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Impacts of Land Use and Land Cover Changes on Biomass and Carbon Sequestration in Coastal Kinondoni, Tanzania

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This study analyzes the impact of land use and land cover (LULC) alterations on biomass depletion and carbon sequestration in Kinondoni, Tanzania, over a 30-year period from 1993 to 2023. This study employs the National Forest Resources Monitoring and Assessment (NAFORMA) models and geospatial analysis to quantify the environmental and economic effects of urbanization, agricultural growth, and infrastructural development on local ecosystems. The deterioration of mangrove forests, essential for carbon sequestration, has resulted in an estimated biomass reduction of 65,600 tonnes, with mangroves representing 93.1% of the overall losses. This deterioration has

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markedly diminished the region's carbon storage capacity, leading to the emission of 30,830 tonnes of carbon, which is equivalent to 113,150 tonnes of carbon dioxide (CO_2). The economic impact of this decrease in carbon sequestration capacity is estimated at around US$ 452,610, signifying a lost opportunity for carbon trading. The degradation of mangroves is recognized as the principal cause of these losses. The study highlights the critical necessity for conservation and restoration measures, specifically aimed at mangrove ecosystems, to alleviate additional environmental and economic deterioration. It promotes sustainable land use regulations and the incorporation of ecosystem services valuation in decision-making processes to improve resilience in coastal Tanzania.

Keywords: Biomass loss; carbon emission; carbon dioxide emission; economic loss.

1. INTRODUCTION

The swift alteration of land use and land cover (LULC) in coastal locations has emerged as a significant global concern, especially in rapidly urbanizing locales such as Kinondoni District, Tanzania. Coastal habitats, including mangroves, seagrass beds, and coastal forests, are crucial for carbon sequestration and biomass preservation, functioning as large carbon sinks that store substantial quantities of carbon and contribute to the reduction of atmospheric greenhouse gas emissions [1]. Nonetheless, increasing pressures from urban expansion, agricultural encroachment, and infrastructural development are inducing significant land use and land cover changes, resulting in the deterioration of these ecosystems [2]. Kinondoni District, located along the Indian Ocean near Dar es Salaam, is facing significant challenges from population growth and economic activity owing to its closeness to Tanzania's major urban center. These pressures have led to extensive deforestation, the transformation of natural landscapes into urban and agricultural areas, and the deterioration of vital coastal ecosystems [3]. The consequent reduction of biomass in these regions decreases their carbon sequestration ability, releasing stored carbon into the atmosphere and intensifying climate change [4].

Mangrove forests, commonly known as "blue carbon" ecosystems because of their remarkable capacity to sequester and store carbon in biomass and sediments, are vital for carbon sequestration. The degradation of these ecosystems resulting from land use and land cover changes impairs their carbon storage capabilities, resulting in heightened carbon emissions and the forfeiture of essential ecosystem services vital for climate change mitigation [5]. Furthermore, the deterioration of mangroves and other coastal ecosystems has resulted in less biodiversity, modified hydrological cycles, and increased susceptibility to climate-related threats such as storm surges and coastal erosion [1]. The land use and land cover changes in Kinondoni have both local and global ramifications. The transformation of forests and vegetation into urban environments diminishes biomass and, therefore, the carbon sequestration capacity of the region [6]. Studies indicate that deforestation and land degradation in coastal regions markedly elevate carbon emissions, highlighting the imperative to mitigate these environmental effects [7].

A primary problem in overseeing land use and land cover changes in Kinondoni is the absence of efficient land management and conservation policies. Although the significance of coastal ecosystems is acknowledged, conservation initiatives frequently suffer due to conflicting land-use requirements and inadequate policy enforcement [8]. The absence of competent governance has facilitated the ongoing deterioration of vital ecosystems, hence jeopardizing the region's environmental sustainability. Given the escalating population of Kinondoni and increasing economic constraints, there is an imperative for cohesive land management strategies that harmonize economic advancement with environmental conservation. Urban expansion and infrastructure development yield immediate economic advantages but incur substantial environmental costs, especially with the destruction of mangrove forests and other coastal ecosystems essential for carbon sequestration and climate resilience [5].

