THEME IV:

ENVIRONMENTAL STEWARDSHIP AND COMMUNITY DEVELOPMENT: LESSONS FROM NYERERE'S LEADERSHIP

Biomass Depletion and Carbon Emissions in Tanzania's Kilombero Valley Floodplain: How Nyerere's Legacy Informs Today's Climate Action Strategies

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Abstract

Land use and cover change (LULCC), driven by human activities and natural processes, has emerged as a significant factor in biomass depletion and increased carbon emissions, a key contributor to global climate change. This study examines the impact of LULCC on biomass loss and carbon emissions in Tanzania's Kilombero Valley floodplain (KVFP), an ecologically significant area, from 1990 to 2020. By utilizing moderate-resolution Landsat imagery from 1990, 2010, and 2020, the research applied a random forest (RF) algorithm for land classification and ArcGIS software for spatial analysis. Biomass and carbon stock estimations were based on models from Tanzania's National Forest Resources Monitoring and Assessment (NAFORMA). The findings reveal a substantial biomass reduction of 26.93 million tonnes, releasing 12.66 million tonnes of carbon, leading to 46.46 million tonnes of CO_2 emissions. This release equated to an estimated economic loss of USD 185.83 million in the global carbon market. Forest degradation accounted for 95.9% of biomass loss, underscoring the critical role of forest management in combating carbon emissions. While agricultural and grassland expansions contributed to minor biomass gains, they did not offset the overall loss. The study draws on the environmental vision of Mwalimu Julius Nyerere, advocating for sustainable land use and the integration of climate resilience in land management policies. These findings emphasize the need for urgent policy interventions to safeguard natural resources and mitigate climate change in the KVFP, highlighting the relevance of Nyerere's legacy in shaping modern climate strategies.

Keywords: Land uses, Biomass, Carbon, Carbon dioxide, Kilombero Valley floodplain

1. Introduction

1.1 Background of the study

Climate change remains one of the most pressing global challenges, with profound implications for ecosystems, biodiversity, and human societies. The primary driver of this crisis is the increase in atmospheric greenhouse gases, particularly carbon dioxide (CO_2), resulting from human activities such as deforestation, industrial emissions, and land-use changes. These activities disrupt the delicate balance of the Earth's carbon cycle, accumulating heat-trapping gases that drive global warming (IPCC, 2021). A critical mechanism for mitigating climate change lies in terrestrial carbon sinks, which include soils, forests, and vegetation. These ecosystems are vital in absorbing nearly half of the annual CO_2 emissions generated by fossil fuel combustion (IPCC, 2022). Forests, in particular, act as dual agents in this system, functioning as both carbon sources and sinks. When forests are intact, they sequester carbon through photosynthesis and store it in biomass. However, when forests are cleared or degraded, the carbon stored in trees and soil is released back into the atmosphere, exacerbating global warming (IPCC, 2021).

In the context of developing nations like Tanzania, deforestation and forest degradation contribute significantly to national carbon emissions. Tanzania is estimated to emit roughly 126 million tons of CO_2 per year, with 78 million tons attributed to deforestation and 48 million tons to forest degradation (FAO, 2022). These emissions represent a substantial portion of the country's carbon footprint, reflecting the broader global trend where land use changes are a key factor in climate dynamics. Forest loss in Tanzania, driven by agricultural expansion, logging, and other land-use pressures, contributes to atmospheric carbon and threatens biodiversity and ecosystem services essential for local livelihoods (Kulindwa et al., 2016).

Sub-Saharan Africa, where Tanzania is situated, is highly vulnerable to climate change. Shifting climatic patterns have already begun to affect ecosystems across the region, leading to species extinction, altered migration routes, and changes in reproductive behaviors (Fordham et al., 2013). The degradation of terrestrial and aquatic ecosystems due to unsustainable land use practices exacerbates these challenges, creating new ecological niches for invasive species and further accelerating biodiversity loss (Williams et al., 2021). In response, there have been calls for expanding protected areas (PAs) and establishing wildlife corridors to maintain ecosystem connectivity, enabling species migration and adaptation to changing environmental conditions (Heller & Zavaleta, 2009).

