Implications of Land Use and Cover Transformation on Biomass and Carbon Sequestration in Coastal Areas of Kinondoni, Tanzania

Abstract

This study investigates the impacts of land use and land cover (LULC) changes on biomass loss and carbon sequestration in Kinondoni, Tanzania, from 1993 to 2023. Using the National Forest Resources Monitoring and Assessment (NAFORMA) models and geospatial analysis, the research quantifies the environmental and economic consequences of rapid urbanization, agricultural expansion, and infrastructural development. Mangrove forests, vital for carbon sequestration, have been significantly degraded, leading to an estimated biomass loss of 65,600 tonnes, with mangroves accounting for 93.1% of these losses. This degradation has critically reduced the region's carbon storage capacity, releasing 30,830 tonnes of carbon, equivalent to 113,150 tonnes of carbon dioxide (CO_2). Additionally, the study estimates an economic loss of approximately US$ 452,610 due to the reduction in carbon sequestration potential, which could have been mitigated through carbon trading markets. The destruction of mangroves is identified as the main driver of these losses. The findings highlight the urgent need for targeted conservation and restoration efforts, particularly in mangrove ecosystems, to prevent further environmental and economic degradation. The study advocates for sustainable land use policies and emphasizes incorporating ecosystem services valuation into decision-making processes to enhance resilience in coastal Tanzania.

Comment [L1]: The summary should specify the methods for estimating biomass, carbon and the economic value of carbon

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

1. Introduction

The rapid transformation of land use and land cover (LULC) in coastal regions has emerged as a major global concern, particularly in fast-urbanizing areas like Kinondoni District, Tanzania. Coastal ecosystems such as mangroves, seagrass beds, and coastal forests play a critical role in carbon sequestration and biomass maintenance. These ecosystems act as essential carbon sinks, storing substantial amounts of carbon that would otherwise contribute to atmospheric greenhouse gases (Osland et al., 2021). However, growing pressures from urban expansion, agricultural encroachment, and infrastructural development are causing significant LULC changes, leading to the degradation of these ecosystems (Bunting et al., 2022). Kinondoni District, located along the Indian Ocean in Dar es Salaam, faces intense pressure from population growth and economic activities due to its proximity to Tanzania's largest urban center. This has led to widespread deforestation, the conversion of natural landscapes into urban and agricultural land, and the degradation of vital coastal ecosystems (Nguyen et al., 2023). The subsequent loss of biomass in these areas reduces their carbon sequestration

capacity and releases stored carbon back into the atmosphere, exacerbating the effects of climate change (Friess et al., 2023).

Mangrove forests, in particular, are crucial for carbon sequestration, often referred to as "blue carbon" ecosystems due to their efficiency in capturing and storing carbon in both biomass and sediments. However, the destruction of these ecosystems, driven by LULC changes, disrupts their carbon storage functions, leading to higher carbon emissions and a loss of ecosystem services vital for mitigating climate change (Chausson et al., 2023). Furthermore, the degradation of mangroves and other coastal ecosystems has led to reduced biodiversity, altered hydrological cycles, and increased vulnerability to climate-related hazards such as storm surges and coastal erosion (Osland et al., 2021). Likewise, the LULC changes in Kinondoni have extensive local and global implications. The conversion of forests and other vegetative cover into urban areas reduces biomass and, consequently, the region's carbon sequestration potential (Bai et al., 2022). Research has demonstrated that deforestation and land degradation in coastal regions significantly increase carbon emissions, highlighting the urgency to address these impacts (Wang et al., 2021). Compounding these challenges is the lack of effective land management and conservation strategies in Kinondoni. Despite recognition of the importance of coastal ecosystems, conservation efforts are hindered by competing land use demands and weak policy enforcement (Lu et al., 2022).

