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Environmental and Economic Forecasting of Biomass Depletion and Carbon Release in Kazimzumbwi Forest Reserve, Tanzania

Luzabeth J. Kitali[1*]

[1]*Department of Geography and History, Faculty of Arts and Social Sciences, The Mwalimu Nyerere Memorial Academy, P.O Box 9193, Dar es Salaam, Tanzania*

luzabeth.kitali@mnma.ac.tz

[*]*Corresponding author*

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Abstract

Forests play a crucial role in the global climate system, acting as significant carbon sinks that absorb approximately 2.6 billion tonnes of carbon annually. However, anthropogenic pressures such as deforestation, illegal logging, and urban expansion are threatening this function, particularly in sub-Saharan Africa. Tanzania, with over 33 million hectares of forest at risk, exemplifies this crisis, particularly in the Kazimzumbwi Forest Reserve (KFR), which is experiencing accelerated biomass depletion and land-use conversion due to weak law enforcement and limited community engagement. This study adopts a multi-disciplinary approach to assess the environmental and economic impacts of biomass depletion and carbon release in KFR from 2024 to 2054. Utilizing land use and land cover change (LULCC) analysis, carbon stock modeling, and market-based carbon valuation, the study employs satellite imagery and national forest inventory data to simulate future land cover transitions using the CA-Markov model. The findings indicate a net biomass gain of 19,534.11 tonnes, primarily from passive regrowth in shrubland and bare land. However, significant degradation in open woodlands and grasslands results in a loss of over 9,977.4 tonnes of biomass. By 2054, the total carbon stock is projected at 9,181.03 tonnes, translating to approximately 33,694.39 tonnes of CO_2, with closed forests remaining the primary carbon sink. The economic valuation of carbon loss, based on a conservative market price of USD $4 per tonne, estimates a cumulative financial loss of USD $134,777.58, with the most significant losses occurring in open woodlands and grasslands. Conversely, closed forests represent a substantial ecological and economic asset, valued at nearly USD $199,389.31. The study emphasizes that forest degradation poses both environmental and economic risks, particularly as global carbon prices increase. To address these challenges, the study recommends strengthening forest governance, promoting community-based forest management, and leveraging carbon finance mechanisms. It advocates for the restoration of degraded lands through assisted natural regeneration and native species reforestation. By integrating environmental science, economics, and policy, this research provides strategic insights for sustainable land-use planning and climate action in Tanzania, positioning reserves like KFR as vital assets for a climate-resilient economy.

Keywords: Biomass depletion, Carbon emissions, Land use change (LULC), Carbon valuation, Sustainable Forest management

1. Introduction

Forests play a pivotal role in the global climate system by acting as significant carbon sinks, absorbing around 2.6 billion tonnes of carbon annually (Pan et al., 2011; FAO, 2020). However, human activities such as deforestation, unsustainable land use, and forest degradation are diminishing their capacity to sequester carbon, leading to increased carbon emissions and threats to biodiversity and ecosystem services. In sub-Saharan Africa, forests are vital for the livelihoods of millions, providing food, fuel, and cultural services. Tanzania, with over 33 million hectares of forest, faces a concerning annual deforestation rate of approximately 470,000 hectares, driven by factors like shifting cultivation, charcoal production, illegal logging, and urban expansion (MNRT, 2021; URT, 2022).

The Kazimzumbwi Forest Reserve (KFR) in Tanzania's Pwani Region is a critical ecosystem within the Eastern Arc Mountains and Coastal Forests Biodiversity Hotspot (Burgess et al., 2007; CEPF, 2020). Despite its ecological importance and high levels of species endemism, KFR is threatened by illegal logging, charcoal burning, agricultural encroachment, and urban sprawl, compounded by weak governance and limited community engagement (WWF, 2020; TFCG, 2018; Milder et al., 2014). Given these challenges, there is an urgent need for research that assesses both current and future forest dynamics. Existing studies on deforestation in Tanzania often focus on historical trends or short-term monitoring, lacking integration of biophysical and economic dimensions and failing to provide long-term predictive modeling (URT, 2019; Ndilahomba et al., 2021). This gap hinders the ability of forest managers and policymakers to effectively plan for and mitigate forest loss, particularly in peri-urban areas like Kazimzumbwi.

This study aims to fill this gap by forecasting the environmental and economic impacts of biomass depletion and carbon emissions in KFR from 2034 to 2054. The study emphasizes the need for proactive forest governance, where decision-making is informed by both historical data and scenario-based forecasting. By projecting long-term land use and carbon dynamics, the study seeks to contribute to climate mitigation efforts and local development planning. Kazimzumbwi was selected for this study due to its high conservation value, proximity to urban centres like Dar es Salaam, and its vulnerability to anthropogenic pressures. The forest's relevance extends to Tanzania's climate and development agenda, including commitments under the Paris Agreement and the REDD+ mechanism (REDD+ Secretariat, 2020).

