have led to species extinctions and significant disruptions in migration patterns and ecosystem dynamics (Araujo et al., 2022; Fordham et al., 2023). The region's ecosystems are particularly vulnerable to climate change, which exacerbates the ongoing degradation caused by unsustainable exploitation of natural resources. Degraded ecosystems create niches for invasive species, further exacerbating ecosystem change and degradation. Historically, natural factors such as shifts in the earth's orbit, ocean circulation, volcanic activity, and solar intensity have driven climate change. However, the current crisis is primarily driven by human activities, including the burning of fossil fuels, deforestation, and land development for agriculture and urbanization (IPCC, 2023).

Protected areas (PAs) are crucial for conserving biodiversity and ecosystem services, acting as refuges for indigenous species and functioning as carbon sinks that contribute to climate change mitigation. However, the effectiveness of these areas is challenged by climate change, necessitating new conservation strategies to maintain ecological connectivity and enable species migration in response to shifting climatic conditions (Williams et al., 2023; Heller & Zavaleta, 2023). A significant research gap exists in assessing biomass loss and carbon emissions resulting from habitat conversion in PAs. Kahe Forest Reserve (KFR) in Northern Tanzania faces significant pressure from human activities. The conversion of forest habitats to agricultural land leads to substantial biomass loss and carbon emissions, threatening the reserve's integrity.

Addressing climate change requires both mitigation and adaptation. Mitigation involves reducing greenhouse gas emissions through energy efficiency, renewable energy sources, and sustainable land use practices. Adaptation involves adjusting to inevitable climate changes, including planning for more severe weather and ensuring wildlife population resilience (Milad et al., 2022; Munishi, 2023). Unsustainable resource use by adjacent communities poses a significant challenge, necessitating urgent measures to estimate biomass loss and carbon emissions from habitat conversion in KFR. This information is crucial for developing sustainable management strategies to preserve the reserve's ecological integrity.Thus, understanding the extent of biomass loss and carbon emissions due to habitat conversion in KFR is critical for effective conservation and climate change mitigation. This paper aims to fill the gap by providing accurate estimates and insights into the ecological and economic impacts of habitat conversion. The findings will inform policy and conservation efforts, promoting sustainable land use and enhancing the resilience of KFR's ecosystems in the face of climate change.

2. Methods

2.1 Description of the study area

Kahe Forest Reserve is situated in the Moshi Rural District of the Kilimanjaro Region in northern Tanzania, geographically positioned between latitudes 3°15' and 3°20' south and longitudes 37°15' and 37°30' east. The reserve is located at an elevation of 1000-1200 meters above sea level, bordered by Hai District to the north, Same District to the south, Moshi Urban District to the west, and Kenya to the east (Mndeme, 2016). The region receives an annual rainfall of 700 to 900 mm, and the average temperature hovers around 30°C, which significantly influences the forest's diverse flora and fauna and its carbon sequestration potential (Mndeme, 2016).

Local communities, including the villages of Oria, Mwangaria, Mawala, and Ngasinyi, heavily rely on the forest for firewood, leading to notable levels of forest degradation (URT, 2003). Addressing these socio-economic pressures is crucial for sustainable forest management and enhancing carbon sequestration. As part of the Eastern Arc Mountains, Kahe Forest Reserve is recognized as a biodiversity hotspot, characterized by high levels of species endemism and ecological significance (WWF, 2023). The forest supports a variety of tree species and complex ecological interactions, making it an ideal site for studying carbon dynamics and understanding the role of tropical forests in climate change mitigation.

This study aims to quantify the biomass loss, carbon emission, and sequestration potential of Kahe Forest Reserve for the period 2003 - 2023, providing critical data for developing effective forest management strategies. The research supports broader conservation efforts and aligns with international climate goals aimed at reducing atmospheric carbon levels (IPCC, 2023; UNEP, 2023). Understanding these dynamics is essential for promoting sustainable land use and enhancing the resilience of Kahe Forest Reserve's ecosystems in the face of climate change.