To address these concerns, the current study examines the implications of LULC transformations on biomass loss and carbon sequestration in Kinondoni's coastal areas. It aims to analyze the spatial and temporal dynamics of LULC changes and their impact on carbon storage, providing insights to inform sustainable land use planning and conservation strategies (Osland et al., 2021). A major challenge in managing LULC changes in coastal regions like Kinondoni is balancing economic development with the preservation of vital ecosystems. While urban expansion and infrastructure development offer immediate economic benefits, they come at a high environmental cost. The loss of mangrove forests and other coastal habitats reduces carbon sequestration and increases the region's vulnerability to climate-related risks (Chausson et al., 2023). Furthermore, to effectively mitigate the impacts of LULC changes, integrated land management approaches are necessary. These strategies should prioritize ecosystem preservation alongside sustainable development, including strict land use regulations, incentives for reforestation, and sustainable agricultural practices (Nguyen et al., 2023). Additionally, enhanced monitoring and enforcement of environmental policies are crucial to ensure conservation efforts are not undermined by illegal land use or poor management practices (Lu et al., 2022). By identifying the most affected areas and key drivers of LULC changes, the study aims to contribute to targeted conservation strategies that address the challenges posed by urbanization and land degradation.

2. Methods

2.1 Description of the study area

This study focuses on the coastal wards of Mbweni and Ununio in Kinondoni District, Dar es Salaam, Tanzania (Figure 1), a region of significant ecological and economic importance. Spanning 531 square kilometers along the Indian Ocean, Kinondoni is part of the biodiversity-rich Western Indian Ocean region, crucial for supporting both local and regional economies (URT, 2020; Richmond et al., 2017). The district's coastal ecosystems, including coral reefs, mangroves, and seagrass beds, are essential for maintaining biodiversity and providing ecosystem services like fisheries, coastal protection, carbon sequestration, and tourism (Osland et al., 2021). Mangroves, in particular, play a vital role as carbon sinks, storing carbon in their biomass and sediments, thus mitigating climate change (Chausson et al., 2023). However, these ecosystems face severe threats from rapid urbanization, population growth, and unsustainable practices, leading to habitat loss and degradation, especially in Mbweni and Ununio (Nguyen et al., 2023; Mohammed et al., 2021). This study aims to quantify the economic value of these ecosystem services, assessing land use impacts on biomass and carbon sequestration to inform sustainable management strategies (Bunting et al., 2022; Friess et al., 2023).

