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Forecasting biomass depletion, carbon emission and economic loss of coastal areas of Kinondoni District, Tanzania

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Abstract
This study examines the impacts of land use and land cover (LULC) changes on biomass depletion, carbon emissions, and economic losses in Kinondoni District, Tanzania, from 2023 to 2033. Utilizing the National Forest Resources Monitoring and Assessment (NAFORMA) approach alongside modern GIS techniques, the research quantifies the ecological and economic consequences of these changes. Coastal habitats, particularly mangrove forests, serve as vital carbon sinks, aiding climate change mitigation by sequestering carbon. However, rapid urbanization, agricultural expansion, and infrastructure development have led to significant ecological damage in Kinondoni. The study predicts a biomass reduction of approximately 17,868.4 tonnes, primarily due to deforestation and mangrove degradation, which contributes to 103.4% of total biomass and carbon losses. This decline in carbon sequestration capacity results in the release of 8,390.1 tonnes of carbon, equating to 30,821.2 tonnes of CO_2. Additionally, the research forecasts an economic loss of around US$ 123,284.8 due to diminished carbon sequestration potential. The findings emphasize the urgent need for conservation and restoration efforts, particularly for mangrove ecosystems, and advocate for sustainable land use policies that incorporate ecosystem service valuation to bolster environmental and economic resilience in coastal Tanzania.

Keywords: Land use and land cover (LULC) changes, biomass depletion, carbon emissions, mangrove forests, economic losses

1. Introduction
The coastal regions of Kinondoni District in Tanzania exemplify a vital nexus of ecological diversity and socio-economic importance, with significant ramifications for both local and global environmental sustainability. Coastal ecosystems, including mangrove forests, seagrass beds, and coastal forests, are crucial for carbon sequestration, which is necessary for alleviating climate change. These ecosystems are acknowledged as very effective carbon sinks, proficient in sequestering significant quantities of atmospheric carbon dioxide (CO_2), thereby diminishing greenhouse gas (GHG) concentrations and mitigating global warming (Osland *et al*., 2021) [16].

The swift degradation of these ecosystems, chiefly attributable to human actions such as urbanization and alterations in land use, presents a considerable risk to their capacity to operate as carbon sinks. The incursion of urban, agricultural, and infrastructure activities into previously pristine coastal regions has exerted significant strain on Kinondoni's ecosystems (Chausson *et al*., 2023) [2]. The degradation is particularly pronounced in the district's mangrove forests, where alterations in land use have led to substantial biomass loss and the emission of stored carbon into the atmosphere, hence elevating CO_2 levels and intensifying climate change (Nguyen *et al*., 2023) [15]. The continuous development exacerbates the destruction of mangroves and other coastal ecosystems, increasing the region's susceptibility to climate change effects and intensifying environmental deterioration.

Mangroves, seagrasses, and diverse coastal ecosystems function as natural carbon sinks. The degradation of these ecosystems results in the release of carbon stored in their biomass and sediments, consequently elevating atmospheric CO_2 levels and exacerbating global warming (Friess *et al*., 2023) [4]. The conversion of coastal forests to urban and agricultural zones in

Kinondoni has markedly increased carbon emissions, presenting a substantial obstacle to global climate change mitigation initiatives. The depletion of "blue carbon," which refers to carbon sequestered in coastal ecosystems, has attracted global focus because of the significant carbon absorption and storage potential of these environments. Their destruction not only intensifies climate change but also leads to forfeited economic prospects, especially in nascent carbon pricing markets (Bai *et al*., 2022) [1].

The economic consequences of biomass depletion and carbon emissions are especially significant in Kinondoni, where local residents rely extensively on coastal resources for their livelihoods and food security. The deterioration of mangrove ecosystems diminishes their capacity to deliver vital ecological services, including fisheries, tourism, and coastal protection. This decline negatively impacts the local economy, particularly for individuals dependent on these resources (Osland *et al*., 2021) [16]. Moreover, the depletion of coastal protection provided by mangroves heightens the district's susceptibility to storm surges, coastal erosion, and other natural calamities, resulting in escalated expenses for disaster recovery and infrastructure upkeep (Chausson *et al*., 2023) [2]. The economic significance of preserving these ecosystems is increasingly acknowledged, especially through methods such as carbon trading, which underscore the substantial carbon storage capacity of mangroves as a lucrative possibility. The continuous deterioration of these forests jeopardizes their economic sustainability, rendering conservation and restoration initiatives crucial for capitalizing on these opportunities (Bai *et al*., 2022) [1].