Despite efforts to enhance biodiversity conservation, the effectiveness of various habitat configuration strategies remains difficult to quantify. Limited ecological models hinder the ability to fully assess how well wildlife corridors and other conservation approaches support biodiversity in the face of climate change (Carroll et al., 2020). The situation is particularly critical in ecosystems like Tanzania’s Kilombero Valley Floodplain (KVFP), an ecologically significant area that provides essential ecosystem services to local communities and acts as a natural carbon sink. However, land use intensification, wetland degradation, and population growth pose significant threats to this ecosystem (Leemhuis et al., 2017). Over recent decades, deforestation, agricultural expansion, and other land use changes have disrupted the valley's water balance and degraded wildlife corridors, resulting in a decline in biodiversity and the loss of carbon sequestration potential (Muro et al., 2017; Msofe et al., 2020).

Addressing these issues requires a comprehensive understanding of the link between land use changes and carbon dynamics in the KVFP. Although the valley’s ecological importance has been recognized, the specific impacts of land use and cover change on biomass depletion and carbon emissions are not fully understood. Assessing the extent of biomass depletion and quantifying the associated carbon emissions are crucial steps toward developing sustainable management strategies for the valley (Msofe et al., 2019). Moreover, such assessments are essential for raising awareness about the broader consequences of ecosystem degradation, estimating the economic costs of carbon emissions, and informing climate policy.

This study, therefore, aims to contribute to these efforts by providing a detailed analysis of biomass depletion and carbon emissions in the Kilombero Valley Floodplain over the past three decades. Specifically, the study seeks to:

(i) Estimate the biomass lost due to land use and cover change (LULCC) in KVFP from 1990 to 2020.
(ii) Quantify the carbon emissions associated with LULCC in KVFP from 1990 to 2020.
(iii) Assess the financial cost of carbon emissions from LULCC in KVFP from 1990 to 2020.

In doing so, the study also reflects on the legacy of Julius Nyerere, Tanzania's founding president, whose environmental stewardship and sustainable development vision remain relevant in shaping contemporary climate action strategies. By exploring these dimensions, this research aims to provide a critical understanding of how land-use policies and practices in Tanzania's Kilombero Valley contribute to climate change and how strategic interventions can mitigate these impacts.

1.2 Motivation of the study

The motivation for this study stems from the pressing need to address the dual crises of environmental degradation and climate change, particularly in regions like Tanzania's Kilombero Valley, which are both ecologically significant and highly vulnerable to anthropogenic pressures. As the world continues to grapple with the adverse impacts of climate change, there is an urgent need to understand better how local and regional land-use practices contribute to global carbon emissions. This understanding is crucial for informing policies and actions to mitigate these impacts.

The Kilombero Valley Floodplain (KVFP) is a critical ecosystem, providing vital services such as water regulation, biodiversity conservation, and carbon sequestration. However, the valley faces significant threats from deforestation, agricultural expansion, and other land-use changes, leading to biomass depletion and increased carbon emissions. Despite the recognized importance of the KVFP, there has been limited research on the extent of biomass loss and the resulting carbon emissions over time. This study aims to fill this knowledge gap by offering a detailed assessment of the valley's biomass depletion and carbon dynamics over the past three decades.

Another key motivation for this paper is to highlight the relevance of Julius Nyerere's legacy in shaping sustainable development and environmental stewardship in Tanzania. Nyerere, Tanzania's first president, advocated for the sustainable use of natural resources and was a proponent of policies promoting conservation and community-based management of ecosystems. In light of contemporary climate challenges, revisiting Nyerere's principles can provide valuable insights for developing strategies that address environmental conservation and socio-economic development in Tanzania. By linking Nyerere's legacy to modern climate action strategies, this paper inspires policymakers to integrate historical perspectives with current scientific findings to craft effective, context-specific solutions for mitigating climate change.

Moreover, this paper is motivated by the need to raise awareness among stakeholders- from local communities to policymakers—about the long-term consequences of unchecked land-use change in the Kilombero Valley. By quantifying the financial cost of carbon emissions resulting from deforestation and land degradation, the study provides a concrete basis for advocating sustainable land management practices. It also contributes to the broader discourse on climate justice, as developing countries like Tanzania, which are disproportionately affected by climate change, require data-driven strategies to adapt and mitigate the effects of global warming.

Thus, this paper aims to advance scientific understanding, inform policy, and stimulate meaningful action to protect the Kilombero Valley's ecosystem, while offering a framework that draws on historical legacies to tell today's climate solutions. By publishing this research, the authors hope to contribute to the global knowledge on climate change mitigation and encourage more sustainable land-use practices in Tanzania and beyond.