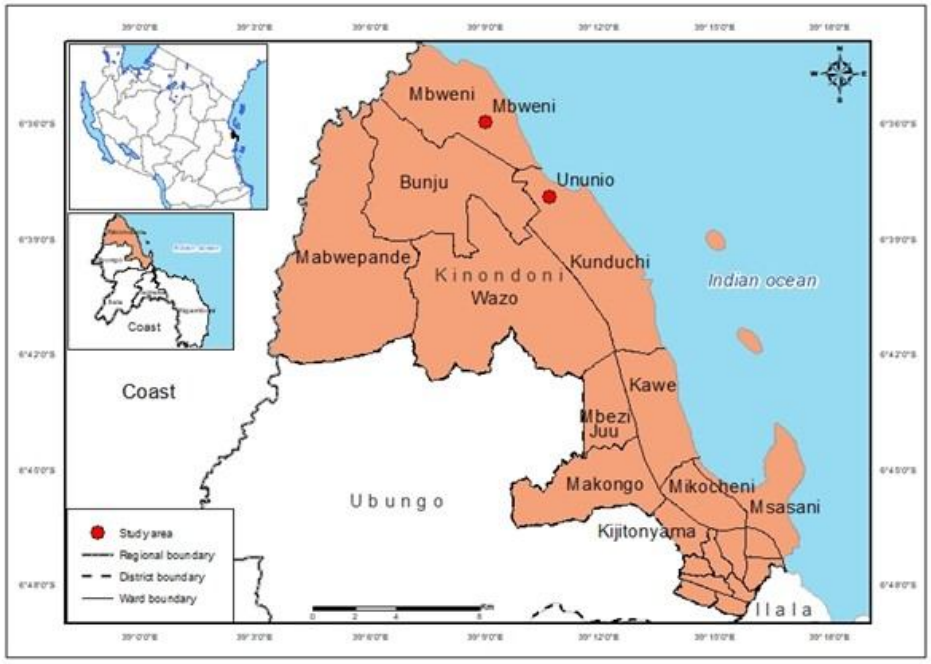

Figure 1: The Map of the study area

2.2 Data sets

2.2.1 Spatial data

The study evaluated the impact of land use and cover transformation on biomass loss and carbon sequestration in Kinondoni, Tanzania, from 1993 to 2023 using diverse spatial data sets. Satellite imagery from the United States Geological Survey (USGS), including data from the Global Visualization Viewer (USGS-GLOVIS) and Earth Explorer platforms, was crucial for mapping land use changes and assessing coastal ecosystems. The study utilized Landsat images from 1993 and Sentinel-2 images from 2023, sourced through Tanzania's Department of Urban Planning and the Earth Resources Observation and Science (EROS) Center, providing detailed insights into LULC changes and their effects on biomass and carbon sequestration (USGS, 2023; EROS, 2023; DoSUP, 2022).

Comment [L2]: What materials and data are used?
There should be a section presenting the types of data used, another for the hardware and another for the software.

Comment [L3]: Describe the method used to process satellite images to assess land-use change between 1993 and 2023.
Why were images from two different sensors (Landsat and sentinel) chosen?
If you have used images that have already been classified, please specify this.

Table 1: Area statistics for LULC change (ha) in the study area (1993 -2023)

LULC	Mangrove forest	Shrub land	Bare area	Water	Built-up area	Cultivated land
1993 - 2023	737.62	546.41	402.11	-7.22	-1780.93	167

2.2.2 Socio-economic and population data

The study integrated socio-economic and population data, including the 2022 census from the National Bureau of Statistics (NBS), to assess the impact of human activities on land use changes in Kinondoni, Tanzania, from 1993 to 2023. By correlating population growth with land use changes, such as deforestation, the research highlighted the socio-economic drivers behind biomass loss and carbon sequestration, offering a comprehensive understanding of the relationship between human development and environmental changes (NBS, 2023).

Comment [L4]: Apart from the 2022 census, what other sources of socio-economic data are being used?

2.2.3 Geospatial analysis tools

The study utilized advanced geospatial analysis tools, specifically Geographic Information System (GIS) software, to integrate various data sets, including satellite imagery, population statistics, and socio-economic data. This integration facilitated the creation of detailed land use and forest type maps, enabling the visualization of changes over time and identifying areas most impacted by deforestation and degradation. By merging spatial and socio-economic data, the study provided a comprehensive analysis of biomass loss, carbon emissions, and sequestration potential in Kinondoni's coastal areas, informing effective conservation strategies (GIS Software, 2023).

Comment [L5]: Which GIS software was used to map land use?

2.3 Data analysis

2.3.1 Biomass loss of the study area for the period 1993 – 2023

The estimation of biomass loss in Kinondoni District's coastal areas from 1993 to 2023 involves detailed calculations of both living and dead biomass components. Living biomass is divided into above-ground biomass (AGB) and below-ground biomass (BGB), while dead biomass includes dead wood (DW) as indicated in equations 1-3 and details in Table 2. Together, these components offer a comprehensive understanding of carbon emissions and sequestration potential, crucial for assessing the environmental impacts of land use changes (Henry et al., 2011).

AGB, which includes tree trunks, branches, and leaves, represents a significant portion of carbon storage. This study follows the United Republic of Tanzania's (URT) 2015 National Forest Resources Monitoring and Assessment (NAFORMA) framework, utilizing allometric equations specific to local conditions to estimate biomass accurately (URT, 2015). BGB, encompassing root biomass, complements AGB by accounting for subterranean carbon storage, often estimated using root-to-shoot ratios suitable for tropical ecosystems (IPCC, 2019). DW biomass estimation includes the mass of dead trees and woody debris, further informing carbon dynamics in these ecosystems (Kauffman et al., 2020). Thus, by integrating these methodologies, the study effectively quantifies total biomass loss and assesses its impact on carbon sequestration in Kinondoni's coastal regions over three decades. This analysis is essential for guiding sustainable land management and conservation strategies to mitigate climate change and preserve vital ecosystem service

AGB (tonnes / ha) = Tree stem volume (m^3 / ha) x wood density / 1000 ……1

BGB (tonnes / ha) = AGB x 0.25 (as default), or root to shoot ratios……..……,,,.……2