Given the urbanization and population growth in Kinondoni, it is essential to foresee the future effects of land-use alterations on biomass depletion, carbon emissions, and economic detriment. Predictive models offer significant insights into ecosystem degradation patterns and inform conservation actions to alleviate these impacts (Wang *et al*., 2021) [19]. Identifying regions most susceptible to future land-use conversion enables policymakers and environmentalists to prioritize efforts to save surviving ecosystems and augment their carbon storage capacity.

2. Materials and methods

2.1 Description of the study area

The study area encompasses the coastal wards of Mbweni and Ununio in Dar es Salaam, Tanzania, situated within the biodiverse Western Indian Ocean region. This region features vital ecosystems, including mangrove forests, seagrass meadows, and coral reefs, which are crucial for fisheries, shoreline protection, and carbon sequestration (Nguyen *et al*., 2023; Friess *et al*., 2023) [15, 4]. However, rapid urbanization has led to habitat destruction and ecosystem degradation, increasing vulnerability to climate impacts and releasing stored carbon (Wang *et al*., 2021; Osland *et al*., 2021) [19, 16]. The research aims to assess the economic and ecological effects of these changes from 2023 to 2033 (Lu *et al*., 2022) [12].

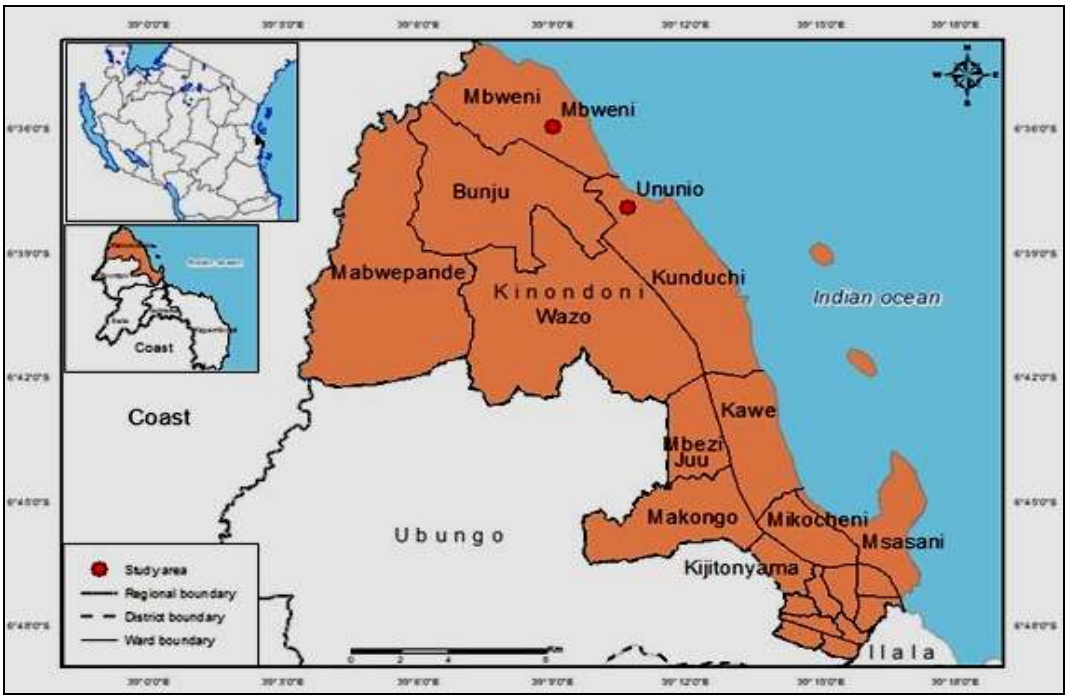

Fig 1: The map of the study area

2.2 Data sets: Figure 2 below shows the flow chart of the methodological approach used in this study for the forecasting of the biomass loss, carbon emission and sequestration, and economic loss from carbon trade for the period 2023-2033.