This study examines the effects of land use and land cover changes on biomass reduction and carbon sequestration in the coastal regions of Kinondoni. The research examines the geographical and temporal dynamics of land use and land cover changes and their impact on

carbon storage, providing essential insights for guiding sustainable land use planning and conservation initiatives [1]. Effective mitigation of land use and land cover impacts necessitates a holistic strategy that emphasizes ecosystem conservation while facilitating sustainable development. This entails enforcing stringent land-use restrictions, advancing reforestation and sustainable agriculture techniques, and offering incentives for the conservation of coastal ecosystems [3]. Improved oversight and enforcement of environmental regulations are crucial to prevent illicit land-use practices and inadequate management from compromising conservation initiatives [8].

This study seeks to identify the most impacted areas and primary factors influencing land use and land cover changes, thereby contributing to the formulation of targeted conservation plans that mitigate the environmental difficulties associated with urbanization and land degradation. The results will aid in developing policies that protect the ecological and economic significance of coastal habitats, assuring the enduring sustainability of Kinondoni's natural resources and its ability to contribute to global climate change mitigation initiatives.

2. METHODS

2.1 Description of the Study Area

This study took place in the coastal wards of Mbweni and Ununio in the Kinondoni District of Dar es Salaam, Tanzania, a place of considerable ecological and economic significance. Covering 531 square kilometers along the Indian Ocean, Kinondoni is situated within the biodiversity-rich Western Indian Ocean region, essential for sustaining both local and regional economy [9,10]. The coastal ecosystems of the district, comprising coral reefs, mangroves, and seagrass beds, are vital for sustaining biodiversity and delivering ecosystem services such as fisheries, coastal protection, carbon sequestration, and tourism [1]. Mangroves serve as crucial carbon sinks, sequestering carbon in their biomass and sediments, hence alleviating climate change [5]. These habitats are significantly threatened by fast urbanization, population expansion, and unsustainable practices, resulting in habitat loss and degradation, particularly in Mbweni and Ununio [3,11]. This research seeks to measure the economic worth of these ecosystem services, evaluating the effects of land use on biomass and carbon sequestration to guide sustainable management approaches [2,4].

2.2 Data Sets

Fig. 2 shows the flow chart of the methodological approach used in this study for the estimation of biomass loss, carbon emission, carbon dioxide emission, economic loss for the period 1993 - 2023.

The study evaluated the effects of land use and land cover (LULC) changes on biomass reduction and carbon sequestration in Kinondoni, Tanzania, from 1993 to 2023, utilizing several spatial datasets. Satellite photography from the United States Geological Survey (USGS), encompassing data from the Global Visualization Viewer (USGS-GLOVIS) and Earth Explorer platforms, was crucial in delineating land-use alterations and assessing the status of coastal ecosystems. Landsat imagery from 1993 and Sentinel-2 images from 2023, obtained from Tanzania's Department of Urban Planning and the Earth Resources Observation and Science (EROS) Center, offered comprehensive insights into land use and land cover (LULC) changes and their resultant impacts on biomass and carbon sequestration (USGS, 2023; EROS, 2023; DoSUP, 2022).

Advanced geospatial analysis methods, specifically Geographic Information System (GIS) software, were utilized to amalgamate diverse data sets, encompassing satellite imagery, demographic statistics, and socio-economic information. This connection allowed for the creation of comprehensive land use and forest type maps, which enhanced the display of land use and land cover changes over time and the identification of regions most impacted by deforestation and degradation. The study integrated spatial and socio-economic data to conduct a thorough analysis of biomass loss, carbon emissions, and carbon sequestration potential in the coastal regions of Kinondoni, offering essential insights for the development of effective conservation and land management strategies (GIS Software, 2023).

