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Three Decades of Land Use and Land Cover Changes in Mjini Magharibi, Zanzibar, Tanzania: Implications on the Coastal Mangrove Forest Ecosystems and Urban Development

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ABSTRACT

Mangroves are vital coastal ecosystems that serve as natural barriers against erosion, support diverse marine life, and play a crucial role in mitigating climate change through carbon sequestration. This study employed remote sensing techniques to examine land use and land cover (LULC) changes in Mjini Magharibi, Zanzibar, from 1994 to 2024. The classification of LULC changes using Landsat images achieved high accuracy in thematic mapping, with overall accuracy and kappa coefficients ranging from 79.7% to 92.5%. The results revealed significant landscape transformations with environmental sustainability and coastal management implications. Furthermore, the results depicted a consistent increase in areas covered with water bodies, from 20,736.27 ha in 1994 to 22,422.51 ha in 2024, suggesting potential sea level rise and coastal land erosion. Concurrently, bare soil and built-up areas expanded from 1,981.44 ha in 1994 to 3,406.14 ha in 2024 signifying rapid urbanization. The study divulged a substantial decrease in mangrove and dense forest cover, with a loss of approximately 35.5% over 31 years, portraying significant ecological and socioeconomic challenges. Sparse vegetation and farmland areas also decreased, while mixed land uses increased, reflecting the diversification of land use patterns. These changes underscore the adverse pressure of urban expansion on natural resources, including pristine beaches, mangrove areas, and marine ecosystems. The findings emphasise the urgent need for sustainable management practices and conservation initiatives to protect the remaining mangrove forests, mitigate land use change impacts, and ensure the long-term ecological balance of Mjini Magharibi's mangrove ecosystems.

1. Introduction

Mangrove forests stand out as ecologically and physically valuable resources, serving critical transitional ecosystems between land and sea (Mohamed et al., 2023). As highly productive ecosystems, their importance are recognized globally; consequently, their protection and wise management are central goals within international initiatives like the Ramsar Convention and the UN Sustainable Development Goals (SDGs) (Seto and Fragkias, 2007). The ecological functions of mangrove forests include their capability to form spawning areas, nurseries, and feeding habitats for various fish and invertebrate species, including those of commercial significance. Past studies have highlighted the role of mangrove forests in mitigating climate change, as they demonstrate a greater capacity for carbon fixation than many terrestrial forests (Adanguidi et al., 2020). A recent study by Hagger et al. (2022) has emphasized that mangrove conservation and restoration are strategies of paramount importance in addressing climate change, owing to their unique ability to absorb and store significant amounts of carbon dioxide gas.

At the same time, their physical roles include, safeguarding coastlines against erosion and storm impacts (Islam, 2024, Kathiresan, 2012), facilitating nutrient cycling, and maintaining water quality (Afonso et al., 2021, Chang and Mori, 2021). Subsequently, stabilization of shorelines has resulted in protection of coastal communities and infrastructures from the damaging impacts of storms and high wave energy (Omar et al., 2019, Srikanth et al., 2015). Despite these multifaceted roles played by mangrove ecosystems, recent studies have reported the escalating and alarming pace of decline of mangrove coverage both at global and local scales (Daulat et al., 2019; Seto and Fragkias, 2007; Valderrama-Landeros et al., 2018). During the 1990's alone, mangrove loss was estimated to decline by 35% worldwide (Cao et al., 2021). In more recent decades, that is between 2000 and 2016, it was estimated that approximately 2.1% similar to 3,363 km^2 of global mangrove coverage was lost, primarily driven by human activities (Hagger et al., 2022).

However, another study conducted by Mohamed et al. (2023) has reported a decline of global mangrove at coastline coverage from 20.1 million ha in 2002 to 13.8 million ha by 2010 and further diminished to approximately 8.3 million ha by 2016. Multiple factors have been recognized to drive the decline of mangrove forests worldwide which scholars have categorised into anthropogenic disturbances and natural causes such as climate change (Ellison, 2015). Anthropogenic factors include rapid coastal development and urbanization, harvesting of mangrove trees for construction and firewood, and the conversion of mangrove areas for salt farming, agriculture, and aquaculture (Nair, 2015, Nehemia et al., 2019). Coastal pollution from plastic waste and industrial chemicals also exacerbate the decline of mangrove forests (Adanguidi et al., 2020; Mohamed et al., 2023; Seto and Fragkias, 2007). Natural factors such as climate change have been reported to aggrivate the decline of mangrove forests, and also its impacts, including sea-level rise, have further accelerated its rate of decline (Friess et al., 2022, Hagger et al., 2022).

In response to this alarming decline of mangrove forest, numerous initiatives have been undertaken worldwide to address the problem. For instance, during 1992 the Convention on Biological Diversity (CBD) established a goal that targeted to protect 10% of the world's ecological regions; however, this target remained unmet as of 2010 (Lopera et al., 2023). Furthermore, various countries and conservation practitioners have also established various interventions, including the adaptation of effective regulations, socioeconomic incentives, and rehabilitation programs, aiming to reverse declines by reducing loss rates and increasing gains (Hagger et al., 2022). These initiatives have, however, faced various challenges, such as an increase in adverse biophysical events which exacerbate complexity in meeting conservation efforts targets. In parallel with these interventions, mapping of mangrove forests has emerged as a vital effort for ensuring effective protection by offering substantial data through monitoring of mangrove distribution (Mohamed et al., 2023; Omar et al., 2019; Tuholske et al., 2017).

Tanzania has not been exempted from the decline of mangrove forests. Mangrove forests play a substantial role in Tanzania's socioeconomic development, offering necessary resources for local populations and significantly bolstering the fishing industry (Afonso et al., 2021). Likewise, on islands like Zanzibar, mangrove ecosystems are reported to support tourism activities and coastal agriculture (Mohamed et al., 2023). However, in recent decades, Zanzibar Island has experienced a surge in investments leading to rapid urbanization along its coastlines. Such development has brought potential threats to both terrestrial and marine ecosystems, leading to the decline of mangrove forests and disruption of their associated ecosystem functions (Mohamed et al., 2023). The Mjini Magharibi region is among the hotspots of significant mangrove forests, particularly in Maruhubi Ward (Mchenga et al., 2015). Maruhubi ward presents a distinctive combination of urban and natural environments, making the balance between development and ecological conservation particularly challenging (Lee et al., 2016). While other areas in Zanzibar, like Menai and Chwaka bays, feature well-known mangrove-protected areas (Mohamed et al., 2023), the Mjini Magharibi region itself has received comparatively less research focus regarding its specific mangrove dynamics (Daud et al., 2022; Islam Mchenga, 2015; Mohamed et al., 2023). The rapid expansion of tourism and urban infrastructure yields economic advantages but simultaneously creates complex challenges that threaten the region's fragile mangrove ecosystems. Therefore, the objective of this study was to monitor mangrove forests in this specific region in order to generate vital information to fuel effective mangrove forests management and conservation efforts. The availability of reliable, accurate, and consistent data regarding mangrove coverage and its spatial distribution patterns is essential for successful mangrove forests conservation.

Currently, the absence of a robust monitoring system specifically for Mjini Magharibi's mangrove forests has created knowledge gaps concerning their spatial patterns and extent, thereby limiting effective management potential.