2. Methodology

2.1. Study Area

The study focuses on the Kilombero Valley floodplain (KVFP) (Figure 1), situated in the Morogoro region of southeastern Tanzania. Spanning approximately 30,500 km², the Kilombero Valley lies within the floodplain of the Kilombero River catchment, nestled between the Udzungwa Great Escarpment to the north and the Mahenge Highlands to the south. Administratively, the valley is divided into three districts: Kilombero, Ulanga, and Malinyi, with coordinates ranging from 10°00′ to 08°40′ S and 35°10′ to 37°10′ E. The Kilombero River flows through the valley and is fed by permanent and seasonal rivers originating from the mountains. These rivers nourish the seasonal Kilombero wetlands, covering an area of 7967 km², making them the largest freshwater wetland in Africa below 300 meters above sea level. Renowned for their rich biodiversity and serving as vital wildlife corridors, the wetlands harbour numerous endemic species of flora and fauna. Recognized as a Ramseur site in 2002, the Kilombero Valley is managed by the Ministry of Natural Resources and Tourism following the rules and regulations stipulated by the Ramsar Convention of 1971.

The Kilombero Valley floodplain (KVFP) experiences a sub-humid tropical climate, characterized by an annual rainfall ranging from approximately 1200 to 1400 mm and a relative mean humidity between 70 and 90% (Wilson *et al.*, 2018). However, precipitation within the floodplain exhibits notable spatiotemporal variability, with the mountainous regions receiving up to 2100 mm of rainfall, approximately 1000 mm more than the floodplain itself (Wilson *et al.*, 2018). The valley experiences two rainy seasons, with an annual mean temperature ranging from 24 °C in the valley to 17 °C in higher altitudes

(Wilson *et al.*, 2018). Geologically, the KVFP is characterized by sedimentary basin infillings, forming a seasonal alluvial floodplain dominated by fluvisols. The natural vegetation in the area varies depending on the proximity to rivers. Vegetation along riversides is typically dominated by *Hyparrhenia* spp. and Reed (*Phragmites mauritianus* Kunth.). At the same time, low-lying valley grasslands feature perennial grasses such as Guinea grass (*Panicum maximum* Jacq.), occasionally interspersed with trees. Marginal woodlands, combretaceous wooded grasslands, and miombo woodland and forests are found in the upper valley (Starkey *et al.*, 2002).