The primary objective of this study is to forecast the environmental and economic consequences of ongoing biomass depletion and carbon release in KFR. Specific objectives include quantifying historical and current biomass stocks and carbon emissions, developing land use and land cover change (LULCC) models, assessing the economic value of carbon loss, and proposing sustainable forest management strategies. The study is guided by several research questions: What are the historical and current patterns of biomass depletion and carbon emissions in KFR? What are the projected land use and biomass dynamics under various scenarios? What is the estimated economic cost of projected carbon emissions? What policy interventions can mitigate biomass loss and enhance sustainability? methodologically, the study focuses on KFR and its buffer zones, utilizing historical satellite data, remote sensing classification, and predictive modelling techniques, including the CA-Markov chain model. Carbon accounting standards from the Intergovernmental Panel on Climate Change (IPCC) will be applied, and economic evaluations will be based on contemporary carbon market pricing (World Bank, 2022).

The significance of this study lies in its interdisciplinary approach, bridging ecology, economics, spatial analysis, and policy. By providing scientifically grounded forecasts, the study aims to equip policymakers with data for sustainable land-use planning, justify investments in conservation, support local governments and conservation organizations, and contribute to climate action aligned with national and global environmental goals. Thus, this study aspires to foster a resilient, economically informed, and ecologically sustainable future for KFR and other vulnerable ecosystems in Tanzania and East Africa.

2. Materials and methods

2.1 Description of the study area

Kazimzumbwi Forest Reserve (KFR) in Tanzania's Pwani Region spans approximately 4,975 hectares and is part of the Eastern Arc Mountains and Coastal Forests Biodiversity Hotspot, known for its rich biodiversity and endemic species, including Syke's monkey (Cercopithecus mitis) (MNRT, 2018; Burgess et al., 2007; TFCG, 2018). KFR is crucial for ecological functions such as carbon sequestration and water conservation. However, local communities rely on the forest for agriculture and charcoal production, facing pressures from urban expansion and population growth (URT, 2019; Babili et al., 2021). Challenges include weak law enforcement, limited community involvement, and insufficient conservation funding (MNRT, 2021; TFCG, 2018).

Over the past two decades, KFR has experienced over 30% deforestation due to illegal logging and agricultural activities, with projections indicating further biomass loss by 2054 if current trends persist (Ndilahomba et al., 2021; URT, 2022). Managed by the Tanzania Forest Services, KFR suffers from inadequate staffing and lack of community-based management (Kajembe et al., 2016). Understanding KFR's environmental and economic impacts is vital, particularly regarding biomass depletion and carbon emissions, with future scenarios projected from 2034 to 2054 to assess forest degradation and economic loss.

2.2 Data sets

This study aims to forecast the environmental and economic impacts of biomass depletion and carbon emissions in the Kazimzumbwi Forest Reserve from 2024 to 2054 by integrating various multi-temporal and multi-source datasets. The datasets (Figures 1 -2; Tables 1-2) include satellite imagery, socioeconomic data, forest inventory reports, climatic records, and economic valuation parameters. Remote sensing data is pivotal for analysing land use and land cover changes (LULCC). Historical and projected satellite images from sources such as Landsat (2000-2024) and Sentinel-2 are utilized to monitor forest cover and biomass changes (USGS, 2022; ESA, 2023). MODIS NDVI datasets are employed for analysing vegetation health over time (Huete et al., 2002).

Forest inventory and biomass estimates are derived from ground-truth data, including the National Forest Resources Monitoring and Assessment (NAFORMA) and Permanent Sample Plots (PSPs) established by the Tanzania Forest Services Agency (MNRT, 2021). Allometric models, such as those by Chave et al. (2014), help estimate aboveground biomass. Carbon stock and emissions factors are calculated using IPCC guidelines (2006, 2019) and specific forest carbon density values for Tanzania (Henry et al., 2011; Donfack et al., 2020). Economic valuation incorporates carbon prices from voluntary and compliance markets (World Bank, 2022). This comprehensive approach aims to provide a robust framework for assessing future impacts on the Kazimzumbwi Forest Reserve.