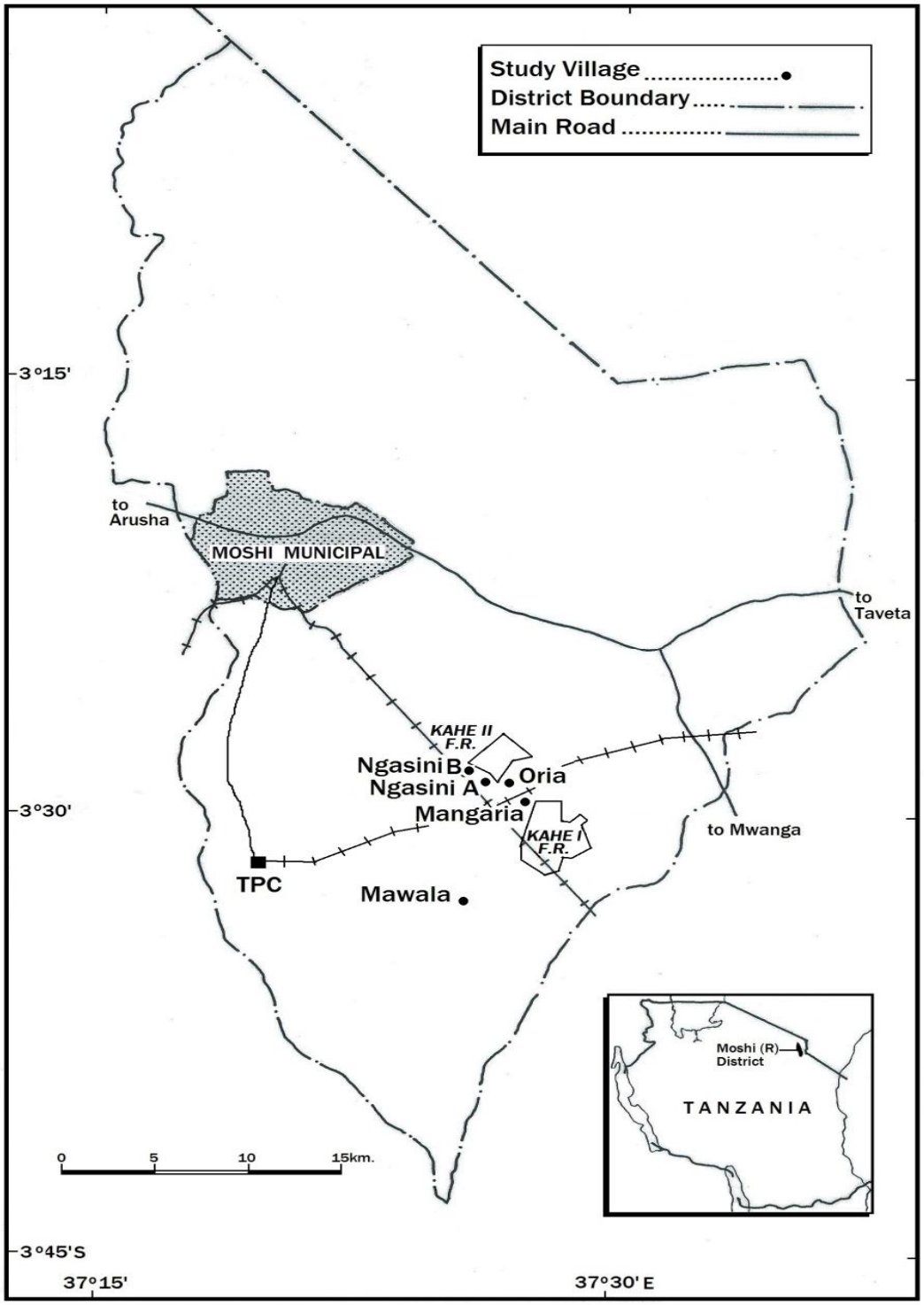

Figure 1: Moshi (Rural) District showing the study area

2.2 Data sets

2.2.1 Spatial data

The study analyzed losses in biomass, carbon, and sequestration potential in Kahe Forest Reserve for the period 2003 - 2023 using various spatial data sets. Key to this analysis were satellite images from the United States Geological Surveys (USGS-GLOVIS) and Earth Explorer, crucial for mapping land-use changes, assessing forest conditions, and updating forest maps (USGS, 2023). To detect land-use changes, Landsat images from 2003 and RapidEye images from 2023 were used, sourced from Tanzania's Department of Urban Planning and downloaded via the Earth Resources Observation and Science (EROS) Center. This comprehensive geospatial analysis provided insights into land-use changes (LULC) over two decades, impacting forest dynamics (EROS, 2023; DoSUP, 2022). Area statistics for LULC change are shown in Table 1 and Figures 2& 3.