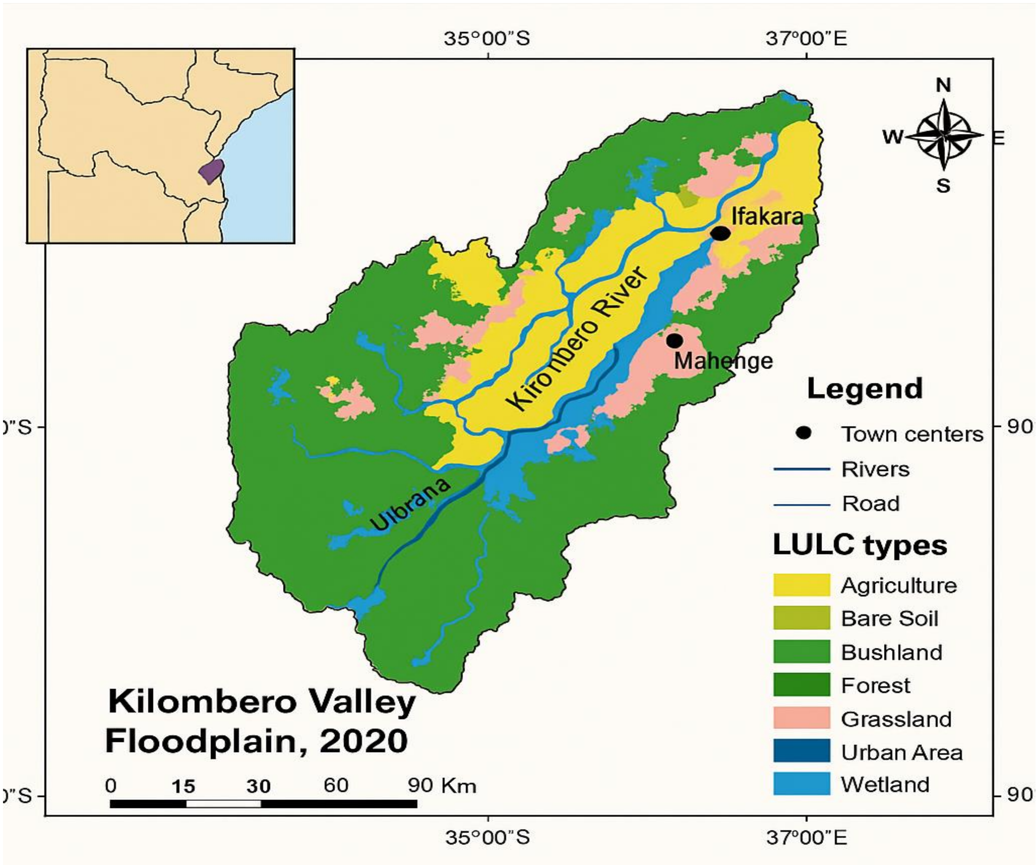

Figure 1: Map of the study area

Socio-economic activities in the KVFP primarily revolve around crop production, livestock keeping, and fishing (Wilson *et al.*, 2018). The fertile floodplain has historically attracted farmers to crop production, with approximately 80% of the rural population involved in subsistence, small-scale irrigated, and rain-fed agriculture. Rice, maize, sugarcane, and cocoa, and banana cultivation are prevalent (URT, 2010). Agriculture plays a significant role in national and local economies, contributing to 25% of the Gross Domestic Product (GDP) nationally and representing three-quarters of the region's income for individual rural households (Wilson *et al.*, 2018). Presently, rice and sugarcane cultivation, along with livestock keeping, dominate the landscape's land use pattern.

2.2. Data Used and Methods

The Land Use/Cover Change (LULC) datasets utilized in this study were generated through supervised image classification using the random forest (RF) algorithm applied to Landsat-5 Thematic Mapper (TM) imagery from 1990 and 2010, as well as Landsat-8 Operational Land Imager (OLI) imagery from 2020, all with a spatial resolution of 30 meters. The classification was conducted using ArcGIS Desktop version 10.2 software by Esri, California, USA. The land use and land cover types were categorized into eight classes: forest, bushland, grassland, agriculture, urban area, bare soil, water, and wetland.

LULC change detection was performed using spatial automatic overlay analysis and the Zonal Tabulate Area function in ArcGIS version 10.2 to generate the Markov chain transition matrix of the study area. Subsequently, a post-classification process was carried out, involving recoding, majority filtering, clumping, elimination, and mosaicking of the classified maps to minimize errors in the produced maps.

An accuracy assessment was conducted, revealing overall classification results with an accuracy of 86.7% and a kappa coefficient of 0.82, meeting the requirements of the accuracy test and validating the classification results. The eight LULC types and their respective biomes were identified as follows: cropland for agriculture, desert for bare land, tropical forest for bushland, tropical forest for forest, grass/rangelands for grassland, urban area for settlement, rivers/lakes for water, and wetland/marsh for wetland (Table 1).

Table 1: Land use and land cover (LULC) types

	Year & Area (ha)			
LULC Type	**1990**	**2010**	**2020**	**Equivalent Biome**
Agriculture	141,200	405,300	484,200	Cropland
Bare land	1,100	700	700	Desert
Bush land	549,700	594,300	246,000	Tropical Forest
Forest	1,954,400	1,679,200	1,641,500	Tropical Forest
Grassland	237,000	266,000	642,500	Grasslands
Settlement	0	100	3,800	Urban area
Water	22,900	5,600	3,000	Fresh water
Wetland	141,500	96,600	26,100	Wetland

Figure 2 shows the flow chart of the methodological approach used in this study to estimate the biomass and carbon stocks for 1990, 2010 and 2016 years and the computation of changes between study periods.