The study forecasts land use and land cover changes in Kinondoni District's coastal areas from 2023 to 2033, using high-resolution satellite imagery and GIS software (USGS, 2023; EROS, 2023). It highlights significant deforestation, habitat degradation, and urban expansion due to population growth and agricultural shifts (NBS, 2022) [14]. Predictive modeling suggests severe biomass depletion and increased carbon emissions, particularly impacting mangrove forests crucial for carbon sequestration (URT, 2015; Lu *et al*., 2022) [17, 12]. The expected findings will concentrate on ongoing urbanization and agricultural development leading to substantial coastal ecosystem loss, undermining their carbon storage and essential services (Wang *et al*., 2021; Friess *et al*., 2023) [19, 4].

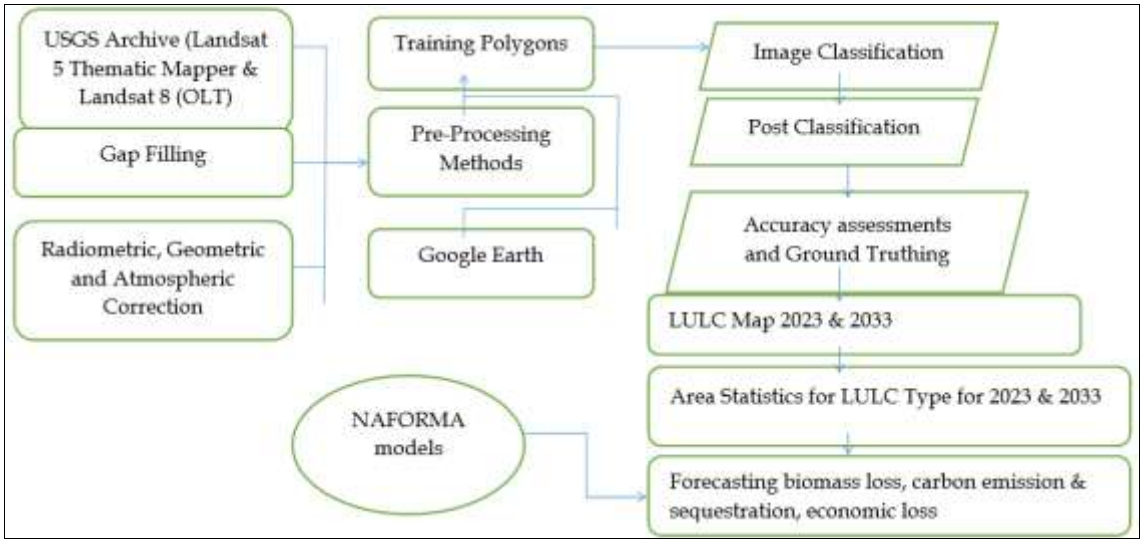

Fig 2: Flowchart of the methodological approach for this study

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

LULC Type	Year & Area (ha)		LULC change (ha)
	2023	2033	2023-2033
Mangrove forest	1100.37	877.3	223.07
Shrub land	193.06	194.35	-1.29
Bare area	113.75	96	17.75
Water	2243.63	2142.05	101.58
Built up area	1905.14	2248.96	-343.82
Cultivated land	5.88	3.17	2.71