DW (tonnes / ha) = V × Wood Density……...3

Where; V= 0.5L (A_1 +A_2) 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

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

Vegetation type	Mangrove forest	Shrubland	Bare area	Water	Built up area	Cultivated land
AGB(t/ha)	59.5	11	2.9	4.6	2.9	5.9
BGB (t/ha)	18.2	4.4	1.1	1.7	1.1	2.1
DWB(t/ha)	5.09	0.77	0.22	1.31	0.22	0.96

2.3.2 Carbon emission of the study area for the period 1993 – 2023

Estimating carbon emissions is crucial for understanding the role of Kinondoni's coastal areas in carbon sequestration and climate change mitigation. This study uses the United Republic of Tanzania's (URT, 2015) National Forest Resources Monitoring and Assessment (NAFORMA) methodology to calculate carbon emissions by measuring

biomass and applying conversion factors to estimate carbon content in living and dead organic matter as indicated in equations 4 – 5 and details in Table 3. This approach helps assess the impact of land use changes, like deforestation, on carbon sequestration, providing valuable insights into the region's contribution to global carbon cycles and the effectiveness of conservation strategies (URT, 2015).

Carbon (tonnes)=Biomass (tonnes)×0.47……..4

Total C (tonnes) =AGC (tonnes) +BGC (tonnes) +DWC (tonnes)……..5

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

Vegetation type	Mangrove forest	Shrubland	Bare area	Water	Built up area	Cultivated land
AGC(t/ha)	28.0	5.2	1.4	2.2	1.4	2.8
BGC(t/ha)	8.6	2.1	0.5	0.8	0.5	1.0
DWC(t/ha)	2.4	0.4	0.1	0.6	0.1	0.5

2.3.3 Carbon dioxide (CO_2) emission from the study area for the period 1993 - 2023

Estimating carbon dioxide (CO□) emissions from the coastal areas of Kinondoni, Tanzania, over the period from 1993 to 2023 involves converting the total carbon emissions into CO□ equivalents, a critical step in understanding the region's role in climate mitigation. This conversion is essential for accurately assessing the impact of land use and cover changes on greenhouse gas emissions. The Intergovernmental Panel on Climate Change (IPCC) provides standardized guidelines for this conversion, utilizing a factor of 3.67, which represents the molecular weight ratio of CO□ to carbon (IPCC, 2006; IPCC, 2023). The formula used to calculate CO□ emissions from carbon estimates is shown equations 6 &7 as follows:

CO□ emissions (tonnes) = Carbon emissions (tonnes) ×3.67……..6

Total CO□ emissions (tonnes) =AGCO□ (tonnes) +BGCO□ (tonnes) +DWCO□ (tonnes)…..7

2.3.4 Economic loss of the study area for the period 1993 -2023

Estimating the potential loss in carbon trading value due to land use and cover transformation in the coastal areas of Kinondoni, Tanzania, involves calculating the economic value of the carbon that could have been sequestered. Drawing on methodologies from Jenkins (2014) and Lobora et al. (2017), this study uses the standard carbon market price of approximately US$ 4 per ton of CO□ (World Bank, 2023). To determine the total CO□ sequestered, the study converts the carbon stock into CO□ equivalents using the IPCC's conversion factor of 3.67 (IPCC, 2006). The formula used to calculate the potential economic loss from reduced carbon sequestration is:

Potential Economic Loss (US$) = Total CO_2 emission (tonnes) ×Carbon market price

Comment [L6]: The analysis of the data is well presented, but merits further study.
GHG emissions from the land use sector consist mainly of CO2 gas, generated mainly through cultivated land, grassland and forest management, including carbon gains and losses linked to anthropogenic changes in land use.
Given that land use change has been mapped, then the method used should be consistent with the IPCC Good Practice Guidance on Greenhouse Gas Inventories, according to which historical emissions from deforestation and degradation are calculated by multiplying activity data (AD) by emission factors (EF).
The ADs correspond to the areas lost by each land during the transitions due to degradation and deforestation. The EFs correspond to the quantity of carbon released into the atmosphere during transitions (deforestation, degradation, etc.) between 1993 and 2023. The formula proposed by the IPCC (www.ipcc.ch) for the estimate is of the form :

$$EH = \sum_{classe=i} DA_i \times FE_i$$

This approach provides a monetary estimate of the carbon sequestration potential lost due to changes in land use and cover, offering valuable insights for understanding the economic implications of environmental degradation and informing policy decisions related to climate change mitigation and sustainable land management.