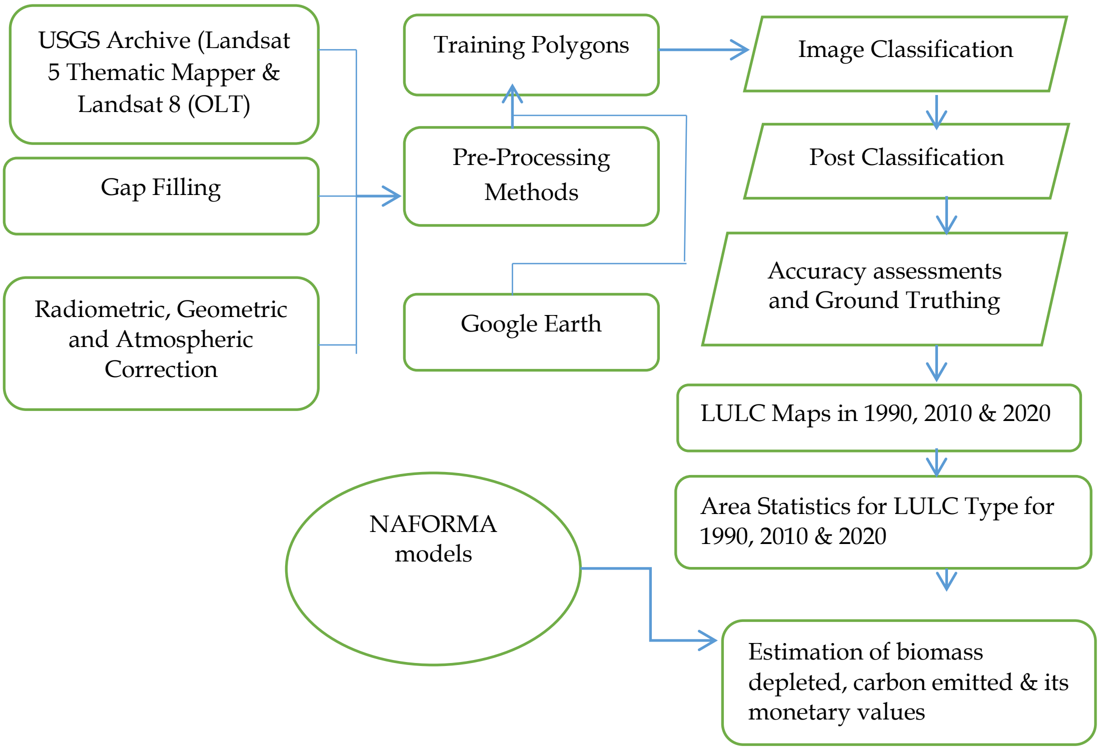

Figure 2: Flowchart of the methodological approach for this study

2.3 Data analysis

2.3.1 Amount of biomass depleted as a result of LULCC in KVFP from 1990 to 2020

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 in the 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's formula multiplied by wood density of

619 kg/m^3 (Chidumayo, 2012, cited by URT, 2015). URT (2015), through NAFORMA, reveals that the dead wood biomass of Tanzania (Table 3) is relatively low since most dead wood in accessible areas is collected as fuelwood. As woodlands are generally more accessible than forests, collecting deadwood for fuelwood from these areas is easier. The relatively high volume of dead wood in water is assumed to be because dead trees lying in areas with water/wetlands are difficult to access and decay slowly, and because they are wet and therefore unattractive for fuelwood, as shown in Table 2.

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

Vegetation Type	AG	BRL	BS	FT	GL	ST	WTR	WTL
AGB (t/ha)	5.9	2.9	11.0	59.5	2.9	2.9	4.6	4.6
BGB (t/ha)	2.1	1.1	4.4	18.2	1.1	1.1	1.7	1.7
DWB(t/ha)	0.91	0.22	0.73	4.87	0.35	0.22	1.31	1.31

AG = Agriculture, **BRL** = Bareland, **BS** = Bushland, **FT** = Forest, **GL** = Grassland, **ST** = Settlement, **WTR** = Water, **WTL** = Wetland

2.3.2 Amount of carbon emitted to the atmosphere as a result of LULCC in KVFP from 1990 to 2020

According to URT (2015), carbon in the 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 3.

Table 3: Living tree stemwood, deadwood carbon by primary vegetation type

Vegetation Type	AG	BRL	BS	FT	GL	ST	WTR	WTL
AGC + BGC (t/ha)	3.8	1.9	7.2	36.5	1.8	1.9	3.0	3.0
DWC (t/ha)	0.45	0.11	0.36	2.39	0.17	0.11	0.64	0.64

2.3.3 Carbon dioxide emitted to the atmosphere

Estimating the carbon dioxide (CO_2) emitted from KVFP 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:

$$CO_2\text{(tonnes)} = \text{Carbon(tonnes)} \times 3.67$$

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

$$\text{Total } CO_2 \text{ (tonnes)} = AGCO_2 \text{ (tonnes)} + BGCO_2 \text{ (tonnes)} + DWCO_2 \text{ (tonnes)}$$

2.3.4 Economic loss of KVFP resulted from carbon emissions from 1990 to 2020

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 Kilombero Valley floodplain for the period 1990-2020.