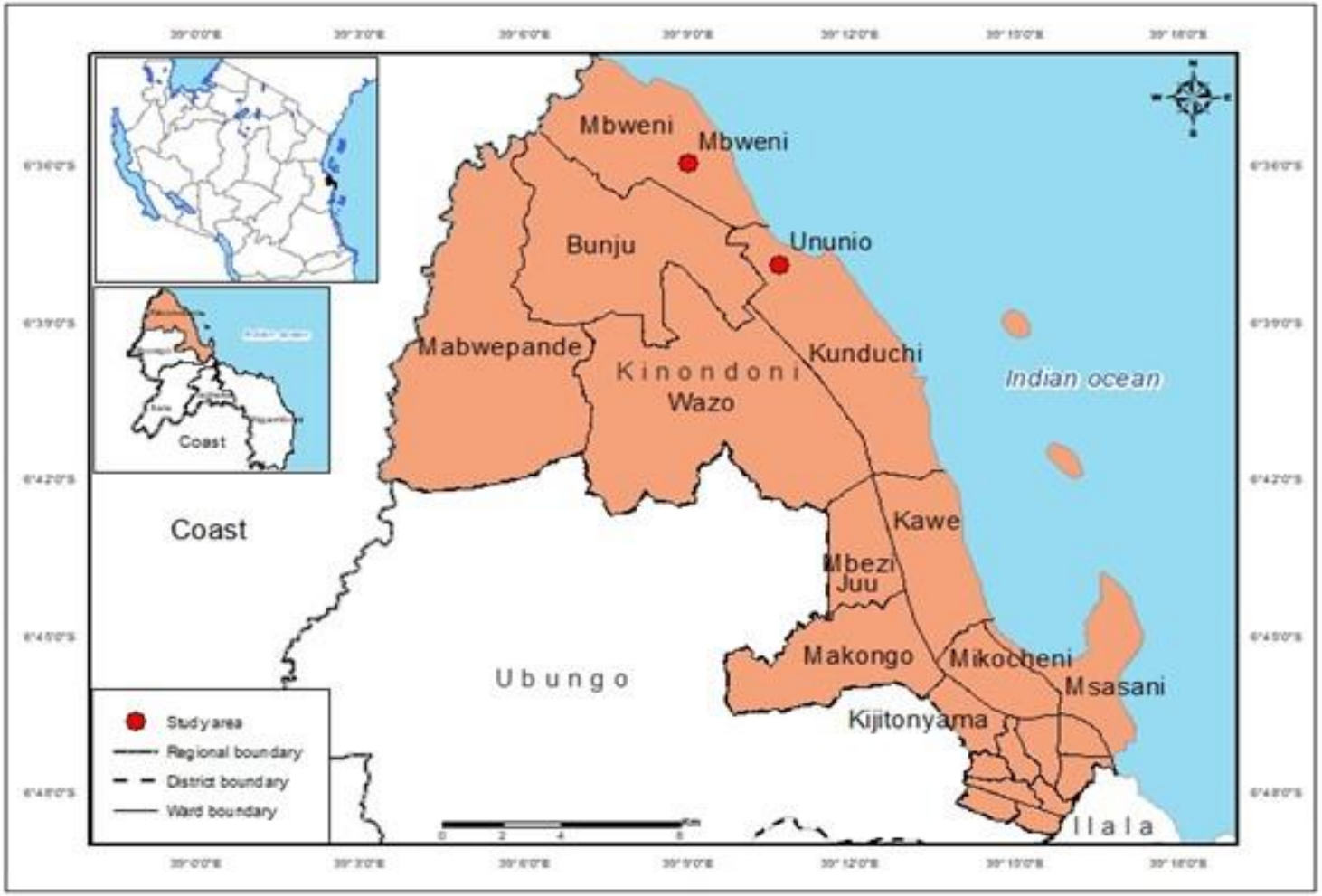

Fig. 1. The Map of the study area

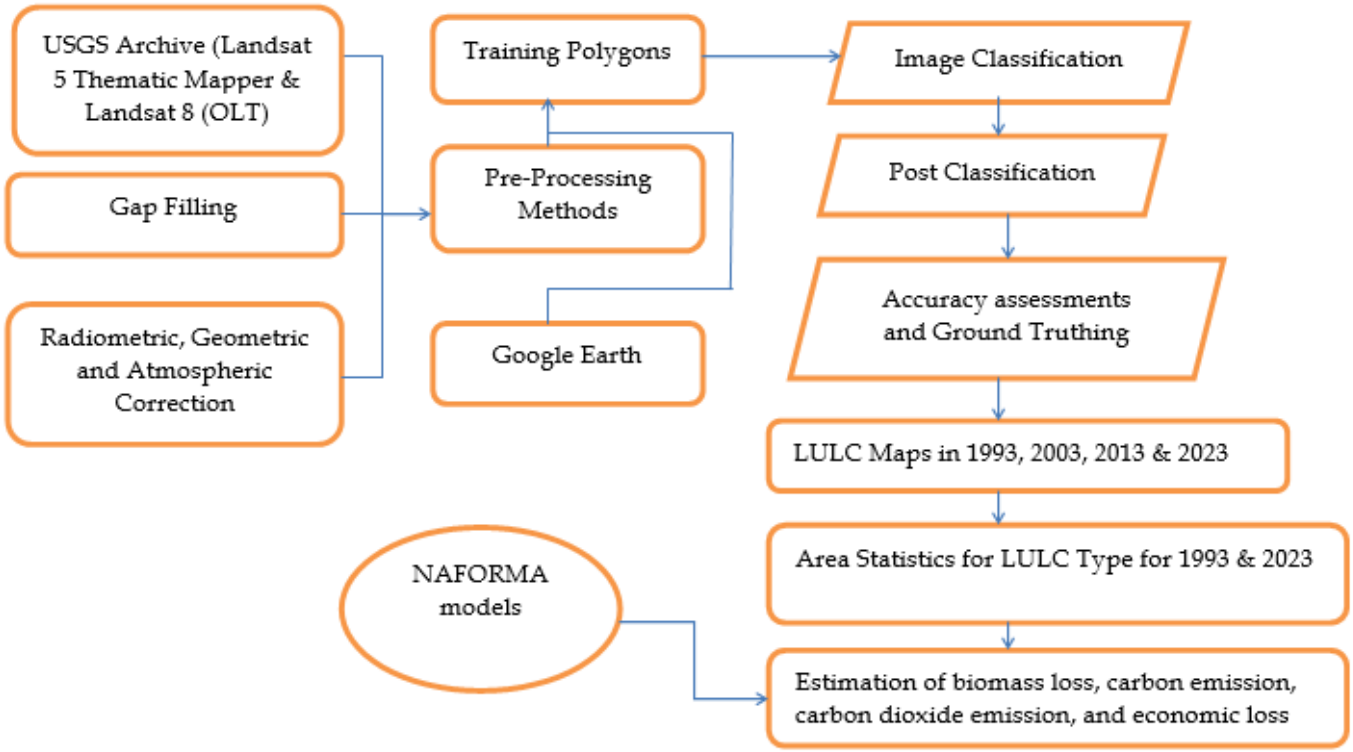

Fig. 2. Flowchart of the methodological approach for this study

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	1837.99	739.47	515.86	2171.41	124.20	172.90
2023	1100.37	193.06	113.75	2243.63	1905.14	5.88
1993 - 2023	737.62	546.41	402.11	-7.22	-1780.93	167