Table 1: Area statistics for LULC change(ha) in KFR for the period 2003 - 2023

LULC	Forest	Bushland	Grassland	Woodland	Cultivated land
2003 - 2023	326(-38)	-86 (9)	-136 (14)	-35 (4)	-69 (7)

Figure 2: LULCmap for KFR, 2003

Figure 3: LULCmap for KFR, 2023

2.2.2 Socio-Economic and population data

The study also incorporated socio-economic and population data to assess the impact of human activities on land use change and resource consumption. Population data from the 2022 census, obtained from the National Bureau of Statistics, were crucial for understanding demographic trends and their link to forest degradation and deforestation. This information was essential for correlating population pressures with land use and forest cover changes, providing a comprehensive view of the socio-economic drivers of environmental change in Kahe Forest Reserve (NBS, 2023).

2.2.3 Geospatial analysis tools

The integration of diverse data sets was facilitated through advanced geospatial analysis tools. Geographic Information System (GIS) software processed and analyzed

spatial data, enabling the creation of detailed land-use and forest type maps. These tools allowed visualization of land-use changes over time and identification of areas most affected by deforestation and degradation. By combining spatial and socio-economic data, the study provided a holistic understanding of the factors influencing forest dynamics and carbon sequestration potential (GIS Software, 2023).

Utilizing varied and comprehensive data sets, including satellite imagery, population statistics, and socio-economic data, enabled a robust analysis of biomass loss, carbon emission, and sequestration potential in Kahe Forest Reserve from 2003 to 2023. This integrated approach is crucial for developing effective conservation strategies and sustainable land-use plans that enhance the forest's role in carbon sequestration and climate change mitigation.

2.3 Data analysis

2.3.1 Biomass loss of Kahe Forest Reserve (2003 – 2023)

The estimation of biomass loss in the Kahe Forest Reserve (KFR) involves calculating living biomass, divided into above-ground biomass (AGB) and below-ground biomass (BGB), along with dead wood (DW) biomass. These components collectively offer a comprehensive understanding of the forest's carbon emission and carbon sequestration potential. AGB includes the total biomass of living trees above the soil, such as stems, branches, and leaves. The AGB estimation in KFR follows the United Republic of Tanzania (URT) methodology from 2015, part of the National Forest Resources Monitoring and Assessment (NAFORMA) framework. The formula used is:

AGB (tonnes / ha) = Tree stem volume (m^3 / ha) * wood density / 1000

Tree stem volume is measured in cubic meters per hectare (m^3 / ha), and wood density is specific to each tree species, ensuring accurate AGB estimation (URT, 2015; Liu et al., 2023). Below-ground biomass, including tree roots, is estimated as a fraction of AGB using a default root-to-shoot ratio of 0.25, or specific ratios if available. The formula is:

BGB (tonnes / ha) = AGB * 0.25 (as default), or root to shoot ratios.

This standardized approach provides a complete assessment of the forest's carbon stock (FAO, 2023; Brown et al., 2023). Dead wood biomass includes standing dead trees and fallen wood. Estimating DW involves measuring the volume of dead wood and converting it into biomass using density factors. The Smalian formula is applied for irregularly shaped logs:

$V = 0.5L\ (A_1 + A_2)$

Where; V is the volume of the log, L is the length of the log, and A_1 &A_2 are the cross-sectional areas at the two ends of the log

This computed volume is then multiplied by the wood density to estimate the biomass. For KFR, the wood density used is 619 kg/m³, a value based on regional averages and studies (IPCC, 2023; Chidumayo, 2012, as cited by URT, 2015).

DW (tonnes/ha) = V × Wood Density

The 2015 NAFORMA report by the URT highlights the relatively low deadwood biomass in Tanzanian forests, primarily due to extensive collection for fuel in accessible areas like woodlands (URT, 2015). In contrast, waterlogged regions have higher deadwood levels due to less accessibility and slower decay, enhancing long-term carbon storage. The report underscores the importance of environmental conditions in estimating carbon stocks. NAFORMA provides standardized methods and conversion factors for accurate biomass estimation across Tanzanian ecosystems, detailed in Tables 2 (URT, 2015), crucial for understanding forest roles in carbon sequestration and effective management strategies.