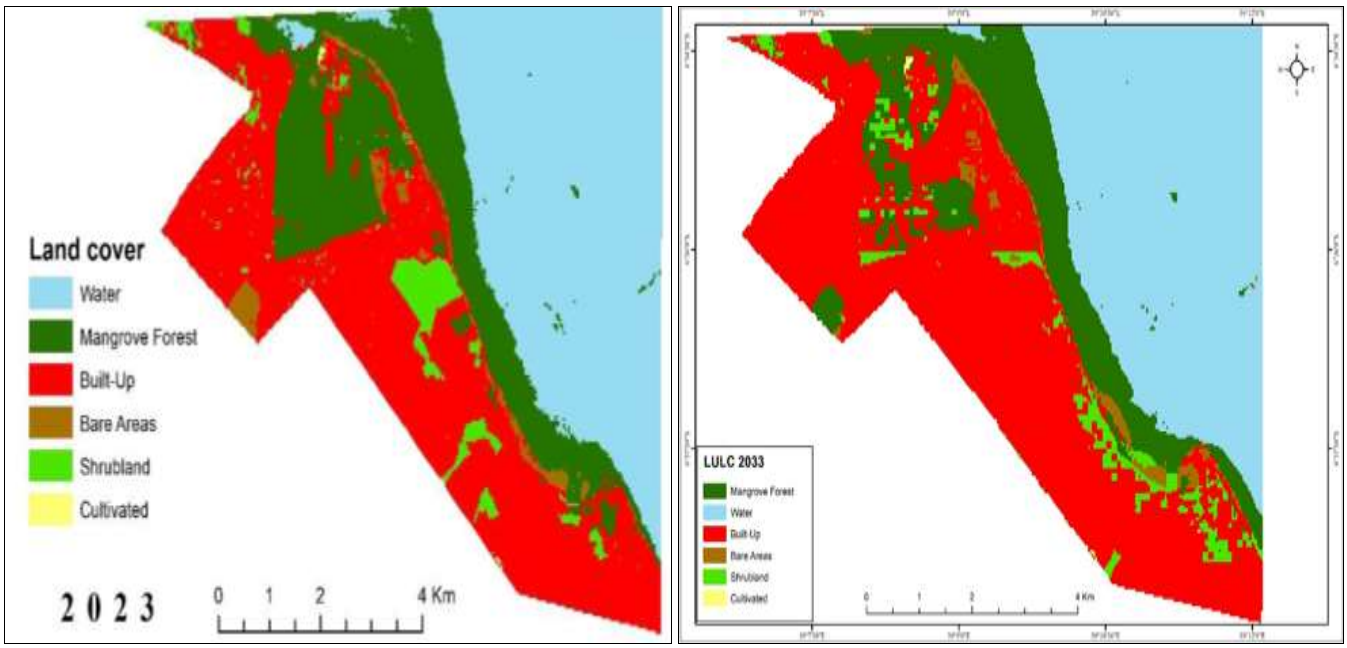

Fig 3: LULC for the years 2023 & 2033

2.3 Data analysis

2.3.1 Biomass depletion of the study area for the period 2023-2033: The analysis of biomass in Kinondoni District's coastal regions highlights a projected reduction from 2023 to 2033, driven by deforestation and urbanization (Henry *et al*., 2011) [6]. The study categorizes biomass into above-ground (AGB), below-ground (BGB), and dead wood (DW), each critical for carbon dynamics. AGB, sensitive to land use changes, is calculated using specific allometric equations 1-3 and summary in Table 2 (URT, 2015) [17]. Significant declines in AGB are anticipated, increasing carbon emissions (Friess *et al*., 2023) [4]. BGB, essential for carbon sequestration, and DW, a long-term carbon sink, underscore the need for sustainable land management to mitigate climate change impacts (Kauffman *et al*., 2020; IPCC, 2019) [10, 8].

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 2023-2033: Forecasting carbon emissions in Kinondoni District's coastal regions from 2023 to 2033 is vital for understanding carbon sequestration and climate change impacts. Rapid urbanization and land-use changes, particularly the degradation of mangroves, have significantly affected carbon dynamics, leading to increased emissions. This study employs the National Forest Resources Monitoring and Assessment (NAFORMA) guidelines and IPCC biomass-to-carbon conversion factors to project emissions, categorizing them into above-ground biomass (AGB), below-ground biomass (BGB), and deadwood (DW) as indicated in equations 4-5 and summary in Table 3 (URT, 2015; IPCC, 2019; Kauffman *et al*., 2020; Friess *et al*., 2023; Lu *et al*., 2022) [17, 8, 10, 4, 12].

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

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

Table 3: Living tree stem wood (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 2023-2033: This study estimates carbon dioxide (CO_2) emissions in Kinondoni District, Tanzania, from 2023 to 2033, focusing on land use and land cover (LULC) changes. Utilizing the Intergovernmental Panel on Climate Change (IPCC) methodology, it converts carbon stock losses into CO_2 equivalents, emphasizing the impact of urbanization and ecological degradation on climate change as indicated in equations 6-7 (IPCC, 2006; IPCC, 2019; Friess *et al*., 2023; Kauffman *et al*., 2020; Lu *et al*., 2022) [7, 8, 4, 10, 12].

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)

2.3.4 Economic loss of the study area for the period 2023-2033: The projected economic loss in Kinondoni District from 2023 to 2033 due to land-use changes and reduced carbon sequestration underscores the urgent need for integrating ecosystem services into policy frameworks. This study employ equation 8 to evaluates the financial impact of coastal ecosystem degradation, particularly mangroves, which are vital for carbon storage. It estimates CO_2 emissions, translating to an economic loss over the decade, based on current carbon market prices (World Bank, 2023; Chausson *et al*., 2023; Lu *et al*., 2022) [20, 2, 12].