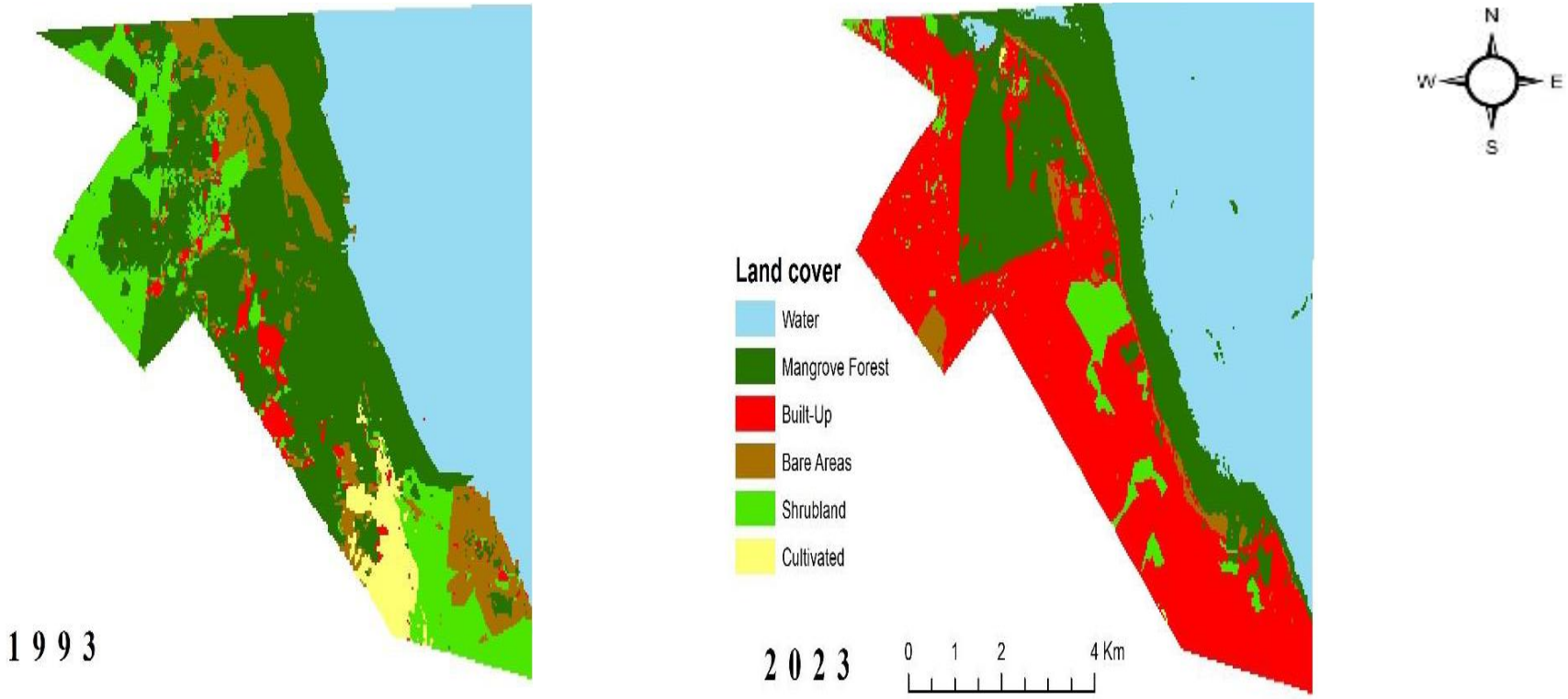

Fig. 3. LULC for the years 1993 & 2023

2.3 Data Analysis

Biomass loss of the study area for the period 1993 – 2023: Estimating biomass loss in Kinondoni District from 1993 to 2023 involves calculating live and dead biomass, distinguishing between above-ground biomass (AGB) and below-ground biomass (BGB) [12]. AGB, which includes tree trunks and leaves, is critical for carbon storage, while BGB accounts for root biomass and subterranean carbon [13]. Dead biomass, including dead wood (DW), is essential for understanding ecosystem carbon dynamics [14]. Utilizing local allometric equations within the URT's 2015 NAFORMA framework, this study assesses biomass loss and its implications for carbon sequestration over three decades as indicated in equations 1-3. The findings are vital for sustainable land management and conservation efforts to mitigate climate change and preserve ecosystem services.

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.

Carbon emission of the study area for the period 1993 – 2023: Estimating carbon emissions is vital for evaluating Kinondoni's coastal areas' role in carbon sequestration and climate change mitigation. Utilizing Tanzania's NAFORMA methodology, this study measures biomass and applies conversion factors to estimate carbon content in organic matter as indicated in equations 4-5. This approach assesses land use changes, such as deforestation, on carbon sequestration, offering insights into the region's contribution to global carbon cycles and the effectiveness of conservation strategies [15].

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

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

Carbon dioxide (CO_2) emission from the study area for the period 1993 – 2023: Estimating CO_2 emissions in Kinondoni, Tanzania, from 1993 to 2023 requires converting total carbon emissions into CO_2 equivalents, crucial for climate mitigation assessment. This conversion, guided by IPCC standards, uses a factor of 3.67, reflecting the molecular weight ratio of CO_2 to carbon [13]. Accurate calculations of CO_2 emissions from carbon estimates are essential for understanding the effects of land use changes on greenhouse gas emissions as indicated in equations 6-7.

CO_2 emissions (tonnes) = Carbon emissions (tonnes) ×3.67 (6)

Total CO_2 emissions (tonnes) =AGCO_2 (tonnes) +BGCO_2 (tonnes) +DWCO_2 (tonnes) (7)

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 This study estimates the potential loss in carbon trading value due to land use changes in Kinondoni, Tanzania, by calculating the economic value of sequestered carbon. Utilizing methodologies from Jenkins (2014) and Lobora et al. (2017), it applies a carbon market price of US$ 4 per ton of CO_2 (World Bank, 2023) and converts carbon stock into CO_2 equivalents using the IPCC's factor of 3.67 (IPCC, 2006 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_2 (World Bank, 2023). To determine the total CO_2 sequestered, the study converts the carbon stock into CO_2 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

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.