Table 2: Living tree stemwood and dead wood biomass by primary vegetation type

Vegetation type	Forest	Bushland	Grassland	Woodland	Cultivated land
AGB(t/ha)	59.5	11	2.9	27.7	5.9
BGB (t/ha)	18.2	4.4	1.1	9.5	2.1
DWB(t/ha)	5.09	0.77	0.36	1.89	0.96

2.3.2 Carbon emission of Kahe Forest Reserve (2003-2023)

Estimating carbon emissions is crucial for understanding Kahe Forest Reserve's (KFR) role in carbon sequestration and climate change mitigation. Carbon emissions in terrestrial ecosystems are derived from biomass measurements, applying a conversion factor to estimate carbon in both living and dead organic matter. The United Republic of Tanzania (URT, 2015) specifies the formula:

Carbon (tonnes)=Biomass (tonnes)×0.47

This factor indicates that 47% of dry biomass weight is carbon, a widely accepted method in forest carbon assessments (Liu et al., 2023; IPCC, 2023). For living tree biomass, both above-ground (AGB) and below-ground biomass (BGB) are considered, yielding above-ground carbon (AGC) and below-ground carbon (BGC). Deadwood biomass (DWB) uses the same factor to estimate deadwood carbon (DWC). Total carbon is calculated as:

Total C (tonnes) =AGC (tonnes) +BGC (tonnes) +DWC (tonnes)

These calculations as shown in Table 3 offer comprehensive carbon stock estimates in KFR, aiding forest management and conservation strategies. Understanding carbon

storage helps formulate policies to enhance carbon sequestration and develop sustainable land-use plans, mitigating climate change impacts and promoting forest ecosystem resilience (UNEP, 2023; FAO, 2023).

Table 3: Living tree stemwood (Aboveground + Belowground) and dead wood carbon

Vegetation type	Forest	Bushland	Grassland	Water	Wetland	Bare soil
AGC(t/ha)	27.97	5.17	1.36	13.02	2.77	27.97
BGC(t/ha)	8.55	2.07	0.52	4.47	0.99	8.55
DWC(t/ha)	2.39	0.36	0.17	0.64	0.64	0.11

2.3.3 Carbon dioxide (CO_2) emissionfrom Kahe Forest Reserve (203 -2023)

Estimating the carbon dioxide (CO□) emitted from Kahe Forest Reserve (KFR) involves converting total carbon emitted into CO□ equivalents, crucial for understanding its climate mitigation role. The Intergovernmental Panel on Climate Change (IPCC) provides guidelines for this conversion, using a factor of 3.67, representing the molecular weight ratio of CO□ to carbon (IPCC, 2006; IPCC, 2023). The formula is:

CO□ (tonnes)= Carbon (tonnes)×3.67

Applying this to the estimated carbon stocks of living and dead biomass in KFR gives the CO□ sequestration potential:

Total CO□ (tonnes) =AGCO□ (tonnes) +BGCO□ (tonnes) +DWCO□ (tonnes)

This comprehensive estimate highlights KFR's capacity to sequester CO□, emphasizing its significance in climate change mitigation. Converting carbon stocks into CO□ equivalents quantifies the forest's potential, aiding in effective conservation and management strategies to enhance its role as a carbon sink. The findings underscore the importance of preserving and expanding forests to combat climate change (UNEP, 2023; FAO, 2023).

2.3.4 Carbon trade loss of Kahe Forest Reserve (2003 -2023)

Estimating the loss of potential carbon trading for Kahe Forest Reserve (KFR) involves calculating the economic value of the sequestered carbon. Following Jenkins (2014) and Lobora et al. (2017), the study uses standard carbon market prices, approximately US$ 4 per ton of CO□ (World Bank, 2023). The total CO□ sequestered is calculated by converting the carbon stock into CO□ equivalents using the IPCC conversion factor of 3.67 (IPCC, 2006). The formula for potential loss is:

Carbon Trade Profit (US$)} = Total CO□ (tonnes) x Carbon Price (US$ 4 / ton)

3. Results and Discussions

3.1 Biomass loss of Kahe Forest Reserve for the period 2003 - 2023

The analysis of biomass loss in Kahe Forest Reserve (KFR) over the two-decade period from 2003 to 2023 reveals significant changes in the reserve's ecological structure. As indicated in Table 4, KFR experienced a total biomass loss of 23,019.6 tonnes during this period. The loss was primarily attributed to forested areas, which accounted for 117.2% of the total biomass loss. This high percentage indicates that deforestation and degradation of forested areas have had a profound impact on the reserve's overall biomass.In contrast, other vegetation types within the reserve demonstrated a biomass gain of 17.2%. This gain suggests that certain areas within the reserve, likely those less disturbed or undergoing natural succession, have seen some recovery or resilience. However, it is essential to note that this gain does not compensate for the extensive loss observed in forested areas, which are crucial for maintaining the ecological balance and carbon sequestration potential of the reserve.