For decades, researchers have used various methods to analyse satellite imagery for vegetation cover estimation. While datasets like the Moderate Resolution Imaging Spectroradiometer (MODIS) provide extensive insights globally (Wu et al., 2021), their coarse resolution limits utility for detailed local-scale assessments (Hamdi et al., 2022). Although high-resolution images can detect mangroves effectively, particularly along narrow coastlines (Valderrama-Landeros et al., 2018), their cost often restricts availability in regions like sub-Saharan Africa (Vahtmäe et al., 2021). Consequently, to monitor mangrove forests accurately and cost-effectively in this context, this study uses freely available medium-resolution imagery from Landsat 5 TM and Landsat 8 OLI. Combined with the Normalized Difference Vegetation Index (NDVI) spectral index, this approach allowed for the assessment of Land Use and Land Cover (LULC) changes in Mjini Magharibi over the past three decades (1994-2024), following methods suggested by previous studies (Akbar et al., 2020; Martinez and Labib, 2023; Valderrama-Landeros et al., 2018).

2. Materials and Methods

2.1. The study area

This study was conducted in the Mjini Magharibi region, Zanzibar, Tanzania, situated between latitudes 6° 5'0" S and 6° 20'0" S and longitudes 39°10'0"E and 39°15'0" E. The Mjini Magharibi region, which encompasses Zanzibar's capital, Stone Town, has mangrove ecosystems that are fundamental to the district's environmental and economic structure (Figure 1). However, urbanization and other economic activities, such as tourism have been reported to increase in this region, thereby threatening the health of the mangrove forests present in this area thus creating a necessity of assessing the current situation with regard to the mangrove sapling density. The total area under this study was 46192.23 ha, including a part of the Indian Ocean. Among the main mangrove creeks and protected bays found in the Mjini Magharibi region is Maruhubi (Islam et al., 2015) which is famous for four types of mangrove species, namely *C. tagal, R. mucronata, and B. gymnorrhiza* (Mohamed et al., 2023) and *A. marina* sop (Islam et al., 2015).

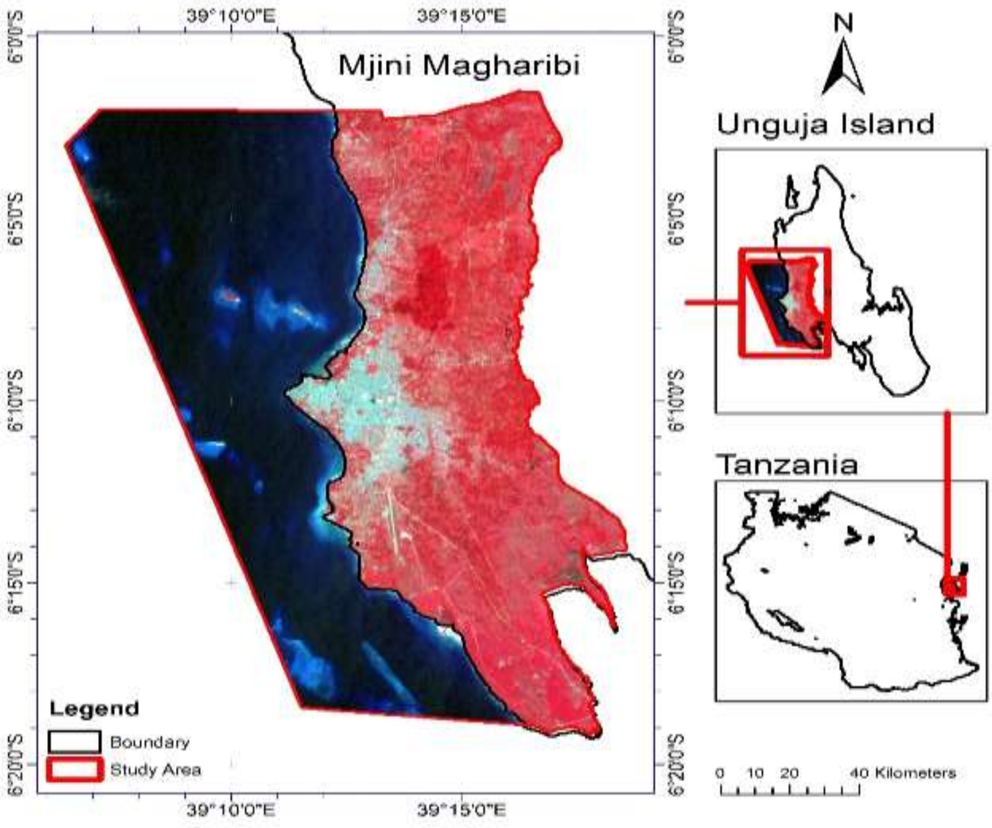

Figure 1. Map of Unguja Island showing the study location

2.2. Data analysis

2.2.1. Data Acquisition and Pre-Processing

This study focused on using satellite imagery datasets to analyse LULC and detect the spatiotemporal dynamics of mangrove forests. Moreover, this study has also applied high-resolution imagery and a survey to collect ground-truthing datasets for validation of classification results. We set the time series for the mangrove forest analysis between 1994 and 2024. The type of image and its availability were Landsat 5 Thematic Mapper (Landsat TM 5) images acquired in 1994 and 2003 and Landsat 8 Operational Land Imager (Landsat OLI 8) images for 2014 and 2024 were acquired from the Google Earth Engine. To overcome clouds in the study area, the use of a median script and filtering by clouds to < 10% were executed to obtain cloud-free images (Noi Phan et al., 2020). The Region of Interest (ROI) for the Mjini Magharibi area was taken from the official borders given by the National Bureau of Statistics (NBS, 2022). Then changed to include more coastal areas by stretching it out to the ocean so it would cover regions not included in the NBS maps. Table 1 displays the details of the Landsat data used.

Table 1. Data used to analyse the patterns and dynamics of mangroves in Mjini Magharibi, Zanzibar

Year	Bands	Satellite imagery				
		Data type	Sensor	Resolution (m)	Path/Row	Source
1994	3,4	Landsat 5	TM	30	Path:166 and Row: 064	https://earthexplorer.usgs.gov/
2003	3,4	Landsat 5	TM	30	Path:166 and Row: 064	https://earthexplorer.usgs.gov
2014	4,5	Landsat 8	OLI	30	Path:166 and Row: 064	https://earthexplorer.usgs.gov
2024	4,5	Landsat 8	OLI	30	Path:166 and Row: 064	https://earthexplorer.usgs.gov
2022	-	Shapefile	Vector	-	-	https://www.nbs.go.tz