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

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

3. RESULTS AND DISCUSSION

3.1 Biomass Loss of the Study Area for the Period 1993 - 2023

The examination of biomass depletion in the coastal regions of Kinondoni, Tanzania, from 1993 to 2023 indicates significant ecological deterioration, with an overall biomass loss of 65,600 tons. This substantial decrease is chiefly ascribed to alterations in land use and land cover (LULC), with mangrove forests suffering the most, representing 93.2% of the overall biomass loss. This aligns with recent studies highlighting the essential role of mangroves in sustaining ecosystem equilibrium, fostering biodiversity, and serving as significant carbon sinks [4]. The deterioration of mangroves in Kinondoni is especially alarming due to their indispensable ecological roles, such as carbon sequestration, habitat providing, and coastline stabilization. Their loss not only emits substantial quantities of stored carbon into the atmosphere but also reduces the region's potential for future carbon sequestration, exacerbating global climate change [1].

Besides mangrove loss, shrublands accounted for 13.5% of the overall biomass decline, illustrating the wider trend of environmental deterioration caused by agricultural expansion and urban growth. Comparable research in East Africa has documented similar patterns, indicating that agricultural encroachment and urbanization have resulted in considerable losses of flora and biomass, hence intensifying carbon emissions and diminishing ecological resilience [3]. The documented decline in biomass in Kinondoni underscores the escalating conflict between development and environmental sustainability, a phenomenon observable in other coastal areas experiencing fast urbanization.

Notwithstanding certain biomass increases (11.5%) in alternative land use categories, especially in urbanized regions, these increments are unable to compensate for the significant losses in mangrove ecosystems. Research indicates that although urban regions may experience minor biomass increases from tree planting or urban greening initiatives, these gains are insignificant relative to the ecological functions and carbon storage capabilities forfeited through the destruction of natural ecosystems, particularly mangroves [6]. The results in Kinondoni align with global patterns, indicating that the advantages of urban greening or reforestation in developed regions are eclipsed by the destruction and degradation of natural habitats that offer significantly greater ecological services.

The necessity of tackling biomass depletion in Kinondoni is evident, especially with mangrove conservation and regeneration. Mangroves are essential for local biodiversity and significantly contribute to global carbon cycles. Research in Southeast Asia and other tropical areas has highlighted the need of conserving mangroves within comprehensive climate change mitigation plans, due to their capacity to sequester up to five times more carbon than terrestrial forests [5]. The results from Kinondoni corroborate this research, highlighting the imperative of prioritizing mangrove conservation to sustain the region's carbon sequestration capacity.

Conservation initiatives in Kinondoni must prioritize rigorous protective measures, including the implementation of land-use regulations to avert further deterioration of mangrove ecosystems. Restoration activities, including reforestation and sustainable management techniques, are essential for reversing the

prevailing trends of environmental degradation (Kiwelu, 2024). The Tanzanian government has acknowledged the necessity for these actions, as seen by its recent conservation plans (URT, 2023). Nonetheless, the effective implementation and enforcement pose significant obstacles, as ongoing pressures from urbanization and agricultural growth jeopardize the long-term sustainability of these ecosystems.

The biomass depletion in Kinondoni during the last thirty years underscores the significant environmental consequences of land use and land cover alterations, especially for mangrove ecosystems. These results align with international and regional research, highlighting the necessity for prompt and ongoing conservation efforts. Rehabilitating degraded mangroves and adopting sustainable land-use practices are crucial for maintaining the region's ecological integrity and its contribution to global carbon sequestration initiatives. In the absence of concerted conservation efforts, the ongoing deterioration of these essential ecosystems would significantly impact local biodiversity and global climate change mitigation.

3.2 Carbon Emission of the Study Area for the Period 1993 – 2023

The examination of land use and land cover (LULC) changes in the coastal regions of Kinondoni, Tanzania, from 1993 to 2023 indicates substantial carbon emissions, highlighting the effects of biomass depletion and diminished carbon sequestration potential. In this timeframe, the region released a total of 30,830 tons of carbon, with 93.1% of these emissions resulting from mangrove forest degradation, whereas shrublands accounted for 13.4%. The data underscore the significant environmental repercussions of deforestation and forest degradation, corroborating research on the essential function of mangroves in carbon sequestration [4,5].

Mangrove forests, noted for their remarkable capacity to absorb carbon, have experienced significant degradation in Kinondoni, resulting in considerable carbon emissions. The degradation of these ecosystems substantially exacerbates global warming by emitting sequestered carbon into the atmosphere and severely diminishing the region's future potential for carbon sequestration. This deterioration adversely impacts local carbon dynamics and reduces the region's capacity to aid in global climate stabilization. Research in coastal places, including Southeast Asia, has demonstrated that mangrove loss leads to significant carbon emissions and diminishes the climate change mitigation capacity of these areas [1].