Despite the existing policies, laws, guidelines, and regulations that strictly prohibit agricultural activities within forest reserves in Tanzania, the findings indicate an alarming increase in cultivated land within KFR. The encroachment by adjacent communities, who have expanded agricultural activities into the reserve, has contributed to the observed changes in biomass. This illegal encroachment has led to plant succession in previously forested areas, where agricultural land has now become vegetated, contributing to the marginal biomass gain.The continued encroachment and agricultural expansion within KFR highlight a critical gap in the enforcement of conservation policies. The failure to adequately protect the reserve from such activities undermines the integrity of the forest ecosystem and threatens its ability to function as a vital carbon sink. The situation calls for immediate and stringent action to safeguard the remaining forested areas and to enforce existing regulations more effectively. Strengthening the governance of forest reserves and involving local communities in conservation efforts are essential steps to curbing further biomass loss and ensuring the long-term sustainability of KFR.These findings underscore the urgent need for comprehensive conservation strategies that not only protect the existing forest cover but also promote the restoration of degraded areas. Such efforts are vital to maintaining the ecological health of Kahe Forest Reserve and enhancing its role in climate change mitigation through carbon sequestration (Kiwelu, 2024; URT, 2023).

Table 4: Biomass loss (tonnes) of Kahe Forest Reserve for the period 2003 - 2023

Vegetation type	Forest	Bushland	Grassland	Woodland	Cultivated land	Total
AGB (t)	9,397.0	(946.0)	(394.4)	(969.5)	(407.1)	6,680.0
BGB (t)	5,933.2	(378.4)	(149.6)	(332.5)	(144.9)	4,927.8
DWB (t)	1,659.3	(66.2)	(49.0)	(66.2)	(66.2)	1,411.8
Total (t)	26,989.5	(1,390.6)	(593.0)	(1,368.2)	(618.2)	23,019.6
Percentage	117.2	(6.0)	(2.6)	(5.9)	(2.7)	100.0

3.2 Carbon emission of Kahe Forest Reserve for the period 2003 -2023

The findings presented in Table 5 reveal that Kahe Forest Reserve (KFR) emitted a total of 10,819.2 tonnes of carbon during the period 2003 to 2023. This significant emission was primarily concentrated in forested areas, which accounted for 117.2% of the total carbon emissions. This data underscores the substantial impact of deforestation and forest degradation on carbon release within the reserve, reflecting a major environmental concern given the critical role of forests in carbon sequestration.In contrast, other vegetation types within KFR exhibited a carbon gain of 17.2%, indicating some areas of vegetative recovery or resilience. However, this gain does not offset the extensive carbon emissions resulting from the loss of forest cover. The marginal increase in carbon stock from other vegetation highlights the uneven nature of land cover changes and the limited capacity of non-forest vegetation to sequester carbon compared to mature forested areas.

The encroachment of cultivated land into KFR, despite the Reserve's legal protection under Tanzanian regulations that prohibit anthropogenic activities, points to a troubling shift in land use. The increase in agricultural activities within the Reserve reflects a broader trend of protected areas transitioning from being managed as private goods—where access and use are restricted—to de facto public goods, where the "tragedy of the commons" is prevalent. This concept refers to the situation where commonly accessible resources are overexploited because individual users act in their own interest, disregarding the long-term consequences for the resource and the community at large.

The encroachment and subsequent carbon emissions from KFR highlight a critical failure in the enforcement of conservation policies and the need for more effective governance of protected areas. The transition from protected forest land to cultivated land not only exacerbates carbon emissions but also undermines the ecological integrity of the Reserve. This scenario calls for urgent and decisive actions to strengthen the enforcement of existing regulations and to engage local communities in conservation efforts to prevent further encroachment and degradation.Effective management strategies must prioritize the restoration of degraded forest areas and the protection of remaining forest cover to mitigate carbon emissions and enhance the Reserve's role in

climate change mitigation. This includes revisiting land use policies, improving monitoring systems, and fostering collaboration among stakeholders to address the underlying drivers of deforestation and land conversion within KFR (Mndeme, 2023; Mwalyosi et al., 2024).