Potential Economic Loss (US$) = Total CO_2 emission (tonnes) × Carbon market price (8)

3. Results and Discussions

3.1 Biomass depletion of the study area for the period 2023-2033: The analysis of biomass reduction in Kinondoni, Tanzania, from 2023 to 2033 reveals a critical decline in ecosystem health, with an estimated loss of 17,868.4 tonnes of biomass as indicated in Table 4. This decline is primarily attributed to land use and land cover changes (LULC), particularly deforestation, urbanization, and agricultural expansion, with mangrove forests experiencing the most severe impact, accounting for an extraordinary 103.4% of the total biomass loss (Friess *et al*., 2023) [4]. The destruction of mangroves is particularly concerning due to their essential roles as habitats and carbon sinks, which are vital for local biodiversity and global carbon dynamics (Osland *et al*., 2021) [16].

Research indicates that mangrove deforestation leads to the rapid release of sequestered carbon, exacerbating climate change by increasing atmospheric CO_2 levels (Kauffman *et al*., 2020) [10]. The findings in Kinondoni reflect global trends observed in countries like Indonesia and Brazil, where similar patterns of mangrove loss have been documented (Bai *et al*., 2022) [1]. While urban areas in Kinondoni showed a slight biomass increase of 8.2%, this is negligible compared to the significant losses in mangrove habitats, highlighting the inadequacy of urban afforestation efforts (Chausson *et al*., 2023) [2].

The study emphasizes the urgent need for conservation and restoration initiatives in Kinondoni's coastal regions, particularly for mangroves, which are crucial for ecological integrity and climate mitigation. Global studies support the importance of reforestation and mangrove restoration in enhancing carbon sequestration and protecting coastal communities from climate impacts (Chausson *et al*., 2023) [2]. Without immediate and sustained conservation measures, the ongoing biomass depletion will not only diminish the region's carbon sequestration capacity but also heighten ecological vulnerabilities and threaten biodiversity (URT, 2023).

Table 4: Biomass loss (Tonnes) of the study area for the period 2023-2033

LULC Type	AGB	BGB	DWB	Total	Percentage
Mangrove forest	13,272.7	4,059.9	1,135.4	18,468.0	103.4
Shrub land	-14.2	-5.7	-1.0	-20.9	-0.1
Bare area	51.5	19.5	3.9	74.9	0.4
Water	467.3	172.7	133.1	773.0	4.3
Built up area	-997.1	-378.2	-75.6	-1,450.9	-8.1
Cultivated land	16.0	5.7	2.6	24.3	0.1
Total	12,796.1	3,873.9	1,198.4	17,868.4	100.0
Percentage	71.6	21.7	6.7	100.0	

3.2 Carbon emission of the study area for the period 2023-2033: The study reveals alarming trends in carbon emissions from 2023 to 2033, primarily driven by the degradation of mangrove forests as indicted in Table 5. The study area emitted a total of 8,398.1 tonnes of carbon, with a staggering 103.4% of these emissions attributed to mangrove loss, highlighting the severe environmental challenges posed by deforestation and forest degradation (Friess *et al*., 2023; Chausson *et al*., 2023) [4, 2]. Mangroves, recognized for their high carbon sequestration potential, have faced significant degradation, which not only releases stored carbon but also diminishes future carbon capture capabilities, exacerbating global warming.

In contrast, the study noted a slight carbon gain of 8.1% in built-up areas, likely due to urban vegetation growth. However, this gain is insufficient to counterbalance the extensive emissions resulting from mangrove loss, as urban vegetation generally sequesters less carbon than mature forests (Nguyen *et al*., 2023) [15]. The research also identified marginal increases in carbon stock from other land use types, such as shrublands, but these gains are slow and cannot compensate for the rapid loss of mangrove ecosystems.

The findings underscore the urgent need for targeted conservation strategies focused on protecting and restoring mangrove forests (Bai *et al*., 2022) [1]. The implications of these land use changes extend beyond local ecosystems, affecting regional and global carbon cycles. Therefore, integrating local land management practices with international climate change mitigation efforts is crucial. The preservation and restoration of mangrove ecosystems should be prioritized in Kinondoni's conservation strategies due to their vital roles in carbon sequestration, biodiversity conservation, and coastal protection