3. Results and Discussion

3.1 Biomass depleted as a result of LULCC in KVFP from 1990 to 2020

The analysis of biomass depletion in the Kilombero Valley Flood Plain (KVFP) from 1990 to 2020 (Table 4) indicates a dramatic ecological shift, with forest biomass declining by 95.9%, equating to a loss of approximately 25.84 million tons. Bushland areas also faced significant degradation, losing 5.9 million tons, leading to a total biomass depletion of 26.93 million tons over three decades (Njuki et al., 2023). This trend aligns with broader deforestation patterns in sub-Saharan Africa, where forested areas are increasingly converted for agricultural use.

In contrast, agricultural and grassland areas in KVFP saw biomass increases of 3.06 million tons (11.3%) and 1.76 million tons (6.5%), respectively. These gains stem from land-use changes, such as converting forests into agricultural plots, which can temporarily boost biomass due to crop and grass growth (Kilawe et al., 2023). However, these ecosystems lack mature forests' long-term carbon sequestration capabilities (Zhu et al., 2022).

The significant loss of forest biomass seriously impacts carbon emissions, as forests serve as vital carbon sinks. The depletion leads to the release of stored carbon, exacerbating greenhouse gas emissions, a trend supported by recent studies linking deforestation to rising emissions (Chidumayo & Gumbo, 2023). Bushland degradation further compounds this issue, reducing ecological functions essential for climate regulation.

Despite the modest biomass gains in agricultural and grassland areas, they cannot offset the extensive losses from forest and bushland degradation

(Mengesha et al., 2023). The legacy of Julius Nyerere's sustainable practices, emphasizing conservation and community involvement, offers valuable insights for modern climate strategies. Integrating these principles with innovative solutions, such as remote sensing and agroforestry, is crucial for sustainable land management and climate resilience in KVFP (Mshandete & Mwalyego, 2022).

Table 4: Living tree stemwood and deadwood biomass (10^3 tons) depleted from 1990 to 2020

LULC	AG	BRL	BS	FT	GL	ST	WTR	WTL	Total
AGB	-2,023.7	1.2	3,342.9	18,617.6	-1,176.0	-11.0)	91.5	530.8	19,384.3
BGB	-720.3	0.4	1,337.2	5,694.8	-446.1	-4.2	33.8	196.2	6,091.8
DWB	-312.1)	0.1	221.9	1,523.8	-141.9	-0.8	26.1	151.2	1,468.3
Total	-3,056.1	1.7	4,901.9	25,836.2	-1,763.9	-16.0	151.4	878.2	26,933.4
%age	-11.3	0.0	18.2	95.9	-6.5	-0.1	0.6	3.3	100.0

AG = Agriculture, **BRL** = Bareland, **BS** = Bushland, **FT** = Forest, **GL** = Grassland, **ST** = Settlement, **WTR** = Water, **WTL** = Wetland

3.2 Carbon emitted to the atmosphere as a result of LULCC in KVFP from 1990 to 2020

The Kilombero Valley Flood Plain (KVFP) study highlights significant carbon emissions due to land-use changes from 1990 to 2020 (Table 5), totalling approximately 12.66 million tons, predominantly from deforestation (95.9%). Bushland degradation contributed 18.2%, while wetlands and water bodies accounted for 3.3% and 0.6%, respectively. Conversely, agricultural areas (11.3%) and grasslands (6.5%) demonstrated some carbon absorption, although insufficient to counterbalance emissions from forest and bushland loss (Njuki et al., 2023; Zhu et al., 2022).

The findings emphasize the critical role of forests as carbon sinks, where their degradation releases stored CO_2, exacerbating greenhouse gas concentrations and global warming. Despite lower biomass density, bushlands also play a significant ecological role, and their loss is consequential. Wetlands, while contributing minimally to emissions, are vital for carbon cycling, and their degradation diminishes their long-term carbon storage capacity (Mengesha et al., 2023).

The implications for climate action in Tanzania are profound, necessitating urgent forest conservation and restoration initiatives. Policies promoting reforestation, sustainable logging, and alternative livelihoods for communities dependent on forest resources are essential to mitigate further degradation. Enhancing agricultural practices to improve soil carbon storage and afforestation in grasslands and settlements can also help offset emissions (Chidumayo & Gumbo, 2023).

Julius Nyerere's conservation philosophy provides a framework for these challenges, advocating for sustainable resource management and community involvement. By prioritizing community-led reforestation and employing modern technologies for carbon monitoring, Tanzania can effectively address deforestation and promote ecological balance (Mshandete & Mwalyego, 2022). Overall, targeted interventions integrating sustainable land management practices are crucial for mitigating climate impacts while preserving the region's ecological and socio-economic integrity.