3. Results and Discussions

3.1 Biomass loss of the study area for the period 1993 - 2023

The analysis of biomass loss in the coastal areas of Kinondoni, Tanzania, from 1993 to 2023 reveals significant ecological changes, with the region experiencing a total biomass loss of 65,600 tonnes. This loss underscores the profound impact of land use and cover changes on the environment. The most severe losses were concentrated in mangrove forests, which accounted for 93.2% of the total biomass reduction. This extensive deforestation and degradation highlight the critical role of mangroves in maintaining ecological balance, providing habitats, and acting as significant carbon sinks (Friess et al., 2023). The loss of mangrove biomass has serious implications, not only for local biodiversity but also for global carbon dynamics. The degradation of these ecosystems releases stored carbon into the atmosphere, contributing to climate change and reducing the region's carbon sequestration potential (Osland et al., 2021).

Shrublands contributed 13.5% to the total biomass loss, further emphasizing widespread ecological degradation driven by land use changes, such as agricultural expansion and urban development (Nguyen et al., 2023). While the analysis also showed a biomass gain of 11.5% in certain land use and cover types, particularly in built-up areas, these gains are insufficient to counterbalance the extensive losses observed in mangrove forests. The relatively small biomass gains in other LULC types cannot compensate for the critical loss of mangrove ecosystems, which are irreplaceable in their ecological functions and carbon sequestration capacity (Bai et al., 2022).

These findings underscore the urgent need for targeted conservation and restoration initiatives to mitigate further biomass loss and enhance the carbon sequestration potential of the region. Preserving and restoring mangrove ecosystems should be a priority, given their vital role in maintaining the ecological health of Kinondoni's coastal areas and their significance in global climate change mitigation strategies. Effective conservation efforts must include stringent protection measures, reforestation of degraded areas, and sustainable management of remaining mangrove forests to prevent further degradation (Chausson et al., 2023; Kiwelu, 2024; URT, 2023). Immediate and sustained conservation actions are essential to reverse the trends of environmental degradation and to protect the region's capacity to contribute to global carbon sequestration efforts.

Comment [L7]: The results need to be restructured.
Given that the methodology dealt extensively with land-use mapping, it would have been ideal to begin by presenting a land-use map of 1993 and 2023, in order to analyse the changes that have occurred between the two dates using supporting statistics. This will make it possible to generate the activity data needed to estimate emissions from deforestation and vegetation degradation.

GHG emissions from deforestation and forest degradation are estimated in accordance with the 2006 IPCC Good Practice Guidance on Greenhouse Gas Inventories and Methodology. Activity data from land use change and CO2 equivalent emission factors from above-ground biomass are used to calculate historical emissions from deforestation and degradation.
Issifou Moumouni and Toko Imorou (2019)
Toko Imorou et al, 2021
Kosa, V., & Muamba, M. (2018).
IPCC, 2006

Table 4: Biomass loss (10^3 tonnes) of the study area for the period 1993 – 2023

LULC	MF	SL	BA	WTR	BUA	CL	Total
AGB(t)	43.90	6.00	1.20	-	(5.20)	1.00	46.90
BGB (t)	13.40	2.40	0.40	-	(2.00)	0.40	14.60
DWB(t)	3.80	0.40	0.10	-	(0.40)	0.20	4.10
Total (t)	61.10	8.80	1.70	-	(7.60)	1.60	65.60
Percentage	93.2	13.5	2.6	-0.1	-11.5	2.3	100.0

MF=Mangrove forest, SL=Shrubland, BA=Bare area, WTR=Water, BUA=Built-up area & CL=Cultivated land

3.2 Carbon emission of the study area for the period 1993 – 2023

The study of land use and cover transformation in the coastal areas of Kinondoni, Tanzania, from 1993 to 2023 reveals significant carbon emissions and highlights the implications for biomass loss and carbon sequestration. The findings indicate that the region emitted a total of 30,830 tonnes of carbon during this period, with the vast majority of these emissions—93.1%—originating from mangrove forests, while shrublands contributed 13.4%. These figures underscore the profound impact of deforestation and forest degradation on carbon release, pointing to critical environmental challenges (Friess et al., 2023; Chausson et al., 2023).