Table 5: Carbon emission (tonnes) of Kahe Forest Reserve

Vegetation type	Forest	Bushland	Grassland	Woodland	Cultivated land	Total
AGC (t)	9,116.59	(444.62)	(185.37)	(455.67)	(191.34)	7,839.60
BGC (t)	2,788.60	(177.85)	(70.31)	(156.28)	(68.10)	2,316.07
DWC (t)	779.89	(31.12)	(23.01)	(31.09)	(31.13)	663.53
Total (t)	12,685.08	(653.59)	(278.69)	(643.03)	(290.57)	10,819.20
Percentage	117.2	(6.0)	(2.6)	(5.9)	(2.7)	100.0

3.3 Carbon dioxide (CO_2) emissions from Kahe Forest Reserve for the period 2003-2023

The analysis of carbon dioxide (CO_2) emissions from Kahe Forest Reserve (KFR) for the period 2003 to 2023 reveals a significant release of 39,706.46 tonnes of CO_2. This substantial emission primarily originates from forested areas within the Reserve, accounting for 117.2% of the total emissions, with other vegetation types contributing to a carbon stock increase of 17.2%, as detailed in Table 6. The high percentage of emissions from forested areas underscores the severe impact of deforestation and degradation on carbon sequestration capabilities within KFR.

Despite legal protections, including rules, guidelines, and regulations designed to safeguard KFR, the Reserve has been significantly compromised due to the encroachment of agricultural activities. This invasion not only violates the legal frameworks meant to protect the Reserve but also undermines its ecological integrity and its role as a critical carbon sink. The failure to enforce these regulations has allowed illegal activities to proliferate, leading to substantial CO_2 emissions and the degradation of forest ecosystems that are vital for climate change mitigation.The Tanzania Forest Services (TFS) is the primary body responsible for the protection and management of KFR, working in conjunction with local communities. However, the effectiveness of these efforts has been severely challenged by the rapid increase in the human population in adjacent districts. Between 1967 and 2022, the population in these areas surged by 141.4%, from 538,107 to 1,298,838 people, as illustrated in Figure 4. This dramatic population growth has intensified pressure on the Reserve, driving increased land conversion for agriculture and other uses, which in turn accelerates deforestation and CO_2 emissions.

The findings indicate a critical need for more robust enforcement of conservation laws and the implementation of sustainable land-use practices that involve and benefit local communities. Strengthening the capacity of TFS, coupled with enhanced community engagement, is essential to curbing illegal activities and ensuring the long-term protection of KFR. Additionally, addressing the underlying socio-economic drivers of deforestation, such as population growth and the demand for agricultural land, is crucial for reducing CO□ emissions and preserving the Reserve's ecological functions (Mwalyosi et al., 2024; Mndeme, 2023)

Table 6: Carbon dioxide (CO_2) (tonnes) emissionfrom KFR for the period 2003-2023

Vegetation type	Forest	Bushland	Grassland	Woodland	Cultivated land	Total
$AGCO_2$ (t)	33,457.89	(1,631.76)	(680.30)	(1,672.29)	(702.21)	28,771.33
$BGCO_2$ (t)	10,234.18	(652.70)	(258.05)	(573.53)	(249.94)	8,499.96
$DWCO_2$ (t)	2,862.20	(114.22)	(84.45)	(114.10)	(114.26)	2,435.16
Total (t)	46,554.26	(2,398.68)	(1,022.80)	(2,359.92)	(1,066.40)	39,706.46
Percentage	117.2	(6.0)	(2.6)	(5.9)	(2.7)	100.0