Table 5: Carbon emission (Tonnes) in the study area for the period 2023-2033

LULC Type	AGB	BGB	DWB	Total	Percentage
Mangrove forest	6,238.2	1,908.1	533.7	8,679.9	103.4
Shrub land	-6.7	-2.7	-0.5	-9.8	-0.1
Bare area	24.2	9.2	1.8	35.2	0.4
Water	219.6	81.2	62.5	363.3	4.3
Built up area	-468.6	-177.8	-35.6	-681.9	-8.1
Cultivated land	7.5	2.7	1.2	11.4	0.1
Total	6,014.2	1,820.7	563.2	8,398.1	100.0
Percentage	71.6	21.7	6.7	100.0	

3.3 Carbon dioxide emissions from the study area for the period 2023-2033: This study reveals alarming findings regarding CO_2 emissions, totaling 30,821.2 tonnes, primarily attributed to land use and cover transformation from 2023 to 2033 as indicated in Table 6. A significant contributor to these emissions is the degradation of mangrove forests, which accounted for an astonishing 103.4% of the total emissions. This underscores the critical role mangroves play as natural carbon sinks, capable of sequestering substantial amounts of carbon in their biomass and sediments. The degradation of these ecosystems not only intensifies local environmental challenges but also has far-reaching implications for global CO_2 levels, emphasizing the necessity of protecting mangroves as a vital strategy for climate change mitigation (Friess *et al*., 2023; Chausson *et al*., 2023) [4, 2].

In contrast, other land use and land cover (LULC) changes, particularly in built-up areas, showed an 8.2% increase in carbon stock, likely due to urban green spaces or afforestation efforts. However, this increase is insufficient to counterbalance the extensive emissions resulting from mangrove loss, as urban vegetation typically has a lower carbon sequestration capacity compared to mature forests (Nguyen *et al*., 2023) [15].

The findings highlight the uneven nature of land cover changes in Kinondoni, revealing significant ecological degradation in certain areas while showing resilience in others. The marginal gains in carbon stock from urban areas cannot compensate for the substantial loss of carbon sequestration potential in mangrove.

Table 6: Carbon dioxide emission (Tonnes) from the study area for the period 2023-2033

LULC Type	AGB	BGB	DWB	Total	Percentage
Mangrove forest	22,894.0	7,002.9	1,958.5	31,855.4	103.4
Shrub land	-24.5	-9.8	-1.7	-36.0	-0.1
Bare area	88.8	33.7	6.7	129.2	0.4
Water	806.0	297.9	229.5	1,333.4	4.3
Built up area	-1,719.9	-652.4	-130.5	-2,502.7	-8.1
Cultivated land	27.6	9.8	4.5	41.9	0.1
Total	22,072.0	6,682.1	2,067.1	30,821.2	100.0
Percentage	71.6	21.7	6.7	100.0	

3.4 Economic loss of the study area for the period 2023-2033: The study underscores a critical economic loss in potential carbon trade revenue, projected at approximately US$ 123,284.8 between 2023 and 2033 as indicated in Table 7. This loss is predominantly attributed to deforestation and land-use changes affecting mangrove forests, which are recognized as highly efficient carbon sinks. Mangroves alone accounted for 103.4% of the total carbon trade value loss, emphasizing their vital role in global carbon cycles through substantial carbon storage in biomass and soil. The degradation of these ecosystems not only leads to significant carbon emissions but also results in a considerable loss of potential revenue from carbon trading markets, a concern given the global focus on carbon markets as a climate change mitigation strategy (Friess *et al*., 2023; Chausson *et al*., 2023) [4, 2].

Additionally, the study indicates that other land use and land cover (LULC) types contributed to a modest profit gain of 8.2%, highlighting their limited carbon sequestration potential compared to mangroves. While certain LULC types, such as shrublands and built-up areas, exhibited some carbon gains, these were insufficient to counterbalance the extensive losses from mangrove deforestation. This suggests a need for enhanced carbon sequestration efforts through afforestation or urban greening initiatives (Nguyen *et al*., 2023) [15].

The economic implications of these findings are significant, reflecting not only a lost financial opportunity but also broader environmental degradation that could impact the region's ecological stability. The high economic value of mangroves in carbon trading accentuates the urgency of their protection and.