2.2.2. Estimation of Normalized Difference Vegetation Index (NDVI)

The normalised difference vegetation index was a key approach in this study. The NDVI is a widely used metric for assessing vegetation health and density (Hu et al., 2018; Somayajula et al., 2021; Zhao et al., 2017). It has long been used to quantify various LULC types, including mangrove forests (Akbar et al., 2020). In recent years, NDVI datasets have been provided by the Moderate Resolution Imaging Spectroradiometer (MODIS) (Guerschman et al., 2009). However, their coarse spatial resolution (250 m) has limited the effectiveness of detailed vegetation analyses in regions with complex land cover or small-scale disturbances (Cho and Ramoelo, 2019; Liu et al., 2018; Sciortino et al., 2020). Therefore, using Landsat 5 and 8 can offset this obstacle by offering an opportunity to develop a medium-resolution image with a 30 m resolution. The NDVI metric has been widely validated because of its proven effectiveness in extracting relevant features for LULC classification (Campos-Taberner et al., 2020), and it can be adopted for mangrove ecosystems. The scientific estimation of mangroves was calculated using near-infrared (NIR) and red (RED) bands of satellite imagery, as shown in Equation 1 (Tempa et al., 2021). Therefore, in this study for Landsat 5 TM and Landsat 8 OLI, the selected bands (B3 and B4) and (B4 and B5) were termed as RED and NIR, respectively.

$$NDVI = \frac{(\boldsymbol{NIR} - \boldsymbol{RED})}{(\boldsymbol{NIR} + \boldsymbol{RED})} \dots \dots \dots . . \text{(Equation 1)}$$

Where;

NDVI: Normalized Difference Vegetation Index

NIR: Near-infrared reflectance, which is reflected off the leaves in healthy plants and is therefore overly sensitive to chlorophyll content in vegetation

RED: Red reflectance, which is absorbed by chlorophyll and other pigments in vegetation

2.3. Definition and classification of LULC using NDVI

In this study, mangrove forests were treated as LULC categories classified using predefined threshold values (Table 2). (Magidi et al., 2021) described various approaches of applying NDVI for LULC classification. The precise NDVI value ranges typically from -1 to +1.

2.3.1. Classification of mangrove forest and other LULC

Mangrove forests are among the vegetation cover types with high chlorophyll content. The ability of its leaf to reflect over near-infrared (NIR) bands provides an opportunity for researchers to extract spectral information through its canopy chlorophyll (Zhen et al., 2021). However, estimations of vegetation cover based on calculating photosynthetically active NDVI can produce varying thresholds across vegetation types (Huang et al., 2023). Higher values for NDVI indicate denser and healthier vegetation, which usually ranges between 0.5 and 1 (Akbar et al., 2020). (Valderrama-Landeros et al., 2018) established NDVI threshold values for three species of mangrove, namely Rhizophora mangle, Laguncularia, and racemosa, as well as those from dead mangroves using medium- and high-resolution images (Figure 2). The experiment has managed to estimate ranges of NDVI thresholds that mangrove forests can be captured, which ranged between 0.5 and 1 under the Landsat 8 imagery (Valderrama-Landeros et al., 2018). Therefore, in this study, we adopted a similar classification threshold to distinguish mangrove forests from other land-use and land-cover types using Landsat 5 TM and Landsat 8 OLI. The other land cover classification was established based on the expert view, whereby threshold values range from water (0.28–0.015), built-up (0.015–0.14), barren land (0.14–0.18), shrub and grasses (0.18–0.27), sparse vegetation (0.27–0.36), and dense vegetation (0.36–0.74) (Daulat et al., 2019).

Table 2: Definition of LULC categories and threshold values

LULC Category	Definition	Threshold value
Water/Mudflats	Areas covered by water bodies, such as lakes, rivers, and coastal mudflats.	(-0.28–0.015)
Bare Soil/Built-up	Areas with little to no vegetation, including urban areas, roads, and exposed soil surfaces.	(0.14–0.18)
Sparse Vegetation/Farms	Areas with scattered vegetation, including agricultural lands with seasonal crops or grasslands.	(0.18–0.27)
Mangrove	Areas with dense and healthier vegetation indicate mangrove forests.	0.5 - 1
Mixed Land Uses	Areas with a combination of vegetation, including shrubs and other forest types.	(0.27–0.36)

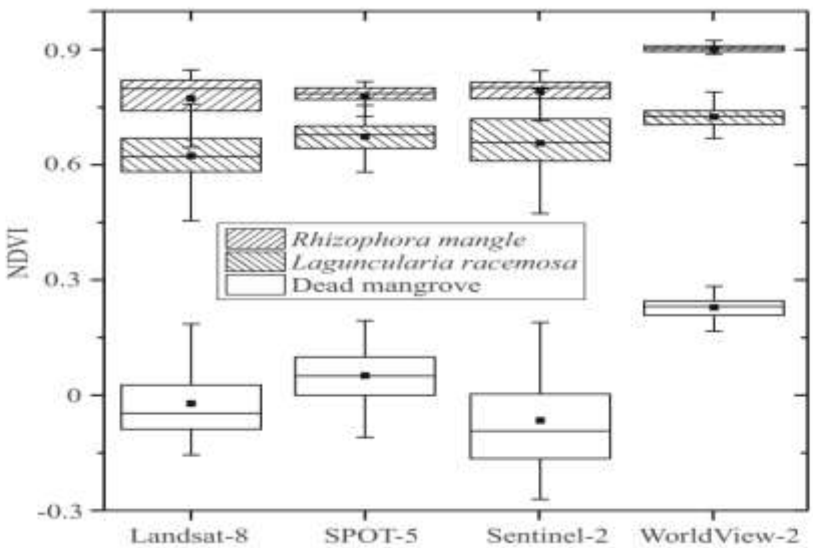

Figure 2. NDVI threshold value (0.5 to 1) that distinguishes mangrove forest from the rest of the LULC categories (Valderrama-Landeros et al., 2018).

2.4. Validation data collection

This study applied the quantitative method to assess the quality of the LULC thematic maps produced using the NDVI algorithm (Mohamed et al., 2023). This approach compared classified LULC categories with ground truth points gathered from high-resolution Google Earth Pro (GEP) images (Ragheb and Ragab, 2015).

GEP is embedded with high-to-medium-resolution pixel sizes (0.3 to >50 m) (Guerriero et al., 2020), and its availability depends on the year of access. GEP provided opportunities for conducting spatial inventory and is among the reliable platforms for acquiring ground-truth data (Adam and Heeto, 2018; Wang et al., 2022). Therefore, ground-truthing sample points (30 for each LULC) were gathered from GEP. However, during sample point collection, the availability of high-resolution images within GEP was predominantly between 2024 and 2014; however, the image sizes between 1994 and 2003 were similar to that of Landsat production (30 m) resolution images and therefore training samples were collected using similar imagery. The collected samples were then exported to ArcGIS 10.8 as a Keyhole Markup Language (KML) file, which was then converted to a shapefile. The shapefile of the ground-truth data was initially projected in the World Geodetic System (WGS) 84 and, therefore, re-projected to the Universal Transverse Mercator (UTM) zone (Arc1960 South) to align the produced thematic maps. Data cleaning was done for the collected ground-truthing points, which were then performed by editing LULC labels, and the predicted rows were added through the attribute table of the collected points (Behn et al., 2018). The extracted raster values were applied to the point tool in ArcGIS 10.8, which extracted the predicted LULC category values from the corresponding ground-truthing value.