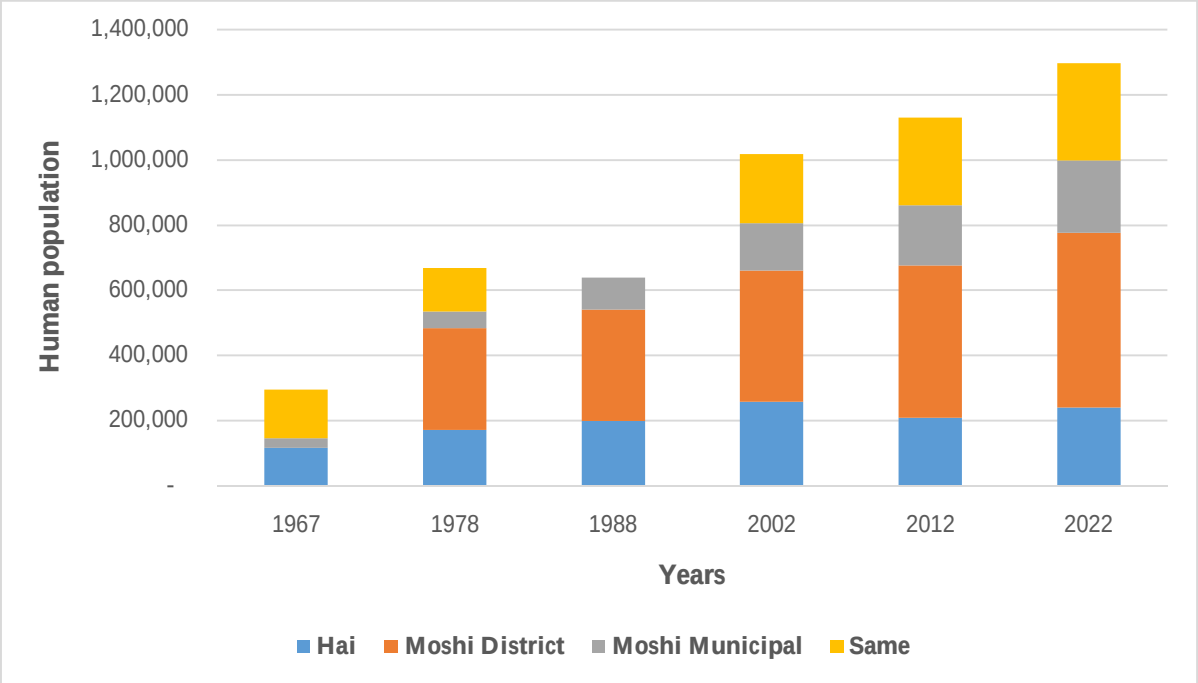

Figure 4: Human population adjacent to KFR for the period 1967 – 2022 (NBS, 2023)

3.4 Carbon trade Loss of Kahe Forest Reserve for the period 2003 - 2023

The findings presented in Table 7 reveal a significant economic loss in potential carbon trade revenue from Kahe Forest Reserve (KFR) over the period 2003–2023, amounting to a total of US$158,825.83. This loss is primarily attributed to deforestation and land-use changes within the Reserve, which have severely compromised its capacity to sequester carbon. The forested areas of KFR, which traditionally serve as the most effective carbon

sinks, accounted for 117.2% of the carbon trade value loss. In contrast, other vegetation types within the Reserve contributed to a smaller profit gain of 17.2%, reflecting their limited carbon sequestration potential compared to forested regions.The presence of cultivated land within KFR highlights a critical issue of illegal encroachment, which has dire consequences for carbon sequestration and, by extension, carbon trade. Agricultural activities within the Reserve not only violate existing conservation laws and regulations but also significantly reduce the area's ability to absorb and store carbon dioxide (CO_2). This encroachment disrupts the ecological balance of the forest, leading to a decrease in the overall carbon stock and a corresponding loss in potential revenue from carbon trading.

The implications of this loss extend beyond mere economic considerations; they underscore the broader environmental and policy challenges facing KFR. The encroachment into protected forest areas reflects a failure in the enforcement of conservation laws and points to the urgent need for more effective governance and management strategies. This situation is further exacerbated by the rising human population in adjacent districts, which has increased by 141.4% from 1967 to 2022, leading to greater demand for land and resources (Mwalyosi et al., 2024; Mndeme, 2023).The loss of potential revenue from carbon trading not only affects the economic sustainability of conservation efforts but also diminishes the incentives for local communities to engage in sustainable land-use practices. To address this issue, there is a critical need for stronger enforcement of existing regulations, alongside initiatives that promote alternative livelihoods for communities living near the Reserve. Additionally, integrating local communities into conservation efforts through participatory management approaches could enhance the protection of KFR and its carbon sequestration capabilities.

Thereof, the findings indicate that the illegal conversion of forest land for agriculture within KFR has led to significant economic losses in carbon trade and has compromised the Reserve's ecological integrity. Addressing these challenges requires a multi-faceted approach that includes stricter law enforcement, community engagement, and the promotion of sustainable land-use practices that align with the goals of carbon sequestration and environmental conservation.

Table 7: Carbon trade loss (US$) of Kahe Forest Reservefor the period 2003 - 2023

Vegetation type	Forest	Bushland	Grassland	Woodland	Cultivated land	Total
$AGCO_2$ (US$)	133,831.54	(6,527.02)	(2,721.20)	(6,689.16)	(2,808.83)	115,085.33
$BGCO_2$ (US$)	40,936.71	(2,610.81)	(1,032.18)	(2,294.12)	(999.75)	33,999.85
$DWCO_2$ (US$)	11,448.78	(456.89)	(337.80)	(456.41)	(457.03)	9,740.65
Total (US$)	186,217.03	(9,594.72)	(4,091.19)	(9,439.69)	(4,265.61)	158,825.83
Percentage	117.2	(6.0)	(2.6)	(5.9)	(2.7)	100.0