The study revealed a small carbon gain of 11.6% in urban areas, presumably attributable to vegetation growth in green spaces and the introduction of freshly planted trees. Nonetheless, this benefit is inadequate to counterbalance the significant emissions resulting from mangrove degradation, as urban vegetation possesses a far lower carbon storage capability than mature mangrove ecosystems. Comparable results have been noted in other swiftly urbanizing coastal regions, where urban greening efforts provide minimal carbon sequestration benefits yet fail to offset the carbon emissions resulting from natural forest destruction [3].

The analysis underscores the disparate character of land cover alterations in Kinondoni, revealing relatively slight gains in carbon stock from alternative land use and land cover types, such as shrublands. Although these improvements suggest partial vegetative rebound in specific regions, they cannot adequately offset the swift and extensive losses of mature mangrove ecosystems. This pattern aligns with other studies in tropical coastal areas, where the gradual recovery of secondary vegetation is frequently surpassed by the swift degradation of mature ecosystems, resulting in net carbon losses over time [6].

The results highlight the immediate necessity for specific conservation initiatives, especially those aimed at safeguarding and rehabilitating mangrove forests, which are essential for carbon sequestration, biodiversity preservation, and coastal defense. Other research has similarly highlighted that mangrove ecosystems are among the most efficient natural strategies for climate change mitigation, owing to their substantial carbon storage capacity and the essential ecosystem services they offer [5]. The study's findings underscore the extensive ramifications of land use alterations on both regional and global carbon cycles, stressing the necessity of aligning local land management strategies with global climate change mitigation initiatives.

In summary, the preservation and restoration of mangrove ecosystems should be a primary

emphasis of conservation measures in Kinondoni, due to their critical role in carbon sequestration and overall ecological significance. Robust conservation strategies, encompassing rigorous protection legislation, reforestation initiatives, and sustainable land management techniques, are essential for reducing carbon emissions and bolstering the region's resistance to climate change. These initiatives must align with worldwide climate objectives to guarantee that local actions significantly contribute to global carbon reduction plans [1].

3.3 Carbon Dioxide Emissions from the Study Area for the Period 1993 – 2023

The study indicates that from 1993 to 2023, the coastal regions of Kinondoni, Tanzania, released a significant 113,150 tons of CO_2, chiefly attributable to land use and land cover (LULC) changes. The deterioration of mangrove forests was the primary source, with 93.1% of the total emissions. This highlights the essential function of mangroves as highly efficient natural carbon sinks, proficient at sequestering substantial quantities of carbon within their biomass and sediments. The degradation of these ecosystems not only intensifies local environmental challenges but also substantially elevates global CO_2 concentrations, underscoring the critical necessity for their preservation as a fundamental approach in global climate change mitigation strategies [4,5].

Shrublands accounted for 13.4% of total emissions, indicating significant environmental degradation in the region. Conversely, urbanized regions exhibited an 11.6% augmentation in carbon stock, presumably attributable to afforestation initiatives or the creation of urban green spaces. Nonetheless, this benefit is inadequate to counterbalance the significant CO_2 emissions arising from the destruction of mangrove ecosystems. Research indicates that urban vegetation generally possesses significantly lower carbon absorption capabilities than mature forests, such as mangroves, highlighting the inadequacy of depending exclusively on urban greening to mitigate extensive deforestation [3].

The results underscore the disparate characteristics of land use and land cover changes in Kinondoni, highlighting substantial ecological deterioration in certain regions and minimal recovery or resilience in others. Although urban areas have seen marginal increases in carbon stock, these increments are negligible and fail to offset the significant reduction in carbon sequestration capacity of mangrove forests. Comparable trends have been noted in other tropical coastal areas, where afforestation and urban greening efforts yield limited advantages, however they are inadequate to mitigate the significant losses resulting from deforestation [6]. This disparity underscores the pressing necessity for focused conservation and restoration efforts aimed at mangrove ecosystems, which are invaluable for their exceptional carbon sequestration capacity and extensive biological roles.

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

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

The study highlights the significant effect of land use and land cover changes on CO_2 emissions in Kinondoni and emphasizes the necessity of safeguarding mangrove forests within global climate change mitigation efforts. Mangroves are vital for carbon sequestration, preserving biodiversity, safeguarding coasts from erosion, and sustaining local livelihoods [1]. Consequently, conservation initiatives must prioritize the safeguarding and rehabilitation of mangrove ecosystems, which are essential for both local and global environmental sustainability.