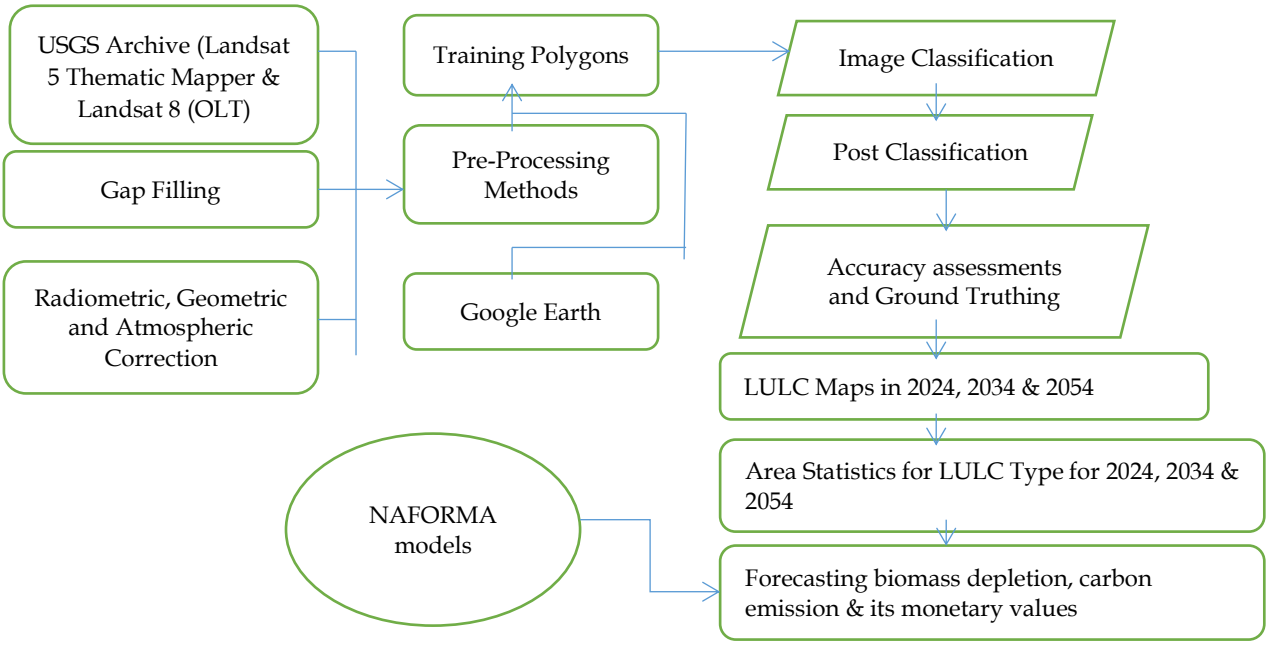


Figure 1: Flowchart of the methodological approach for this study

Table 1: LULC composition and change trend of Kazimzumbwi from 2024 to 2054

	2024		**2034**		**2054**		**2024-2054**	
LULC type	**ha**	**%**	**ha**	**%**	**ha**	**%**	**Ha**	**%**
Closed forest	886.64	17.8	595.24	12.0	537.58	10.8	-349.06	-39.4
Open woodland	1390.09	27.9	1748.03	35.1	1625.97	32.7	235.88	17.0
Shrubs	1160.98	23.3	1225.13	24.6	1131.29	22.7	-29.69	-2.6
Grassland	925.22	171.3	876.83	17.6	1098.81	22.1	173.59	18.8
Bare land	540.01	10.9	464.26	9.3	516.66	10.4	-23.35	-4.3
Built-up	72.23	1.5	65.68	1.3	64.86	1.3	-7.37	-10.2
Total	**4975.17**		**4975.17**		**4975.17**			

Table 2: Description of LULC types

LULC types	**Description**
Closed forest	Area with enclosed formations, tall trees and enclosed formations of dense forest
Open forest	with mixed forest formations, open stands and whose tree tops are less joined or form a clear canopy
Shrubs	woody perennial plants, generally of more than 0.5 m and less than 5 m in height on maturity and without a definite crown
Grassland	Ground covered by vegetation dominated by grasses, with little or no tree cover
Bare land	Areas with no dominant vegetation cover on at least 90 % of the area
Built-up areas	Areas which are characterized by an artificial cover