Table 5: Living tree stemwood and dead wood carbon (10^3 tons) emitted from 1990 to 2020

LULC	AG	BRL	BS	FT	GL	ST	WTR	WTL	Total
AGB	-951.1	0.6	1571.2	8,750.3	-552.7	-5.2	43.0	249.5	9,105.5
BGB	-338.5	0.2	628.5	2,676.6	-209.7	-2.0	15.9	92.2	2,863.1
DWB	-146.7	0.0	104.3	716.2	-66.7	-0.4	12.3	71.1	690.1
Total	-1,436.4	0.8	2,303.9	12,143.0	-829.1	-7.5	71.2	412.8	12,658.7
%age	-11.3	0.0	18.2	95.9	-6.5	-0.1	0.6	3.3	100.0

3.3 Carbon dioxide emitted to the atmosphere as a result of LULCC in KVFP from 1990 to 2020

The analysis of carbon dioxide (CO_2) emissions in the Kilombero Valley Flood Plain (KVFP) from 1990 to 2020 (Table 6) reveals significant environmental changes with implications for climate action. During this period, KVFP emitted approximately 46.46 million tons of CO_2, predominantly from forests (95.9%), followed by bushlands (18.2%), wetlands (3.3%), and water bodies (0.6%). Conversely, carbon sequestration occurred mainly in agricultural lands (11.3%) and grasslands (6.5%) (Njuki et al., 2023).

Forests emerged as the primary source of CO_2 emissions, highlighting the critical issues of deforestation and degradation. The loss of forests due to agricultural expansion and logging releases stored carbon, contributing significantly to greenhouse gas emissions. This trend aligns with global patterns observed in bio-diverse regions, particularly in sub-Saharan Africa. Bushlands, while contributing 18.2% to emissions, are also vulnerable to human activities, and their degradation exacerbates the overall carbon footprint. Wetlands, contributing 3.3% of emissions, are essential for carbon storage and biodiversity, and their loss is linked to increased climate vulnerabilities (Mengesha et al., 2023).

On the positive side, agricultural lands and grasslands demonstrate potential for carbon sequestration through sustainable practices like agroforestry. However, urban settlements show minimal sequestration (0.1%), indicating a need for more green spaces (Zhu et al., 2022). The findings underscore the urgency for climate mitigation strategies focused on forest conservation, sustainable land-use practices, and wetland protection (Chidumayo & Gumbo, 2023).

Drawing on Julius Nyerere's principles of sustainable development, engaging local communities in conservation efforts and utilizing modern technologies for monitoring can enhance the effectiveness of climate strategies (Mshandete & Mwalyego, 2022). Overall, addressing the drivers of emissions while promoting carbon sequestration is essential for advancing Tanzania's climate resilience and contributing to global climate change mitigation efforts.

Table 6: Carbon dioxide (10^3 tons) emitted to the atmosphere from 1990 to 2020

LULC	**AG**	**BRL**	**BS**	**FT**	**GL**	**ST**	**WTR**	**WTL**	**Total**
AGB	-3,490.7	2.1	5,766.2	32,113.5	-2,028.5	-19.0	157.8	915.6	33,417.0
BGB	-1,242.4	0.7	2,306.5	9,823.0	-769.5	-7.2	58.3	338.4	10,507.7
DWB	-5,38.3	0.2	382.8	2,628.4	-244.8	-1.4	45.0	260.8	2,532.7
Total	-5,271.5	2.9	8,455.5	44,564.9	-3,042.7	-27.6	261.1	1,514.8	46,457.4
%age	-11.3	0.0	18.2	95.9	-6.5	-0.1	0.6	3.3	100.0

3.4 Economic loss of KVFP resulted from carbon emissions from 1990 to 2020

The Kilombero Valley Flood Plain (KVFP) has experienced significant economic losses from 1990 to 2020 (Table 7), totalling approximately US$185.83 million, primarily due to biomass depletion and land-use changes. Forests accounted for 95.9% of these losses, highlighting their essential role in providing ecosystem services such as timber, non-timber forest products, and carbon sequestration (Njuki et al., 2023). The degradation of forests not only diminishes the supply of these resources and impacts vital ecosystem functions like water regulation and biodiversity conservation.