Mangrove forests, known for their exceptional carbon sequestration capabilities, have been severely degraded, leading to significant carbon emissions. This not only exacerbates global warming by releasing stored carbon into the atmosphere but also reduces the region's future capacity to sequester carbon, diminishing its potential contribution to climate stabilization. In contrast, the study identified a modest carbon gain of 11.6% in built-up areas, likely due to vegetation growth in urban green spaces or newly planted trees. However, this gain is insufficient to offset the extensive emissions from mangrove loss, as urban vegetation typically has a much lower carbon sequestration capacity compared to mature forests (Nguyen et al., 2023).

The findings also highlight the uneven nature of land cover changes in Kinondoni, with marginal increases in carbon stock from other land use and land cover (LULC) types such as shrublands. These gains are often slow and cannot fully compensate for the rapid, large-scale losses of mature mangrove ecosystems. This underscores the need for targeted and effective conservation strategies, particularly those focused on protecting and restoring mangrove forests (Bai et al., 2022). The study's results emphasize the broader implications of these land use changes on regional and global carbon cycles, highlighting the importance of integrating local land management practices with international climate change mitigation efforts. Preserving and restoring mangrove ecosystems should be central to conservation strategies in Kinondoni, given their

critical role in carbon sequestration, biodiversity conservation, and coastal protection (Osland et al., 2021).

Table 5: Carbon emission (10^3 tonnes) of the study area for the period 1993 – 2023

LULC	MF	SL	BA	WTR	BUA	CL	Total
AGC(t)	20.63	2.82	0.56	-	(2.44)	0.47	22.04
BGC (t)	6.30	1.13	0.19	-	(0.94)	0.19	6.86
DWC(t)	1.79	0.19	0.05	-	(0.19)	0.09	1.93
Total (t)	28.72	4.14	0.80	-	(3.57)	0.75	30.83
Percentage	93.1	13.4	2.6	-	(11.6)	2.4	100.0

MF=Mangrove forest, SL=Shrubland, BA=Bare area, WTR=Water, BUA=Built-up area & CL=Cultivated land

3.3 Carbon dioxide emissions from the study area for the period 1993 – 2023

The study reveals that between 1993 and 2023, the coastal areas of Kinondoni, Tanzania, released a significant 113,150 tonnes of CO□, primarily due to land use and cover transformation. Mangrove forest degradation was the major contributor, accounting for 93.1% of the total emissions, highlighting the critical role of these ecosystems in carbon sequestration. Mangroves are among the most effective natural carbon sinks, capable of storing large amounts of carbon in their biomass and sediments. Their degradation not only exacerbates local environmental issues but also contributes significantly to global CO□ levels, underscoring the need to protect these ecosystems as a key strategy in climate change mitigation (Friess et al., 2023; Chausson et al., 2023).

Additionally, shrublands contributed 13.4% to the emissions, further indicating widespread environmental degradation in the region. In contrast, built-up areas showed a 11.6% increase in carbon stock, likely due to urban green spaces or afforestation efforts. However, this gain is insufficient to offset the extensive CO□ emissions from mangrove loss. Vegetation in urban areas typically has a lower carbon sequestration capacity compared to mature forests, highlighting the limitations of relying solely on urban green spaces to counterbalance deforestation (Nguyen et al., 2023).

The findings emphasize the uneven nature of land cover changes in Kinondoni, with significant ecological degradation in some areas and resilience or recovery in others. The marginal gains in carbon stock from built-up areas cannot compensate for the large-scale loss of carbon sequestration potential in mangrove forests. This imbalance underscores the urgent need for targeted conservation and restoration initiatives focused on preserving mangrove ecosystems, which are irreplaceable in their ecological functions and carbon storage capabilities (Bai et al., 2022). The study highlights the

severe impact of land use transformation on CO emissions and stresses the importance of conserving these ecosystems for global climate change mitigation (Osland et al., 2021).