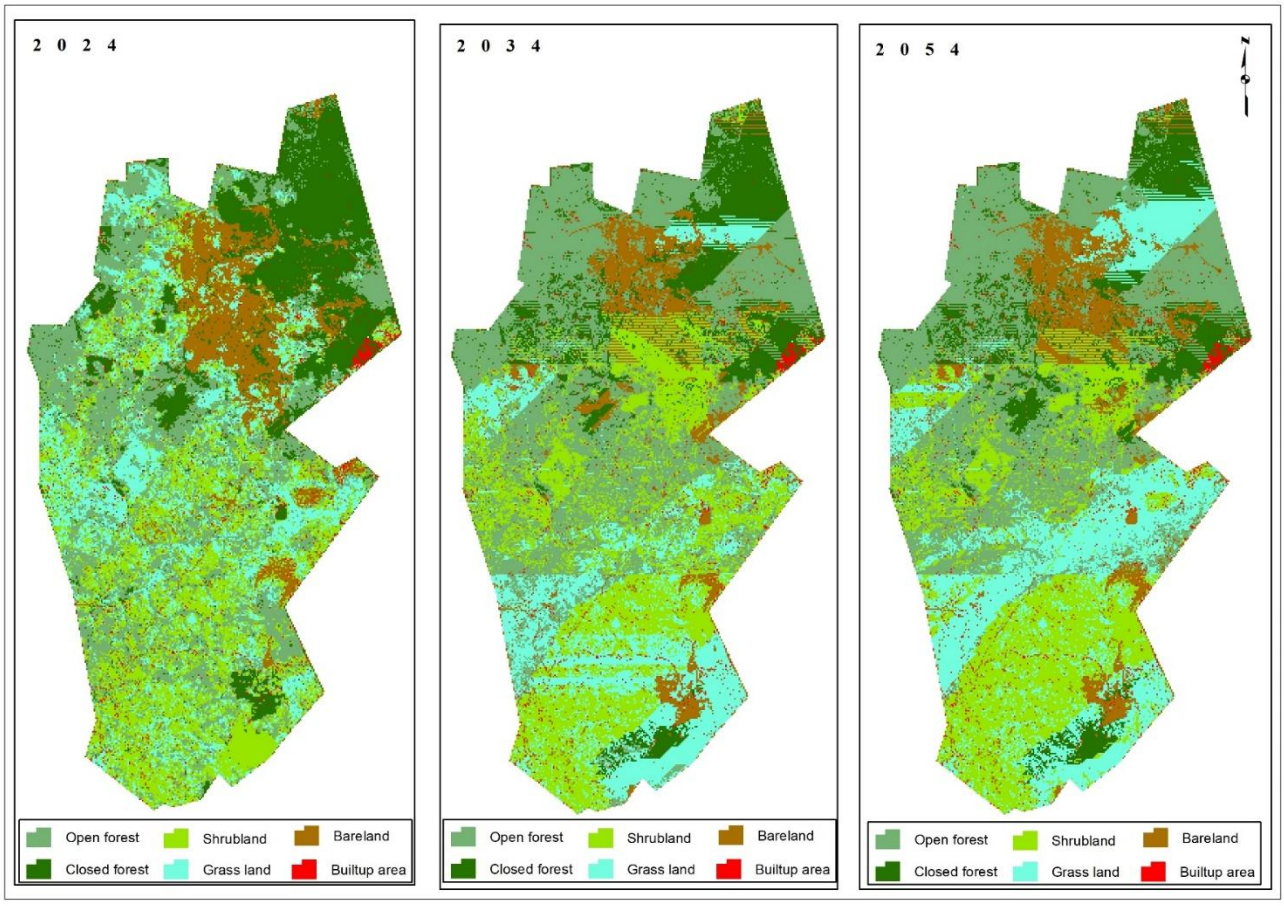


Figure 2: Future trends in LULC of Kazimzumbwi Forest Reserve from 2024 to 2054

2.3 Data Analysis

The study employs a multi-disciplinary approach to analyze land use and carbon trends from 2034 to 2054, integrating spatial analysis, statistical modeling, carbon accounting, and economic valuation. Key methods include Land Use and Land Cover Change (LULCC) analysis, utilizing image pre-processing and supervised classification algorithms like Random Forest (Breiman, 2001), alongside accuracy assessments (Foody, 2002). Change detection evaluates forest loss through comparative LULC maps. Biomass and carbon estimation are conducted using allometric equations to derive aboveground biomass (AGB) and carbon stock (Chave et al., 2014). CA-Markov modeling projects future scenarios, generating land cover maps and carbon emission estimates. Economic valuation of carbon loss incorporates carbon pricing models, assessing impacts through the social cost of carbon (SCC) and market rates (World Bank, 2022; U.S. EPA, 2021). Statistical analyses, including regression and sensitivity tests, enhance model robustness, ensuring reliable predictions for informing policy and management decisions.

2.3.1 Biomass depletion from KFR for the period 2024 to 2054

Tanzania forest Carbon can be estimated in three pools namely AGB (above ground biomass), BGB (below ground biomass) and DW (dead wood) (URT, 2015). BGB was estimated as a fraction of AGB. AGB and BGB were estimated as follows:

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

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

URT (2015) uses conversion factors into programmed NAFORMA analysis system by tree species or species groups to provide standards in each terrestrial ecosystem of Tanzania. Dead wood (DW) biomass is estimated from the volume computed using Smalian formula multiplied by wood density of 619 kg/m^3 (Chidumayo, 2012 cited by URT, 2015). URT (2015) through NAFORMA reveals the dead wood Biomass of Tanzania (Table 3) is relatively low since deadest wood in accessible areas is collected as fuelwood. As woodlands are generally more accessible than forests, collection of deadwood for fuelwood from these areas is easier as shown in Table 3.

Table 3: Living tree stemwood and deadwood biomass

LULC type	Change detected (ha) 2024-2054	Biomass (t/ha) AGB	BGB	DWB	Total biomass
Closed forest	349.06	59.5	18.2	5.09	82.79
Open woodland	-235.88	27.7	9.5	1.89	39.09
Shrubs	29.69	11	4.4	0.73	16.13
Grassland	-173.59	2.9	1.1	0.36	4.36

Bare land	23.35	2.9	1.1	0.36	4.36
Built-up	7.37	2.9	1.1	0.36	4.36
Total		**106.9**	**35.4**	**8.79**	**151.09**

2.3.2 Carbon emission from KFR for the period 2024 to 2054

According to URT (2015), carbon in terrestrial ecosystems of Tanzania can be computed as follows:

Carbon (tonnes/ha) = Biomass * 0.47

Living tree stemwood (AGC + BGC) and dead wood carbon (DWC) (t/ha) by primary vegetation type are illustrated in Table 4.