4. Conclusion and Recommendations

4.1 Conclusion

This study assesses the ecological and economic impacts of habitat conversion in Kahe Forest Reserve (KFR) over two decades (2003-2023). The findings reveal significant biomass loss, estimated at 23,019.6 tonnes, primarily due to agricultural encroachment driven by rapid population growth in nearby districts. This land conversion has also resulted in substantial carbon emissions (10,819.2 tonnes) and carbon dioxide emissions (39,706.46 tonnes), exacerbating environmental degradation and contributing to climate change. Economically, the study estimates a carbon trade loss of US$ 158,825.83, highlighting missed opportunities for monetizing carbon sequestration in global markets a significant concern for Tanzania's economy, already strained by climate challenges.

The study underscores the difficulties in enforcing environmental regulations, particularly with the ongoing agricultural encroachment, which threatens the forest's integrity and its capacity as a carbon sink. The population in adjacent districts has surged by 141.4% from 1967 to 2022, further straining the reserve's resources. Thus, the future of KFR depends on collaborative efforts among the government, local communities, and international stakeholders to protect its ecological and economic value for future generations.

5.2 Recommendations

This study in Kahe Forest Reserve (KFR) identifies nine critical recommendations to address the environmental and socio-economic challenges impacting the reserve. These recommendations target policymakers, conservationists, and community stakeholders to promote sustainable practices and ensure the long-term preservation of KFR.

S/n	Recommendations	Descriptions
1.	Strengthening policy enforcement and regulatory frameworks	The study emphasizes the need for stricter enforcement of environmental regulations that prohibit agricultural activities within KFR. Enhanced monitoring and regular patrols are crucial to prevent illegal encroachment. Additionally, environmental policies should be reviewed and updated to address the challenges posed by population growth and economic pressures, with stricter penalties for violations.
2.	Community engagement and empowerment	Active involvement of local communities in conservation efforts is vital. Establishing community-based conservation programs and conducting continuous education and awareness campaigns can significantly reduce illegal activities and promote sustainable practices. These initiatives will help communities understand the long-term benefits of conservation, including potential income from carbon trading and eco-tourism.
3.	Promoting	To alleviate pressure on KFR, alternative livelihood programs,

	sustainable agricultural practices	such as sustainable agriculture, agroforestry, and non-timber forest product cultivation, should be promoted. Sustainable land use planning is also essential to balance agricultural needs with environmental conservation, directing agricultural expansion away from protected areas.
4.	Restoration and rehabilitation initiatives	The study highlights the importance of reforestation and afforestation programs to rehabilitate degraded areas within KFR. These efforts should involve local communities to ensure long-term sustainability. Broader ecosystem restoration projects are also necessary to restore biodiversity, enhance ecosystem services, and protect water resources.
5.	Integration into global carbon markets	KFR should be integrated into global carbon markets to capitalize on carbon trading opportunities. This involves quantifying the carbon sequestration potential of the reserve and seeking certification under recognized carbon standards. Developing carbon offset programs could provide additional financial incentives for conservation and restoration initiatives
6.	Monitoring and research	Long-term monitoring programs should be established to track conservation efforts and detect changes in biomass and carbon emissions. Ongoing scientific research is essential to understand KFR's ecosystem dynamics and the effectiveness of conservation strategies, informing policy decisions and management practices.
7.	Collaboration and stakeholder engagement	Effective conservation requires collaboration among government agencies, NGOs, local communities, and the private sector. Strengthening partnerships with international organizations can provide technical and financial support for KFR's conservation efforts.
8.	Addressing population pressure	Population control measures, such as family planning and education programs, should be promoted to stabilize population growth and reduce pressure on KFR. Urban planning strategies are also needed to manage population growth and prevent encroachment into protected areas.
9.	Enhancing financial mechanisms	Sustainable funding sources, such as environmental taxes, payments for ecosystem services, and conservation trust funds, should be explored to support KFR's conservation efforts. Engaging the private sector in CSR programs, green investments, and conservation partnerships can provide additional financial resources.

Thereof, these recommendations provide a comprehensive framework for addressing the challenges of biomass loss, carbon emissions, and habitat conversion in KFR. Implementing these strategies can safeguard the reserve's ecological integrity, enhance its role as a carbon sink, and contribute to global climate change mitigation efforts. The success of these initiatives will depend on the collective commitment of all stakeholders.

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