Table 7: Economic loss (US$) of the study area for the period 2023-2033

LULC Type	AGB	BGB	DWB	Total	Percentage
Mangrove forest	91,576.1	28,011.5	7,834.0	127,421.6	103.4
Shrub land	-97.9	-39.2	-6.9	-143.9	-0.1
Bare area	355.2	134.7	26.9	516.8	0.4
Water	3,224.0	1,191.5	918.1	5,333.6	4.3
Built up area	-6,879.4	-2,609.4	-521.9	-10,010.8	-8.1
Cultivated land	110.3	39.3	17.9	167.5	0.1
Total	88,288.2	26,728.3	8,268.3	123,284.8	100.0
Percentage	71.6	21.7	6.7	100.0	

4. Conclusion and Recommendations

4.1 Conclusion: The study on biomass depletion, carbon emissions, and economic loss in Kinondoni District, Tanzania, from 2023 to 2033 reveals significant environmental and socio-economic challenges driven by rapid land use and land cover (LULC) changes. Urban expansion, agricultural encroachment, and infrastructure development have led to the degradation of carbon-rich ecosystems, particularly mangrove forests, which are crucial for carbon sequestration and climate regulation. This degradation has resulted in increased carbon dioxide emissions, exacerbating global warming and compromising biodiversity while heightening vulnerability to climate-related hazards.

The findings highlight a strong correlation between socio-economic drivers, such as population growth and urbanization, and environmental degradation. The demand for land and resources, intensified by pressures from Dar es Salaam, threatens the ecological health of Kinondoni's coastal areas. Without effective intervention, these trends are likely to continue, further endangering the region's ecosystems. The study emphasizes the urgent need for sustainable land management strategies that restore and protect these vital ecosystems. Implementing conservation initiatives that provide socio-economic benefits, such as carbon trading and ecosystem service payments, is essential for addressing these challenges and promoting sustainable development while mitigating climate change impacts in the region.

4.2 Recommendations

In light of the study's findings, eight main recommendations are offered to meet the issues provided by LULC changes in Kinondoni and to improve the sustainable management of coastal ecosystems:

Table 8: Recommendations

S/N	Recommendations	Explanation
1.	Enhancing land use planning and policy implementation	To enhance the protection of coastal habitats, it is essential to improve land use planning and enforce existing environmental regulations. This includes implementing strict zoning laws to prevent the conversion of natural landscapes into urban or agricultural areas, with a focus on preserving mangrove forests and other vital ecosystems that play a significant role in climate change mitigation (Kinondoni Urban Development Strategy).
2.	Advocating for sustainable urban development	Urbanization in Kinondoni should be managed to balance economic growth with environmental sustainability. Sustainable urban development strategies must be adopted, emphasizing the creation of green spaces and promoting vertical development to minimize land consumption. Restoration of degraded urban areas through replanting and urban forest establishment is also crucial (Sustainable Urban Development Guidelines).
3.	Preservation and rehabilitation of mangrove habitats	Given the importance of mangrove forests for carbon sequestration and coastal protection, targeted conservation and restoration efforts are necessary. This includes reforesting compromised areas, protecting existing mangrove populations, and fostering community-led conservation initiatives, supported by ongoing monitoring and research to assess effectiveness (Mangrove Restoration Framework).
4.	Integrating ecosystem services assessment in decision-making	The economic value of ecosystem services from coastal ecosystems should be integrated into land use planning. By quantifying these benefits, policymakers can make informed decisions that reflect the true value of natural capital, potentially facilitating funding for conservation through mechanisms like carbon trading (Ecosystem Services Valuation).

5.	Community involvement and education	Engaging local communities in conservation efforts is vital for the long-term sustainability of coastal habitats. Public awareness campaigns and educational programs should be developed to highlight the importance of mangroves and the impacts of land use changes, fostering local stewardship (Community Engagement Strategies).
6.	Enhancing research and monitoring initiatives	Continuous research and monitoring are essential to understand the impacts of land use changes and evaluate conservation efforts. Long-term monitoring systems should be established to track changes in biomass, carbon sequestration, and ecosystem health, promoting collaboration among government, academia, and international organizations (Research Collaboration Initiatives).
7.	Strategies for mitigating and adapting to climate change	The study emphasizes the need for integrated climate change mitigation and adaptation strategies addressing land use changes. Recommendations include reducing carbon emissions from deforestation, promoting renewable energy, and enhancing coastal community resilience. Incorporating climate risk assessments into land use planning is vital for protecting Kinondoni's coastal areas
8.	Utilizing global assistance and financial resources	Pursuing international funding for conservation, such as through the UN's REDD+ program, can support mangrove restoration. Collaborating with global environmental organizations can also provide essential technical expertise and resources for local conservation efforts, ensuring a comprehensive approach to climate challenges.

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