Table 4: Living tree stemwood and deadwood carbon

LULC type	**Carbon (t/ha)**			
	AGC	**BGC**	**DWC**	**Total carbon**
Closed forest	27.97	8.55	2.39	38.91
Open woodland	13.02	4.47	0.89	18.37
Shrubs	5.17	2.07	0.34	7.58
Grassland	1.36	0.52	0.17	2.05
Bare land	1.36	0.52	0.17	2.05
Built-up	1.36	0.52	0.17	2.05
Total	**50.24**	**16.64**	**4.13**	**71.01**

2.3.3 Carbon dioxide emission from KFR for the period 2024 to 2054

Estimating the carbon dioxide (CO_2) emitted from Kazimzumbwi Forest Reserve (KFR) involves converting total carbon emitted into CO_2 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_2 to carbon (IPCC, 2006 & 2023). The formula is:

CO_2 (tonnes)= Carbon (tonnes)×3.67

Applying this to the estimated carbon stocks of living and dead biomass in KFR gives the CO_2 sequestration

potential as shown in Table 5:

Total CO_2 (tonnes) =$AGCO_2$ (tonnes) +$BGCO_2$ (tonnes) +$DWCO_2$ (tonnes)

Table 5: Living tree stemwood and deadwood carbon dioxide

LULC type	Carbon dioxide (t/ha)			
	$AGCO_2$	**$BGCO_2$**	**$DWCO_2$**	**Total CO_2**
Closed forest	102.63	31.39	8.78	142.80
Open woodland	47.78	16.39	3.26	67.43
Shrubs	18.97	7.59	1.26	27.82
Grassland	5.00	1.90	0.62	7.52
Bare land	5.00	1.90	0.62	7.52
Built-up	5.00	1.90	0.62	7.52
Total	**184.39**	**61.06**	**15.16**	**260.62**

2.3.4 Economic loss of KFR for the period 2024 to 2054

The study adopted from Jenkins (2014), and Lobora *et al.* (2017) emphasized that, the standard carbon market is US$ 4 per ton if REDD+ is implemented; this was used to estimate financial cost of carbon emitted to the atmosphere as a result of land use/cover change in KFR for the period 2024-2054 as indicated in Table 6.

Table 6: Economic loss/gain of KFR from carbon dioxide trade

LULC type	Carbon dioxide (US$/ha)			
	$AGCO_2$	**$BGCO_2$**	**$DWCO_2$**	**Total CO_2**
Closed forest	410.53	125.57	35.12	571.22
Open woodland	191.12	65.55	13.04	269.71
Shrubs	75.90	30.36	5.04	111.29
Grassland	20.01	7.59	2.48	30.08
Bare land	20.01	7.59	2.48	30.08

Built-up	20.01	7.59	2.48	30.08
Total	**737.57**	**244.25**	**60.65**	**1042.46**

3. Results and Discussion

3.1 Biomass depletion from Kazimzumbwi forest reserve for the period 2024 to 2054

The predictive analysis of biomass trends in Kazimzumbwi Forest Reserve (KFR) from 2024 to 2054 (Table 7) indicates a complex scenario of biomass changes across various land use/land cover (LULC) categories. Overall, a net gain of 19,534.11 tonnes of biomass is forecasted, primarily due to the preservation of closed forest patches and slight regrowth in shrublands and bare land. However, this gain is overshadowed by significant losses in open woodlands and grasslands, which are rapidly converting to non-vegetated and built-up areas (Burgess et al., 2007; Donfack et al., 2020; World Bank, 2022).

Closed forest areas are expected to retain the highest biomass stock, contributing 28,898.68 tonnes by 2054, with substantial aboveground (AGB), belowground (BGB), and deadwood biomass (DWB). This retention reflects the ecological stability of these forest patches, often found in less accessible regions (Ndilahomba et al., 2021). However, without formal protection, these gains may be temporary, as fragmentation threatens their integrity (TFCG, 2018). In contrast, open woodlands are projected to experience a dramatic biomass loss of 9,220.55 tonnes, driven by increased accessibility for charcoal production and grazing, leading to accelerated degradation (FAO, 2020; MNRT, 2021). This trend indicates a broader shift in land cover dynamics, particularly in the Kisarawe-Dar es Salaam corridor (URT, 2022). Shrublands and bare land show modest biomass increases, suggesting passive regrowth and potential for future reforestation initiatives under REDD+ frameworks (Mather, 1992; REDD+ Secretariat, 2020). Conversely, grasslands face a net loss of 756.85 tonnes, highlighting their vulnerability to overgrazing and conversion to settlements (Henry et al., 2011). Built-up areas, while contributing minimally to biomass, reflect ongoing peri-urban expansion, necessitating integrated land-use planning to mitigate further encroachment into forest zones (Seto et al., 2012; World Bank, 2020).