Table 6: Carbon dioxide emission (10^3 tonnes) from the study area for the period 1993 – 2023

LULC	MF	SL	BA	WTR	BUA	CL	Total
$AGCO_2$(t)	75.72	10.35	2.07	-	(8.97)	1.72	80.90
$BGCO_2$ (t)	23.11	4.14	0.69	-	(3.45)	0.69	25.18
$DWCO_2$(t)	6.55	0.69	0.17	-	(0.69)	0.34	7.07
Total (t)	105.39	15.18	2.93	-	(13.11)	2.76	113.15
Percentage	93.1	13.4	2.6	-	(11.6)	2.4	100.0

MF=Mangrove forest, SL=Shrubland, BA=Bare area, WTR=Water, BUA=Built-up area & CL=Cultivated land

3.4 Economic loss of the study area for the period 1993 – 2023

The study highlights a significant economic loss in potential carbon trade revenue from the coastal areas of Kinondoni, Tanzania, between 1993 and 2023, amounting to an estimated US$ 452,610. This loss is primarily due to deforestation and land-use changes, particularly in the mangrove forests, which traditionally serve as the most efficient carbon sinks. Mangroves, which accounted for 93.1% of the total carbon trade value loss, are critical in global carbon cycles due to their ability to store large amounts of carbon in their biomass and soil. The degradation of these ecosystems not only resulted in substantial carbon emissions but also led to a significant forfeiture of potential revenue from carbon trading markets. This is particularly concerning given the global emphasis on carbon markets as a strategy for mitigating climate change (Friess et al., 2023; Chausson et al., 2023).

The study also reveals that other land use and land cover (LULC) types contributed to a smaller profit gain of 11.6%, reflecting the limited carbon sequestration potential of non-mangrove vegetative areas compared to mangrove forests. Although certain LULC types, such as shrublands and built-up areas, showed some carbon gain, these increases were insufficient to offset the extensive losses from mangrove deforestation. This finding indicates that efforts to enhance carbon sequestration through afforestation or urban greening need to be significantly scaled up to achieve meaningful impacts (Nguyen et al., 2023).

The economic implications are profound, reflecting not only a missed financial opportunity but also broader environmental degradation, which could have lasting effects on the region's ecological stability. The high economic value of mangroves in

carbon trading underscores the urgency of protecting and restoring these ecosystems. Integrated land management policies that prioritize conservation of high-carbon ecosystems like mangroves are essential for mitigating further losses and capitalizing on the economic opportunities presented by carbon markets (Bai et al., 2022; Osland et al., 2021).

Table 7: Economic loss (thousands US$) of the study area for the period 1993 – 2023

LULC	MF	SL	BA	WTR	BUA	CL	Total
$AGCO_2$ (US$)	302.89	41.40	8.28	-	(35.88)	6.90	323.59
$BGCO_2$ (US$)	92.45	16.56	2.76	-	(13.80)	2.76	100.73
$DWCO_2$ (US$)	26.22	2.76	0.69	-	(2.76)	1.38	28.29
Total (US$)	421.57	60.72	11.73	-	(52.44)	11.04	452.61
Percentage	93.1	13.4	2.6	0.0	-11.6	2.4	100.0

MF=Mangrove forest, SL=Shrubland, BA=Bare area, WTR=Water, BUA=Built-up area & CL=Cultivated land

4. Conclusion and Recommendations

4.1 Conclusion

The study on the implications of land use and cover transformation on biomass loss and carbon sequestration in the coastal areas of Kinondoni, Tanzania, over the period from 1993 to 2023, reveals critical insights into the environmental challenges facing the region. The analysis demonstrates that the rapid transformation of land use and land cover (LULC) in Kinondoni has led to significant biomass loss, particularly in mangrove forests and other coastal ecosystems, which are crucial for carbon sequestration and climate regulation. Over the three decades under review, Kinondoni's coastal areas have undergone substantial changes due to urban expansion, agricultural encroachment, and infrastructural development. These changes have resulted in the degradation and loss of vital ecosystems, notably mangroves, which are recognized as some of the most effective natural carbon sinks. The study's findings indicate that mangrove forests, which accounted for the majority of biomass loss, have been severely impacted by deforestation and land conversion, leading to a substantial reduction in the region's carbon sequestration capacity.