2.5. Accuracy assessment

We evaluated the accuracy of the mangrove classification results using standard remote sensing validation metrics, specifically the kappa coefficient and overall accuracy (Mohamed et al., 2023; Rwanga and Ndambuki, 2017). It has been known that kappa and overall statistics are metrics that provide a robust measure of classification agreement that accounts for chance (Ali et al., 2021; Pan et al., 2021). Therefore, the collected ground-truth data, which were collected through GEP, served as the reference for assessing map accuracy. Subsequently, the calculated KC and OA metrics were compared with the classified thematic maps and verified ground reference points using error matrices.

3. Results and Discussion

The quantitative results of the Land Use Land Cover (LULC) classification for the study area from 1994 to 2024 are shown in Table 3 and Figure 3, while LULC maps are presented in Figure 4. Classification was conducted for four periods: 1994, 2003, 2014, and 2024. This study created very accurate thematic maps, with Overall Accuracy (OA) and kappa coefficients ranging between 79.7% and 81.3% (1994), 84.2% and 83.9% (2003), 87.4% and 84.7% (2014), and 89.8% and 92.5% (2024), respectively. The results revealed notable trends and significant changes in the landscape of the Mjini Magharibi region over the past 31 years, as presented below.

3.1. Water/Mudflats

This study has revealed an alarming increase in seawater within the study area over time, from 20,736.27 ha in 1994 to 22,422.51 ha in 2024, with slight fluctuations in between (Table 3). The observed increase in seawater implies potential coastline changes in the Mjini Magharibi, which can be attributed to sea level rise, coastal erosion linked to depletion of mangrove forests in the coastal area, or changes in land-water interfaces. These results are similar to the study by (Burger et al., 2017) who divulged the rising of the sea level along the Jersey shore in the United States. Similarly, a study conducted in Chwaka and Menai Bay in Zanzibar reported similar results, whereby there is evidence of sea level rise due to former mangrove forest areas being occupied by sea water, registering a loss of 783.5 ha of mangrove between 1973 and 1990 (Mohamed et al., 2023). Likewise, rising sea levels affect substantial wave run-ups to land, especially on exposed open coasts (Almar et al., 2021). For small islands like Zanzibar, which are highly susceptible to climate change impacts, especially rising sea levels and tropical cyclones (Thomas et al., 2020), high commitments to Nationally Determined Contributions (NDCs) are essential. It has been documented that these small islands have an opportunity to employ blue carbon ecosystems to make a substantial impact on the climate change mitigation and adaptation goals, even with small ecosystem ranges (Arkema et al., 2023; Friess, 2023).

3.2. Bare Soil/Built-up area

Subsequently, the study findings revealed a significant increase in bare soil and built-up areas in the Mjini Magharibi region. The estimated area of this LULC category increased from 1,981.44 ha in 1994 to 3,406.14 ha in 2024, showing potential urban expansion or land degradation. The study results imply that there have been some new developments in the Mjini Magharibi region over the past three decades, including developing infrastructures such as touristic resorts and other facilities. Past studies have indicated that sea area edges such as shorelines, beaches, and other nearby interfaces are usually under intense development pressure, attracting populations, tourists, and investments (Burger et al., 2017). In Muara Gembong in Indonesia, significant changes have been observed along the shorelines due to coastal erosion and subsequent land use conversions (Sofue et al., 2025). Similarly, the rapid urban expansion of the Mjini Magharibi region has placed unprecedented pressure on its natural resources, including its pristine beaches, mangrove area in Maruhubi ward, and diverse marine life. Apart from Mjini Magharibi, area of construction land from 1990 to 2020 has been reported to increase by 2.61 times along the coast in Jiangsu Province, China (Zhai, and Pu, 2025).

3.3. Sparse Vegetation/Farms

Subsequently, the study revealed a substantial reduction in the category of sparse vegetation and farmlands within the Mjini Magharibi administrative region. The area coverage estimation shows a reduction from 4,071.42 ha in 1994 to 1,589.13 ha in 2024 (Table 3). These results also signify heightened urbanisation and development pressures in Mjini Magharibi. Previous studies have also indicated that, in coastal areas, there are conflicts in the use of coastal and marine resources in Tanzania, where agricultural activities have been replaced by other activities such as tourism, fisheries, aquaculture, seaweed cultivation, and shipping activities (Gates et al., 2021). Elsewhere, in China, studies by Huang et al. (2021) and Chen et al. (2022) have reported substantial deterioration of coastal vegetation due to urbanization. Futhermore, the study by Yan et al. (2022) in 35 coastal cities along the Maritime Silk Road (MSR) uncovered a considerable damage of the marine vegetation due to urbanization.

3.4. Mangrove forest

This study has revealed an alarming decrease in mangrove forests, which over the past 31 years has decreased from 18,438.57 ha in 1994 to 11,892.33 ha in 2024 (Table 3), representing a 35.5% decline. Analysis of the rate of change has also revealed an average rate of 1.29% over the past 31 years (Figure 5). The spatial distribution of mangrove decline in the Mjini Magharibi region is more prominent along the shoreline of Maruhubi Ward, which has recently experienced the construction of hotels and other infrastructure developments. This study's results also are in good agreement with a previous study conducted in Zanzibar, which suggested that mangrove deforestation in Zanzibar is at a higher rate when compared with a global average annual mangrove loss rate of 0.21% (Mohamed et al., 2023). In Bangladesh the mangrove forest in the Sundarbans region has been reported to decrease at a rate of 2.66% per year from 2004 to 2022, linked to deforestation and land conversion for agricultural and infrastructure development (Saoum and Sarkar, 2024). Wartman et al. (2025) also reported a similar situation in Seychelles, where Mah´e's mangrove forests are facing direct threats from urban activities such as coastal development and pollution. In the Philippines, Sofue et al. (2025) recounted a decline in mangrove forest due to urbanization and tropical cyclones in Balangkayan in Eastern Samar while Quevedo et al. (2022) attributed the decline of mangrove forests in the same area to urbanization, where part of mangrove forests was dedicated for residential areas from 2001 to 2012.

The decline in mangrove and dense forest areas in the Mjini Magharibi region has several implications for both ecology and socioeconomics. Ecologically, mangroves have a higher affinity toward carbon sequestration than terrestrial forests (Adanguidi et al., 2020; Afonso et al., 2021). Therefore, a decline of mangrove forests in the Mjini Magharibi region has negative implications for the global efforts to curb current climate change trends. Moreover, mangroves play a significant role in protecting coastlines (Tuholske et al., 2017); therefore, the decline of mangrove forests in the Mjini Magharibi region exposes its coastal zone to a range of risks, such as hurricanes (Neumann et al., 2015) and soil erosion (Brunier et al., 2019). Moreover, mangrove forests are key to aquatic ecosystems and provide spawning sites for fish (Omar et al., 2019), implying that their degradation may have an adverse effect on the economy of the island's community since fishing is among the key economic activities in Zanzibar. A study conducted at Maruhubi Creek revealed that *A. marina*, a mangrove species, plays a significant role as a habitat for several crab species, including *N. meinerti* crabs. (Islmail et al., 2015). Similarly, Aye et al. (2019) reported that 28% of the total income of local communities in the Ayeyarwady Region in Myanmar was generated from selling crabs sourced from the mangrove forest.