In light of these findings, urgent policy interventions are recommended, including strengthening forest protection laws, expanding community-based management programs, and promoting reforestation efforts. The economic implications of lost carbon highlight the cost-effectiveness of forest conservation as a climate mitigation strategy, emphasizing the dual benefits of ecological resilience and economic returns.

Table 7: Forecasted KFR's biomass loss from 2024 to 2054

LULC type	**Biomass (t)**			
	AGB	**BGB**	**DWB**	**Total biomass**
Closed forest	20,769.07	6,352.89	1,776.72	28,898.68
Open woodland	(6,533.88)	(2,240.86)	(445.81)	(9,220.55)
Shrubs	326.59	130.64	21.67	478.90

Grassland	(503.41)	(190.95)	(62.49)	(756.85)
Bare land	67.72	25.69	8.41	101.81
Built-up	21.37	8.11	2.65	32.13
Total	**14,147.46**	**4,085.51**	**1,301.14**	**19,534.11**

( ) = -ve

3.2 Carbon emission from Kazimzumbwi forest reserve for the period 2024 to 2054

The carbon emission forecast for Kazimzumbwi Forest Reserve (KFR) from 2024 to 2054 (Table 8) indicates significant changes in carbon stock across various land cover types, with a total projected carbon stock of 9,181.03 tonnes, equivalent to approximately 33,707.38 tonnes of CO_2 (IPCC, 2006). This includes aboveground carbon (AGC), belowground carbon (BGC), and deadwood carbon (DWC), with closed forests acting as the primary carbon sink, storing an estimated 13,582.38 tonnes of carbon (Burgess et al., 2007; Donfack et al., 2020). However, degradation of open woodlands and grasslands is leading to substantial carbon losses, particularly in open woodlands, which are projected to release 4,333.66 tonnes of carbon due to conversion to agricultural land and other uses (FAO, 2020; Henry et al., 2011). In contrast, shrublands and bare lands show modest carbon gains, indicating potential recovery in previously degraded areas, aligning with the "forest transition theory" (Mather, 1992). Grasslands, however, are experiencing a net carbon loss of 355.72 tonnes, exacerbated by overgrazing and urban expansion (World Bank, 2020). Built-up areas contribute minimally to carbon storage, with only 15.10 tonnes of carbon, highlighting the limited role of urban green spaces in carbon sequestration (Seto et al., 2012).

The projected decline in KFR's carbon sink capacity poses significant challenges for Tanzania's Nationally Determined Contributions (NDCs) under the Paris Agreement, which aim to enhance forest-based carbon sequestration by 2030 (REDD+ Secretariat, 2020; URT, 2022). Without intervention, KFR risks becoming a net source of emissions, undermining national climate goals. To address these challenges, several policy and management interventions are recommended: enhancing forest governance and enforcement to combat illegal logging, empowering local communities through Community-Based Forest Management (CBFM), integrating carbon finance and REDD+ strategies, prioritizing afforestation and assisted natural regeneration, and incorporating urban planning measures to mitigate unregulated settlement expansion.

Thus, while KFR's closed forests retain significant carbon stocks, the degradation of surrounding ecosystems threatens its role in climate change mitigation. Proactive, evidence-based management strategies that consider ecological, economic, and community needs are essential to safeguard KFR's carbon resources and enhance its resilience against ongoing land-use pressures.

Table 8: Carbon emission from Kazimzumbwi forest reserve for the period 2024 to 2054

LULC type	**Carbon (t)**			
	AGC	**BGC**	**DWC**	**Total carbon**
Closed forest	9,761.46	2,985.86	835.06	13,582.38

Open woodland	(3,070.92)	(1,053.20)	(209.53)	(4,333.66)
Shrubs	153.50	61.40	10.19	225.08
Grassland	(236.60)	(89.75)	(29.37)	(355.72)
Bare land	31.83	12.07	3.95	47.85
Built-up	10.05	3.81	1.25	15.10
Total	**6,649.31**	**1,920.19**	**611.54**	**9,181.03**