The consequences of these changes are far-reaching. The loss of biomass not only diminishes the natural carbon storage capacity of the region but also contributes to increased atmospheric carbon dioxide (CO_2) levels, exacerbating global climate change. The degradation of coastal ecosystems has also led to a decline in biodiversity, disruption of hydrological cycles, and increased vulnerability to climate-related hazards such as coastal erosion and storm surges. These changes underscore the urgent need for effective conservation and land management strategies to mitigate further

environmental degradation and to enhance the carbon sequestration potential of Kinondoni's coastal areas. Moreover, the study highlights the interconnectedness of socio-economic factors and environmental degradation. Population growth, urbanization, and economic activities in Dar es Salaam have placed immense pressure on the natural landscapes of Kinondoni, driving the demand for land and resources that has fueled the observed LULC changes. Without intervention, these pressures are likely to continue, further compromising the ecological health and sustainability of the region.

4.2 Recommendations

In light of the study's findings, eight key recommendations are proposed to address the challenges posed by LULC changes in Kinondoni and to promote the sustainable management of coastal ecosystems:

S/n	Recommendations	Explanation
1.	Strengthening land use planning and policy enforcement	There is a critical need to strengthen land use planning and enforce existing environmental policies to protect remaining coastal ecosystems. This includes the implementation of strict zoning regulations that limit the conversion of natural landscapes into urban and agricultural areas. Policymakers should prioritize the conservation of mangrove forests and other high-carbon ecosystems, recognizing their vital role in climate change mitigation.
2.	Promoting sustainable urban development	Urbanization in Kinondoni must be managed in a way that balances economic growth with environmental sustainability. Sustainable urban development practices should be adopted, including the integration of green spaces and the promotion of vertical rather than horizontal expansion to minimize land consumption. Additionally, efforts should be made to rehabilitate degraded urban areas through reforestation and the creation of urban forests.
3.	Conservation and restoration of mangrove ecosystems	Given the significant role of mangrove forests in carbon sequestration and coastal protection, targeted conservation and restoration initiatives are essential. Restoration programs should focus on replanting mangroves in degraded areas, protecting existing mangrove stands, and promoting community-based conservation efforts. These initiatives should be supported by ongoing monitoring and research to assess their effectiveness and to adapt strategies as needed.
4.	Incorporating ecosystem services valuation in decision-making	The economic value of ecosystem services provided by coastal ecosystems, such as carbon sequestration, should be incorporated into land use planning and development decisions. By quantifying the economic benefits of preserving these ecosystems, policymakers can make more informed

		decisions that reflect the true value of natural capital. This approach can also help in securing funding for conservation initiatives through mechanisms such as carbon trading or payments for ecosystem services.
5.	Community engagement and education	Engaging local communities in conservation efforts is crucial for the long-term sustainability of coastal ecosystems. Public awareness campaigns and educational programs should be implemented to inform residents about the importance of mangroves and other coastal ecosystems, as well as the impacts of land use changes. Empowering communities to participate in conservation and restoration activities can enhance local stewardship and ensure the success of environmental initiatives.
6.	Strengthening research and monitoring programs	Continuous research and monitoring are essential to understanding the ongoing impacts of LULC changes and to evaluating the effectiveness of conservation strategies. The establishment of long-term monitoring programs that track changes in biomass, carbon sequestration, and ecosystem health will provide valuable data to guide future management efforts. Collaborations between government agencies, academic institutions, and international organizations should be encouraged to enhance research capacity and resource sharing.
7.	Climate change mitigation and adaptation strategies	The findings of this study highlight the need for integrated climate change mitigation and adaptation strategies that address both the causes and impacts of LULC changes. These strategies should include measures to reduce carbon emissions from deforestation, promote renewable energy sources, and enhance the resilience of coastal communities to climate-related hazards. Incorporating climate risk assessments into land use planning and development projects will help to minimize the vulnerability of Kinondoni's coastal areas to future environmental changes.
8.	Leveraging international support and funding	Given the global significance of carbon sequestration in coastal ecosystems, Kinondoni should seek to leverage international support and funding for conservation initiatives. Programs such as the United Nations Reducing Emissions from Deforestation and Forest Degradation (REDD+) can provide financial incentives for preserving and restoring mangrove forests. Additionally, partnerships with international environmental organizations can offer technical expertise and resources to support local conservation efforts.

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