3.5. Mixed Land Uses

The increase in bare soil/built-up areas and mixed land use, coupled with the decrease in sparse vegetation/farms, suggests ongoing land-use changes that may have been triggered by urbanisation and other anthropogenic activities. The observed changes underscore the need for sustainable management practices and conservation initiatives to protect the remaining mangrove forests and mitigate the impacts of land-use changes on coastal ecosystems in the study area. The study revealed a substantial increase in mixed land uses, from 964.53 ha in 1994 to 6,882.12 ha in 2024, as presented in Figure 6. In comparison to these findings, Abdullah et al. (2019) established that Bangladesh's coastal areas experienced a net increase in agricultural land (5.44%), built-up (4.91%) and river (4.52%) areas over the past 28 years from 1990 to 2017 indicating increase in mixed land uses.

Table 3. LULC Classification results (1994-2024) in hectares

LULC TYPE	LULC (1994 – 2024)			
	1994	2003	2014	2024
Water/Mudflats	20736.27	22842.27	22976.37	22422.51
Bare Soil/Built-up area	1981.44	3383.82	1922.58	3406.14
Sparse Vegetation/farms	4071.42	2794.14	4538.07	1589.13
Mangrove forest	18438.57	15530.22	15878.61	11892.33
Mixed Land Uses	964.53	1641.78	876.60	6882.12
Total area	**46192.23**	**46192.23**	**46192.23**	**46192.23**