3.3 Carbon dioxide emission from Kazimzumbwi forest reserve for the period 2024 to 2054

The forecasted carbon dioxide (CO_2) emissions from Kazimzumbwi Forest Reserve (KFR) between 2024 and 2054 (Table 9) indicate a significant decline in carbon storage, with total CO_2 stock projected at 33,694.39 tonnes by 2054. This figure includes aboveground CO_2 ($AGCO_2$), belowground CO_2 ($BGCO_2$), and deadwood CO_2 ($DWCO_2$), highlighting the critical role of different land use/land cover (LULC) types in carbon dynamics (IPCC, 2006). Closed forests are identified as stable CO_2 sinks, with an estimated storage of 49,847.33 tonnes by 2054. These forests are crucial for climate regulation due to their high biomass density and complex structures (Burgess et al., 2007; Donfack et al., 2020). However, even minor disturbances can significantly reduce their CO_2 sequestration capacity (FAO, 2020; Chazdon et al., 2016). In contrast, open woodlands are projected to emit 15,904.53 tonnes of CO_2, representing 47% of the total reduction across all LULC types, primarily due to anthropogenic pressures such as charcoal production and land conversion (Henry et al., 2011; Ndilahomba et al., 2021). This area serves as a buffer against urban expansion but risks transitioning to low biomass land if unmanaged. Shrublands show a modest CO_2 gain of 826.05 tonnes, indicating potential for recovery if managed properly (Mather, 1992; Chazdon, 2014). Grasslands, however, are emerging as hotspots for emissions, with a net loss of 1,305.49 tonnes, exacerbated by overgrazing and urban encroachment (FAO, 2020; Seto et al., 2012). Bare land and built-up areas contribute minimally to CO_2 storage, reflecting ongoing land degradation and ecological transformation.

The overall decline in KFR's carbon sink capacity poses risks to Tanzania's national climate goals and carbon market opportunities, particularly under REDD+ initiatives (Pan et al., 2011; Donfack et al., 2020). To address these challenges, strategic actions are recommended, including enforcing conservation in high-carbon areas, restoring degraded lands, implementing carbon offset projects, and integrating carbon assessments into land-use planning. The projected decline in carbon storage signals a pressing need for integrated conservation efforts to maintain KFR's ecological and economic viability while supporting Tanzania's climate objectives.

Table 9: Carbon dioxide emission for the period 2024 to 2054

LULC type	**Carbon dioxide (t)**			
	$AGCO_2$	**$BGCO_2$**	**$DWCO_2$**	**Total CO_2**
Closed forest	35,824.57	10,958.10	3,064.66	49,847.33

Open woodland	(11,270.28)	(3,865.26)	(768.98)	(15,904.53)
Shrubs	563.34	225.33	37.38	826.05
Grassland	(868.33)	(329.37)	(107.79)	(1,305.49)
Bare land	116.80	44.30	14.50	175.61
Built-up	36.87	13.98	4.58	55.43
Total	**24,402.96**	**7,047.10**	**2,244.34**	**33,694.39**

3.4 Economic loss of Kazimzumbwi forest reserve for the period 2024 to 2054

The projected economic losses from carbon dioxide (CO_2) emissions in the Kazimzumbwi Forest Reserve (KFR) from 2024 to 2054 (Table 10) highlight significant financial implications tied to environmental degradation, particularly concerning carbon sequestration potential. Using a conservative carbon price benchmark of USD $4 per tonne, the total projected economic loss is estimated at USD $134,777.58, reflecting changes across various land use/land cover (LULC) classes, including aboveground, belowground, and deadwood CO_2 (World Bank, 2022).

Closed forests are identified as the most economically valuable LULC type, contributing approximately USD $199,389.31 from retained CO_2. This underscores the importance of forest preservation for both ecological and economic reasons, aligning with Tanzania's Nationally Determined Contributions (NDCs) and international programs like REDD+, which incentivize emission reductions (Pan et al., 2011; REDD+ Secretariat, 2020). Conversely, open woodlands account for the largest economic losses, totaling USD $63,618.10, primarily due to degradation from activities like charcoal production and agricultural expansion (Ndilahomba et al., 2021). This degradation represents a significant economic liability, especially as carbon prices are projected to rise (World Bank, 2022). Shrublands show modest economic gains of USD $3,304.22, reflecting natural regeneration processes, while grasslands face losses of USD $5,221.98 due to land-use conversion and degradation (Henry et al., 2011; FAO, 2020). The findings emphasize the need for improved management practices in these ecosystems to mitigate economic losses.

The overall economic impact from carbon dynamics in KFR illustrates that natural ecosystems are valuable assets, and degraded landscapes impose hidden costs on the economy. The ability to monetize carbon storage through various market mechanisms positions KFR as a potential site for sustainable financing and climate solutions (World Bank, 2022). To address these challenges, several policy recommendations are proposed: institutionalizing carbon valuation in land-use planning, prioritizing protection for carbon-rich areas, introducing Payment for Ecosystem Services (PES) to engage local communities, investing in the restoration of degraded areas, and leveraging access to carbon markets through verification processes. Thus, the economic costs associated with CO_2 emissions in KFR are substantial, particularly in degraded ecosystems. As Tanzania navigates the balance between economic growth and environmental sustainability, integrating carbon economics into planning frameworks is crucial for capitalizing on nature's climate value and mitigating the costs of environmental degradation.