Bushlands and wetlands also contributed to economic losses, with bushlands accounting for 18.2% and wetlands for 3.3%. The degradation of these areas adversely affects local livelihoods reliant on grazing, fuelwood, and resource harvesting, while wetlands play a crucial role in water filtration and flood regulation (Mengesha et al., 2023). Conversely, modest economic gains were noted in agriculture (11.3%) and grasslands (6.5%), driven by agricultural expansion. However, these gains often come at the cost of forest and bushland conversion, raising concerns about long-term sustainability (Zhu et al., 2022).

The minimal contribution of settlements (0.1%) reflects limited urban growth in KVFP, underscoring the need for integrated policy interventions to balance economic development with environmental sustainability. Julius Nyerere's philosophy of sustainable resource use provides a framework for addressing these challenges, advocating for reforestation and sustainable land management (Mshandete & Mwalyego, 2022). Technological solutions, such as remote sensing and community-driven initiatives like payment for ecosystem services, can further support conservation efforts (Chidumayo & Gumbo, 2023). Overall, the findings emphasize the urgent need for sustainable land-use practices to mitigate economic losses and enhance resilience in KVFP.

Table 7: Economic loss (US$103) of KVFP resulted from carbon emissions from 1990 to 2020

LULC	AG	BRL	BS	FT	GL	ST	WTR	WTL	Total
AGB	-13,962.7	8.3	23,064.7	128,454.0	-8,113.9	-75.9	631.3	3,662.3	133,668.0
BGB	-4,969.8	2.8	9,226.1	39,291.8	-3,077.9	-29.0	233.2	1,353.7	42,031.0
DWB	-2,153.4	0.7	1,531.0	10,513.6	-979.1	-5.5	180.1	1,043.2	10,130.7
Total	-21,085.9	11.7	33,821.8	178,259.4	-12,170.9	-110.4	1044.6	6,059.2	185,829.7
%age	-11.3	0.0	18.2	95.9	-6.5	-0.1	0.6	3.3	100.0

4. Conclusion and Recommendations

4.1 Conclusion

The analysis of biomass depletion and carbon emissions in the Kilombero Valley Flood Plain (KVFP) from 1990 to 2020 reveals significant environmental and socio-economic issues. The region has experienced severe biomass loss, primarily from forests, which accounted for 95.9% of the depletion, leading to increased carbon emissions and economic losses. While agricultural and grassland biomass gains were noted, they provided minimal economic benefits and did not compensate for the degradation of forests and wetlands. The study underscores the urgent need for sustainable land management and conservation strategies to mitigate these challenges. Drawing on Julius Nyerere's conservation philosophy, it advocates for community-driven conservation and sustainable resource management, integrating modern technology into climate action. Nyerere's focus on environmental stewardship serves as a framework for aligning development with ecological sustainability, essential in addressing the pressing climate change issues today.

4.2 Recommendations

The proposed strategies for enhancing forest conservation and restoration, promoting sustainable agriculture, and protecting wetlands are crucial for addressing climate change and ecological degradation in Tanzania, particularly in the Kilimanjaro and Volcanic Forest Protected (KVFP) areas. Key initiatives include large-scale reforestation and afforestation projects to restore degraded forests and enhance carbon sequestration. Community-based forest management models are encouraged to empower local populations in sustainable resource utilization, alongside payment for ecosystem services (PES) schemes that financially reward conservation efforts.

Sustainable agricultural practices are promoted through agroforestry systems that integrate trees into farming, improving soil fertility and diversifying farmer incomes. Training in conservation agriculture practices is essential to minimize land degradation, while supportive policies are needed to discourage deforestation linked to agricultural expansion.

Wetland protection is emphasized through strengthened legal frameworks and targeted restoration initiatives to enhance ecosystem functionality. Technology, such as remote sensing and GIS, is recommended for real-time monitoring of biomass changes and carbon emissions, alongside accurate carbon accounting systems.

Integrating climate action into development planning involves aligning land-use policies with climate goals and investing in climate-resilient infrastructure. Drawing inspiration from Julius Nyerere's legacy, community engagement, education, and incorporating indigenous knowledge into conservation strategies are vital for sustainable solutions.

International collaboration and funding are essential for securing resources for conservation projects, while exploring carbon trading mechanisms can generate revenue for local livelihoods. Economic valuation of ecosystem services should be integrated into national accounting systems to underscore the importance of conservation, with compensation mechanisms established for communities affected by conservation efforts.

Thus, by implementing these integrated strategies, Tanzania can align its development with global climate goals, transforming KVFP into a resilient model that balances ecological sustainability with economic progress for future generations.

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