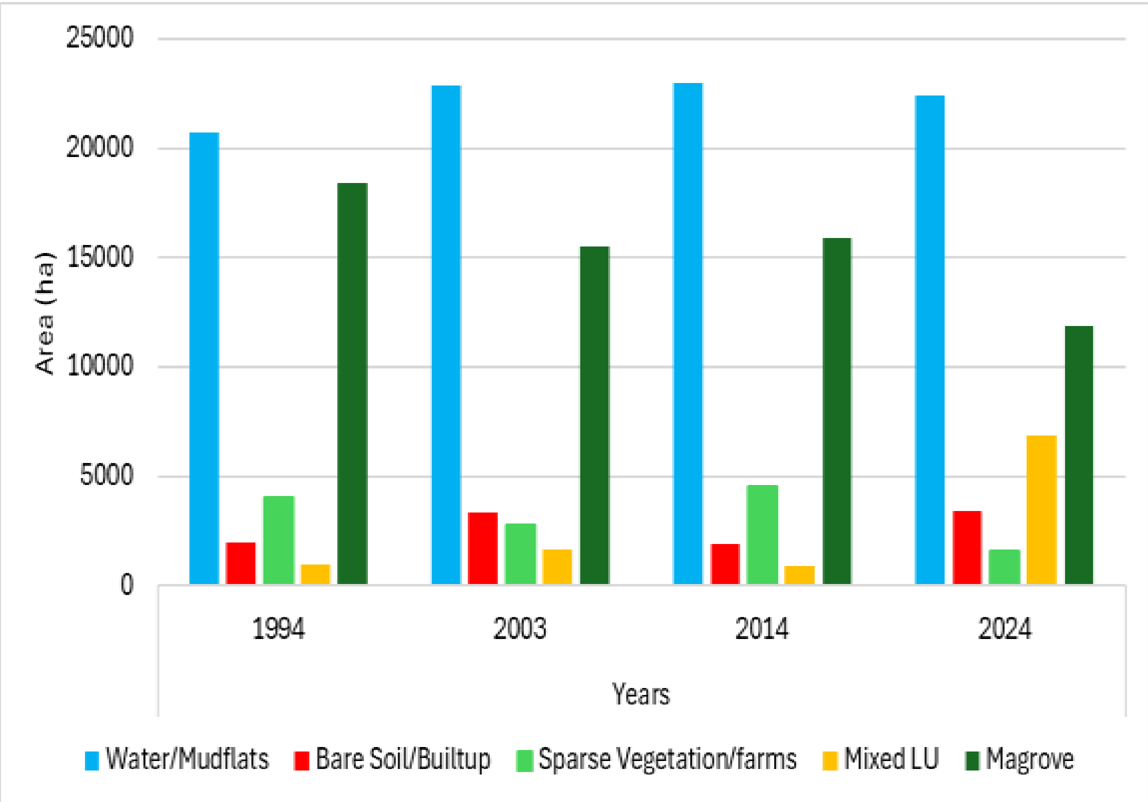

Figure. 3. LULC Dynamics and mangrove change trend between 1994 – 2024

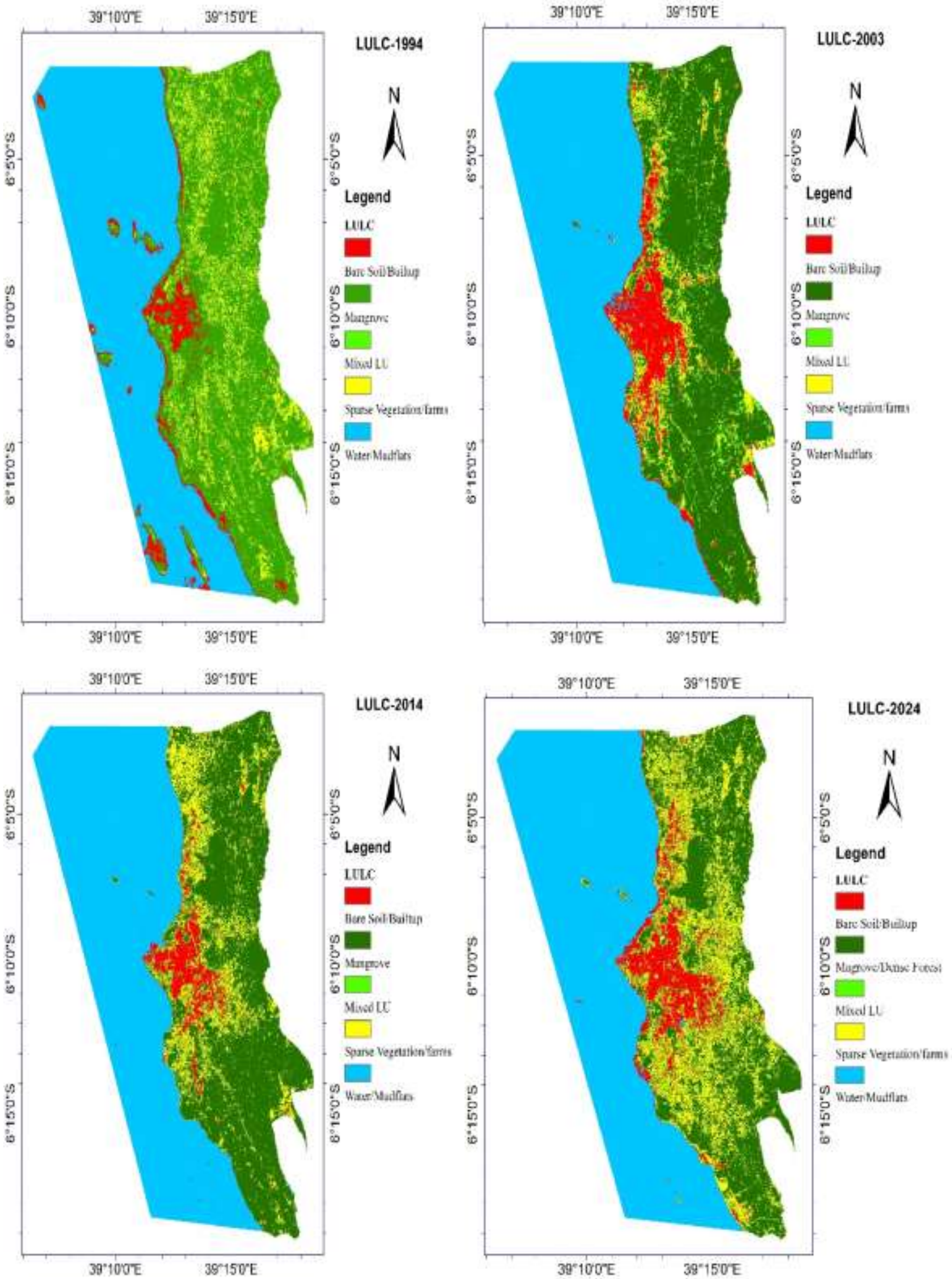

Figure 4. LULC Maps for the Mjini Magharibi region between 1994 – 2024

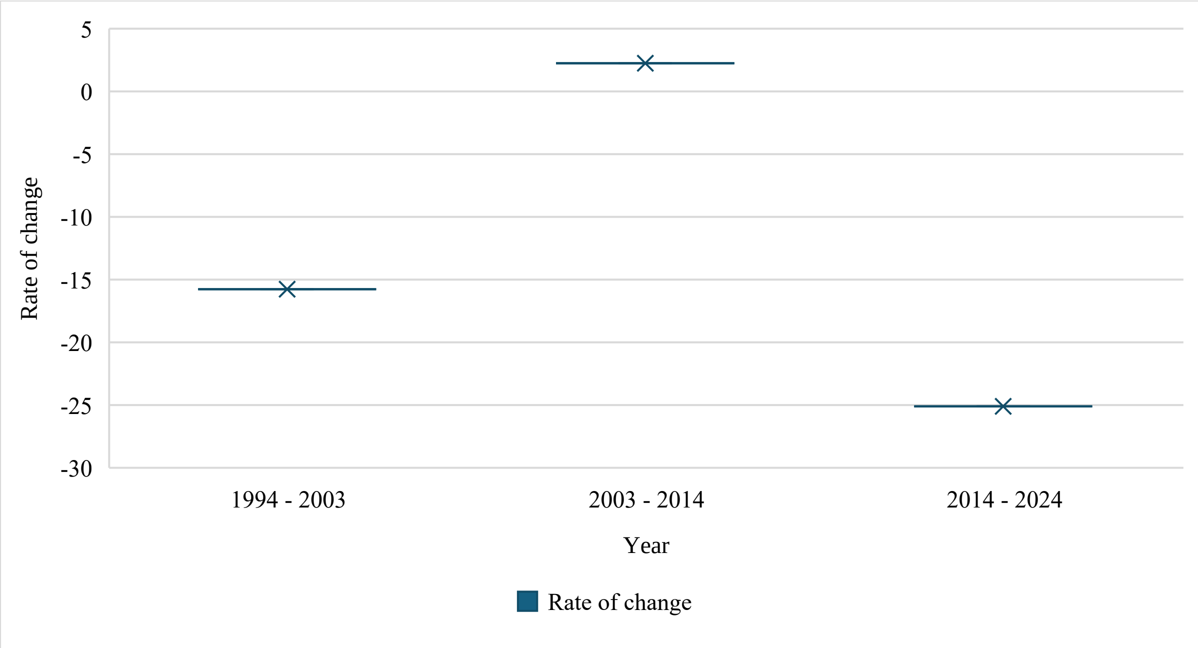

Figure 5. Rate of change for mangrove forest in the Mjini Magharibi, Unguja Island, Tanzania

Figure. 6. Distribution of land use patterns in Mjini Magharibi (Source: Google Earth Pro: 2025): (a). Built-up areas with mangrove forest, (b). Cleared mangrove forest for tourist hotel construction, (c) Shoreline without mangrove forest (posing risk for beach inundation, d). A Gulf area with mangrove forest

4. Conclusion and Recommendations

4.1. Conclusion

In this study, LULC and its changes were detected over the past 31 years (1994-2024) using remote sensing datasets from Landsat 5 TM and Landsat 8 OLI in Mjini Magharibi, Unguja Island, Zanzibar. The study categorized LULC into five classes based on the classification of normalised different vegetation index (NDVI) thresholds. These five (5) classes were water/mudflats, bare soil/built-up, sparse vegetation/farms, mixed land uses, and mangrove forest. The findings indicate that LULC changes have occurred over the past three decades, revealing critical insights into the region's environmental and urban development trends. The study has reached the following conclusions: -

Remotely sensed data, specifically the freely available Landsat 5 TM and Landsat 8 OLI, are reliable medium-resolution images that have produced LULC maps with acceptable accuracy results. The produced maps have proven useful in developing baseline and precision time-series information about the LULC of the Mjini Magharibi, Unguja.

An alarming LULC dynamics has been revealed with a notable decline in mangrove forests, increased water coverage, and increased bare/built-up areas within the Mjini Magharibi region. The decline of mangrove forests will likely pose severe ecological and socioeconomic challenges, particularly along the Mjini Magharibi's entire shoreline and the Maruhubi ward's mangrove creeks. These challenges include environmental concerns such as reduced carbon sinks, compromised coastline protection against climate hazards, and disruption of aquatic ecosystems, specifically at Maruhubi creeks.

Over the past three decades, the increase in water coverage area has been observed signifying a potential sea-level rise and shoreline erosion, exacerbating the vulnerability of the Mjini Magharibi's coastal zones.

Also, the study has revealed a rapid extension of bare soil and built-up LULC category, implying rapid urbanization and increased infrastructure development pressure, such as hotel construction, which is currently facing the Mjini Magharibi region. Other revealed changes, such as the reduction in sparse vegetation and farmland, coupled with the rise in mixed land uses, further emphasize the ongoing LULC transformations that have complex implications for local communities, including food security.