Table 10: Economic loss of KFR for the period 2024 to 2054

LULC type	Carbon dioxide (US$)			
	$AGCO_2$	**$BGCO_2$**	**$DWCO_2$**	**Total CO_2**
Closed forest	143,298.28	43,832.41	12,258.63	199,389.31
Open woodland	(45,081.13)	(15,461.04)	(3,075.93)	(63,618.10)
Shrubs	2,253.34	901.34	149.54	3,304.22
Grassland	(3,473.33)	(1,317.47)	(431.17)	(5,221.98)
Bare land	467.21	177.22	58.00	702.42
Built-up	147.47	55.94	18.31	221.71
Total	97,611.82	28,188.39	8,977.36	134,777.58

4. Conclusion and Recommendations

4.1 Conclusion

This study evaluates the environmental and economic impacts of biomass depletion and carbon release in the Kazimzumbwi Forest Reserve (KFR) in Tanzania over a thirty-year period (2024–2054). Utilizing remote sensing, land use forecasting, carbon stock estimation, and economic valuation, the study provides insights into ecological degradation and its economic ramifications in this vulnerable peri-urban forest ecosystem. Findings indicate a decline in forest biomass, increased carbon and CO_2 emissions, and significant economic losses due to diminished carbon sequestration potential. While closed forest areas maintain high biomass, open woodlands and grasslands face severe degradation from illegal logging, charcoal production, agricultural expansion, and urban encroachment. Projections for 2034–2054 suggest continued biomass reduction, a carbon stock decline of 33,694.39 tonnes of CO_2, and an economic loss of approximately USD $134,777.58. The study warns that without strategic intervention, KFR may face irreversible ecological changes, leading to biodiversity loss and disruption of ecosystem services, undermining Tanzania's climate commitments. It emphasizes that forest degradation poses not only environmental challenges but also economic risks, advocating for a shift towards proactive, finance-driven, and community-led conservation strategies to harness the untapped value of forests in carbon markets and sustainable development.

4.2 Recommendations

Based on the findings, the following strategic, policy, and community-level recommendations are proposed to reverse current degradation trends, enhance carbon retention, and unlock economic potential from forest conservation:

4.2.1 Strengthen legal and institutional frameworks for forest protection

- Reinforce the enforcement of the Forest Act (2002) and related legislation through increased staffing, surveillance, and prosecutorial follow-through in Kazimzumbwi and other peri-urban reserves.
- Establish clear buffer zones around the reserve to protect core forest areas from urban encroachment and illegal activities.
- Integrate KFR into regional spatial plans to ensure forest land is formally zoned and legally safeguarded from incompatible development.

4.2.2 Promote community-based forest management (CBFM)

- Expand Participatory Forest Management (PFM) programs, ensuring that surrounding communities are recognized as custodians and beneficiaries of forest resources.
- Introduce benefit-sharing mechanisms such as revenue from carbon credit sales or sustainable ecotourism, incentivizing conservation behavior.
- Support local capacity building through training on sustainable land use practices, forest monitoring, and alternative livelihoods.

4.2.3 Leverage carbon finance and green investment opportunities

- Register KFR under voluntary carbon offset schemes or REDD+ readiness programs to access international climate finance.
- Develop and implement a carbon baseline registry and pursue third-party verification to generate verified emissions reductions (VERs) that can be traded in global carbon markets (World Bank, 2022).
- Collaborate with donors, the private sector, and environmental NGOs to co-finance restoration initiatives and climate-smart conservation infrastructure.

4.2.4 Restore degraded land cover types

- Target open woodlands and grasslands—the main contributors to CO_2 emissions—for assisted natural regeneration (ANR) and agroforestry-based restoration.
- Invest in reforestation using native tree species that offer both high carbon sequestration potential and co-benefits for biodiversity and local livelihoods (Chazdon, 2014).
- Promote landscape-scale restoration, incorporating corridors and mosaics that enhance ecosystem connectivity and climate resilience.

4.2.5 Institutionalize carbon accounting in policy and planning

- Mainstream carbon valuation in all forest-related planning processes, including impact assessments, land-use zoning, and public investment programs.
- Train district planners and land officers on ecosystem service valuation and carbon economics, ensuring decisions are evidence-based and sustainability-oriented.
- Develop local guidelines for integrating climate-smart land use planning at district and municipal levels, particularly in Kisarawe and neighboring urban expansion areas.

4.2.6 Enhance monitoring, research, and data management

- Establish a long-term ecological monitoring system using remote sensing, GIS, and ground-truthing to track biomass change and inform adaptive management.
- Support partnerships with academic and research institutions for periodic forecasting of carbon trends, enabling more agile and informed policy responses.
- Encourage the use of open-access spatial platforms to improve transparency and stakeholder engagement in forest governance.

4.2.7 Promote cross-sectoral integration and awareness

- Foster collaboration between the environment, energy, agriculture, and urban planning sectors, ensuring a holistic approach to forest conservation.
- Launch targeted public awareness campaigns to educate local residents, developers, and policymakers on the economic and environmental importance of forest carbon.
- Include KFR in national education and climate curricula, positioning it as a model for applied forest-based climate mitigation strategies.

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