3.4 Economic loss of the Study Area for the Period 1993 – 2023

The study indicates a substantial economic deficit in prospective carbon trade earnings from the coastal regions of Kinondoni, Tanzania, from 1993 to 2023, totaling around US$ 452,610. This decline is mostly ascribed to deforestation and alterations in land use, especially within mangrove forests, which have traditionally served as highly effective carbon sinks. Mangroves, responsible for 93.1% of the total carbon trade value loss, are vital to the global carbon cycle because of their ability to sequester significant quantities of carbon in both biomass and soil. The deterioration of these ecosystems not only caused substantial carbon emissions but also resulted in a large loss of potential revenue from carbon trading markets. This economic loss is especially alarming due to the growing worldwide dependence on carbon markets as a method for addressing climate change [4,5].

The study indicates that other land use and land cover (LULC) categories yielded a modest profit increase of 11.6%, demonstrating the restricted carbon sequestration capacity of non-mangrove vegetative regions relative to mangrove ecosystems. Although some land use and land cover types, such as shrublands and urban areas, exhibited some carbon benefits, these increases were unable to counterbalance the significant losses resulting from mangrove deforestation. This corresponds with findings from other research, indicating that afforestation and urban greening initiatives, while beneficial, require considerable expansion to realize significant carbon sequestration effects [3]. The very modest carbon sequestration from non-mangrove regions highlights the distinctive and crucial function of mangrove ecosystems in carbon storage.

This study's economic ramifications are significant, indicating a lost cash opportunity from carbon trading and broader environmental damage that may have enduring consequences for the region's ecological stability. The significant economic worth of mangroves in carbon markets underscores the imperative to maintain and restore these ecosystems. Research in other areas, including Southeast Asia and South America, has similarly highlighted the essential function of mangroves in carbon sequestration and their capacity to produce substantial income via carbon credits [6,1]. The deterioration of these ecosystems signifies a dual loss—both in carbon sequestration potential and the economic advantages that may be derived from their conservation.

To tackle these difficulties, it is imperative to implement integrated land management plans that emphasize the preservation of high-carbon ecosystems such as mangroves. These measures should seek to alleviate additional environmental deterioration and leverage the economic prospects presented by global carbon markets. Conservation initiatives must encompass both rigorous protective measures for existing mangrove forests and extensive restoration operations to regain lost carbon sequestration capacity. The necessity of this strategy is emphasized by the study's findings, which demonstrate the substantial environmental and economic repercussions of ongoing deforestation and land-use alterations in coastal Kinondoni.

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

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 effects of land use and cover change on biomass depletion and carbon sequestration in the coastal regions of Kinondoni, Tanzania, from 1993 to 2023, uncovers significant insights into the environmental issues confronting the area. The research reveals that the swift alteration in land use and land cover (LULC) in Kinondoni has resulted in substantial biomass depletion, especially in mangrove forests and other coastal ecosystems, which are vital for carbon sequestration and climate regulation. Throughout the past three decades, Kinondoni's coastal regions have experienced significant transformations due to urbanization, agricultural intrusion, and infrastructural advancement. The alterations have led to the deterioration and depletion of essential ecosystems, particularly mangroves, acknowledged as very efficient natural carbon sinks. The study's findings reveal that mangrove forests, responsible for the majority of biomass loss, have been significantly affected by deforestation and land conversion, resulting in a considerable decline in the region's carbon sequestration potential.

The ramifications of these alterations are extensive. The reduction of biomass not only decreases the region's natural carbon storage capacity but also elevates atmospheric carbon dioxide (CO_2) levels, intensifying global climate change. The deterioration of coastal ecosystems has resulted in a reduction in biodiversity, disturbance of hydrological cycles, and heightened susceptibility to climate-related threats, including coastal erosion and storm surges. These modifications highlight the pressing necessity for efficient conservation and land management techniques to alleviate more environmental deterioration and to augment the carbon sequestration capacity of Kinondoni's coastal regions. Furthermore, the study emphasizes the relationship between socio-economic variables and environmental degradation. The population increase, urban expansion, and economic activity in Dar es Salaam have exerted significant strain on the natural landscapes of Kinondoni, escalating the demand for land and resources that has driven the observed land use and land cover changes. In the absence of intervention, these pressures are expected to persist, further undermining the ecological integrity 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.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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