4.2. Recommendations

Based on the study findings, the following are the recommendations:

i. It is imperative to prioritize the protection of the remaining mangrove forests across the shorelines of the Mjini Magharibi region. Timely interventions that could secure mangrove degradation should be instituted to realize sustainable coastline management in the Mjini Magharibi region. These initiatives are essential for protecting the remaining mangrove forests and mitigating the impacts of land use changes on coastal mangrove ecosystems in the Mjini Magharibi region.

ii. The application of remote sensing technology has proven valuable for analysing and estimating Land Use and Land Cover (LULC) changes in the Mjini Magharibi, Unguja Island, Zanzibar. This technology has enabled the establishment of baseline information and facilitated time series analysis of LULC changes. Based on the study's findings, it is recommended that responsible authorities in Zanzibar adopt remote sensing (RS) technology for continuous monitoring of LULC. Incorporating RS is crucial for tracking LULC changes and guiding adaptive management practices for land conservation. These findings serve as a call to action for both local and international communities to support efforts in monitoring LULC in the Mjini Magharibi, Unguja Island, Zanzibar. Future research should focus on integrating remote sensing data with ground-based observations and socio-economic factors to provide a more comprehensive understanding of LULC dynamics in the region. This integrated approach could help identify the drivers of land use changes and inform more effective land management policies.

iii. It is vital to increase efforts to conserve the remaining mangrove forests in the Mjini Magharibi region, Unguja Island, Zanzibar. To achieve this, responsible authorities should collaborate and prioritize conservation efforts across all shorelines of the region. Key stakeholders include the Zanzibar Environmental Management Authority (ZEMA), the Ministry of Agriculture, Natural Resources, Livestock and Fisheries, Local Government Authorities in the Mjini Magharibi region, Non-Governmental Organizations (NGOs), and local community members. These entities should work together as a team to strengthen the implementation of laws and regulations that protect the remaining mangrove forests in the Mjini Magharibi. This collaborative approach can help ensure more effective conservation measures and sustainable management of these vital ecosystems.

iv. Additionally, this study suggests that Mjini Magharibi authorities should engage community members in creating rehabilitation programmes by conducting awareness campaigns. These campaigns should emphasize the importance of securing natural resources like land, beaches, and mangrove forests through conservation efforts.

v. The study also recommends the importance of collaborative efforts to reduce the impacts of increased water levels along shorelines in the Mjini Magharibi region through initiating adaptive practices such as mangrove replantation, construction of protective walls to reduce water inundation to shorelines, and promotion of sustainable land use practices.

vi. Lastly, this study recommends using a multidisciplinary approach that combines ecological, socioeconomic, and technological perspectives to address the challenges of the rapid increase of bare/built-up areas in the Mjini Magharibi region by developing green infrastructures that can respond to changing LULC.

References

Abdullah, A. Y. M., Masrur, A., Adnan, M. S. G., Baky, M. A. A., Hassan, Q. K., and Dewan, A. (2019). Spatio-temporal patterns of land use/land cover change in the heterogeneous coastal region of Bangladesh between 1990 and 2017. *Remote Sensing*, 11(7), 790. https://doi.org/10.3390/rs11070790.

Adam, S. M., and Heeto, A. F. (2018). The Use of Semi-Automated Method for Assessing the Horizontal Positional Accuracy of Google Earth imagery. *Academic Journal of Nawroz University*, *7*(4), 173. https://doi.org/10.25007/ajnu.v7n4a287.

Adanguidi, J., Padonou, E. A., Zannou, A., Houngbo, S. B., Saliou, I. O., and Agbahoungba, S. (2020). Fuelwood consumption and supply strategies in mangrove forests-Insights from RAMSAR sites in Benin. *Forest Policy and Economics*, *116*, 102192. https://doi.org/10.1016/j.forpol.2020.102192.

Afonso, F., Félix, P. M., Chainho, P., Heumüller, J. A., De Lima, R. F., Ribeiro, F., and Brito, A. C. (2021). Assessing ecosystem services in mangroves: insights from São Tomé Island (Central Africa). *Frontiers in Environmental Science*, *9*, 501673. https://doi.org/10.3389/fenvs.2021.501673.

Akbar, M. R., Arisanto, P. A. A., Sukirno, B. A., Merdeka, P. H., Priadhi, M. M., and Zallesa, S. (2020). Mangrove vegetation health index analysis by implementing NDVI (normalized difference vegetation index) classification method on sentinel-2 image data case study: Segara Anakan, Kabupaten Cilacap. *IOP Conference Series: Earth and Environmental Science*, 584 012069. https://doi.org/10.1088/1755-1315/584/1/012069.

Ali, S. A., Parvin, F., Vojteková, J., Costache, R., Linh, N. T. T., Pham, Q. B., Vojtek, M., Gigović, L., Ahmad, A., and Ghorbani, M. A. (2021). GIS-based landslide susceptibility modeling: A comparison between fuzzy multi-criteria and machine learning algorithms. *Geoscience Frontiers*, *12*(2), 857–876. https://doi.org/10.1016/j.gsf.2020.09.004.

Almar, R., Ranasinghe, R., Bergsma, E. W. J., Diaz, H., Melet, A., Papa, F., Vousdoukas, M., Athanasiou, P., Dada, O., Almeida, L. P., and Kestenare, E. (2021). A global analysis of extreme coastal water levels with implications for potential coastal overtopping. *Nature Communications*, *12*(1), 1–9. https://doi.org/10.1038/s41467-021-24008-9.

Aye, W. N., Wen, Y., Marin, K., Thapa, S., and Tun, A. W. (2019). Contribution of mangrove forest to the livelihood of local communities in Ayeyarwaddy region, Myanmar. *Forests,* 10(5), 414. https://doi.org/10.3390/f10050414.

Behn, K., Becker, M., Burghof, S., Möseler, B. M., Willy, D. K., and Alvarez, M. (2018). Using vegetation attributes to rapidly assess degradation of East African wetlands. *Ecological Indicators*, *89*, 250–259. https://doi.org/10.1016/j.ecolind.2018.02.017.

Burger, J., O'Neill, K. M., Handel, S. N., Hensold, B., and Ford, G. (2017). The shore is wider than the beach: Ecological planning solutions to sea level rise for the Jersey Shore, USA. *Landscape and Urban Planning*, *157*, 512–522. https://doi.org/10.1016/j.landurbplan.2016.08.017.

Campos-Taberner, M., García-Haro, F. J., Martínez, B., Izquierdo-Verdiguier, E., Atzberger, C., Camps-Valls, G., and Gilabert, M. A. (2020). Understanding deep learning in land use classification based on Sentinel-2 time series. *Scientific Reports*, *10*(1), 1–12. https://doi.org/10.1038/s41598-020-74215-5.

Cao, J., Liu, K., Zhuo, L., Liu, L., Zhu, Y., and Peng, L. (2021). Combining UAV-based hyperspectral and LiDAR data for mangrove species classification using the rotation forest algorithm. *International Journal of Applied Earth Observation and Geoinformation*, *102*, 102414. https://doi.org/10.1016/j.jag.2021.102414.

Chen, Y., Huang, B., and Zeng, H. (2022). How does urbanization affect vegetation productivity in the coastal cities of eastern China?. *Science of the Total Environment*, *811*, 152356. https://doi.org/10.1016/j.scitotenv.2021.15235.

Cho, M. A., and Ramoelo, A. (2019). Optimal dates for assessing long-term changes in tree-cover in the semi-arid biomes of South Africa using MODIS NDVI time series (2001–2018). *International Journal of Applied Earth Observation and Geoinformation*, *81*, 27–36. https://doi.org/10.1016/j.jag.2019.05.014.

Damastuti, E., and de Groot, R. (2019). Participatory ecosystem service mapping to enhance community-based mangrove rehabilitation and management in Demak, Indonesia. *Regional Environmental Change*, *19*(1), 65–78. https://doi.org/10.1007/s10113-018-1378-7.

Daud, Z. O., Mchenga, I. S. S., and Ali, A. I. (2022). Blue Carbon Stock of the Dominant Mangrove Species in Zanzibar-Tanzania. *International Journal of Science and Research*, *11*(9), 720–725. https://doi.org/10.21275/SR22905180042.

Daulat, A., Pranowo, W. S., and Amri, S. N. (2018). Mangrove Forest Change in Nusa Penida Marine Protected Area, Bali - Indonesia Using Landsat Satellite Imagery. *International Journal of Remote Sensing and Earth Sciences (IJReSES)*, *15*(2), 141. https://doi.org/10.30536/j.ijreses.2018.v15.a2955.

Ellison, J. C. (2015). Vulnerability assessment of mangroves to climate change and sea-level rise impacts. *Wetlands Ecology and Management*, *23*(2), 115–137. https://doi.org/10.1007/s11273-014-9397-8.

Friess, D. A., Adame, M. F., Adams, J. B., and Lovelock, C. E. (2022). Mangrove forests under climate change in a 2 °C world. *Wiley Interdisciplinary Reviews: Climate Change,* 13(4), e792. DOI: 10.1002/wcc.792

Gates, A. R., Durden, J. M., Richmond, M. D., Muhando, C. A., Khamis, Z. A., and Jones, D. O. B. (2021). Ecological considerations for marine spatial management in deep-water Tanzania. *Ocean and Coastal Management*, *210*, 105703. https://doi.org/10.1016/j.ocecoaman.2021.105703.

Guerriero, L., Di Martire, D., Calcaterra, D., and Francioni, M. (2020). Digital image correlation of google earth images for earth's surface displacement estimation. *Remote Sensing*, *12*(21), 1–14. https://doi.org/10.3390/rs12213518.

Guerschman, J. P., Hill, M. J., Renzullo, L. J., Barrett, D. J., Marks, A. S., and Botha, E. J. (2009). Estimating fractional cover of photosynthetic vegetation, non-photosynthetic vegetation and bare soil in the Australian tropical savanna region upscaling the EO-1 Hyperion and MODIS sensors. *Remote Sensing of Environment*, *113*(5), 928–945. https://doi.org/10.1016/j.rse.2009.01.006.

Hagger, V., Worthington, T. A., Lovelock, C. E., Adame, M. F., Amano, T., Brown, B. M., Friess, D. A., Landis, E., Mumby, P. J., Morrison, T. H., O'Brien, K. R., Wilson, K. A., Zganjar, C., and Saunders, M. I. (2022). Drivers of global mangrove loss and gain in social-ecological systems. *Nature Communications*, *13*(1), 1–16. https://doi.org/10.1038/s41467-022-33962-x.

Hamdi, A., Shaban, K., Erradi, A., Mohamed, A., Rumi, S. K., and Salim, F. D. (2022). Spatiotemporal data mining: a survey on challenges and open problems. In *Artificial Intelligence Review*, 55, 1441–1488. https://doi.org/10.1007/s10462-021-09994-y.

Hu, Y., Dong, Y., and Batunacun. (2018). An automatic approach for land-change detection and land updates based on integrated NDVI timing analysis and the CVAPS method with GEE support. *ISPRS Journal of Photogrammetry and Remote Sensing*, 146*,* 347–359. https://doi.org/10.1016/j.isprsjprs.2018.10.008.

Huang, C., Sun, C., Nguyen, M. T., Wu, Q., He, C., Yang, H., Tu, P., and Hong, S. (2023). Spatio-temporal dynamics of terrestrial Net ecosystem productivity in the ASEAN from 2001 to 2020 based on remote sensing and improved CASA model. *Ecological Indicators*, 154*,* 110920. https://doi.org/10.1016/j.ecolind.2023.110920.

Huang, B., Li, Z., Dong, C., Zhu, Z., and Zeng, H. (2021). The effects of urbanization on vegetation conditions in coastal zone of China. *Progress in Physical Geography: Earth and Environment*, *45*(4), 564-579. https://doi.org/10.1177/0309133320979.

Islam Mchenga, A. I. A. (2015). International Journal of Research and Review. *International Journal of Research and Review*, *2*(6), 343–347.

Islam, M. A., Billah, M. M., Idris, M. H., Bhuiyan, M. K. A., and Kamal, A. H. M. (2024). Mangroves of Malaysia: a comprehensive review on ecosystem functions, services, restorations, and potential threats of climate change. *Hydrobiologia*, 851(8), 1841-1871. https:// doi. org/ 10. 1007/ s10750- 023- 05431-z.

Jadhav Vikram R. Nair, S. G. (2015). International Journal of Research and Review. *International Journal of Research and Review*, *2*(6), 343–347.

Kathiresan, K., 2012. Importance of mangrove ecosystem. International Journal of Marine Science 2: 70–89. https:// doi. org/ 10. 5376/ ijms. 2012. 02. 0010.

Lee, B. X., Kjaerulf, F., Turner, S., Cohen, L., Donnelly, P. D., Muggah, R., Davis, R., Realini, A., Kieselbach, B., MacGregor, L. S., Waller, I., Gordon, R., Moloney-Kitts, M., Lee, G., and Gilligan, J. (2016). Transforming Our World: Implementing the 2030 Agenda Through Sustainable Development Goal Indicators. *Journal of Public Health Policy*, *37*(1), S13–S31. https://doi.org/10.1057/s41271-016-0002-7.

Liu, R., Xiao, L., Liu, Z., and Dai, J. (2018). Quantifying the relative impacts of climate and human activities on vegetation changes at the regional scale. *Ecological Indicators*, *93*, 91–99. https://doi.org/10.1016/j.ecolind.2018.04.047.

Lopera, L., Zapata-Ramírez, P. A., and Cardona, Y. (2023). Overview and potential implementation of a marine protected area network between Colombia, Nicaragua, and Jamaica. *Marine Policy*, 150, 105411. https://doi.org/10.1016/j.marpol.2022.105411.

Magidi, J., Nhamo, L., Mpandeli, S., and Mabhaudhi, T. (2021). Application of the random forest classifier to map irrigated areas using google earth engine. *Remote Sensing*, *13*(5), 1–15. https://doi.org/10.3390/rs13050876.

Martinez, A. de la I., and Labib, S. M. (2023). Demystifying normalized difference vegetation index (NDVI) for greenness exposure assessments and policy interventions in urban greening. *Environmental Research*, 220, 115155. https://doi.org/10.1016/j.envres.2022.115155.

Mohamed, M. K., Adam, E., and Jackson, C. M. (2023). The Spatial and Temporal Distribution of Mangrove Forest Cover from 1973 to 2020 in Chwaka Bay and Menai Bay, Zanzibar. *Applied Sciences (Switzerland)*, *13*(13). https://doi.org/10.3390/app13137962.

Nehemia, A., Chen, M., Kochzius, M., Dehairs, F., and Brion, N. (2019). Ecological impact of salt farming in mangroves on the habitat and food sources of Austruca occidentalis and Littoraria subvittata. *Journal of Sea Research*, *146*, 24-32. https://doi.org/10.1016/j.seares.2019.01.004.

Neumann, B., Vafeidis, A. T., Zimmermann, J., and Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding - A global assessment. *PLoS ONE*, *10*(3). https://doi.org/10.1371/journal.pone.0118571.

Noi Phan, T., Kuch, V., and Lehnert, L. W. (2020). Land cover classification using google earth engine and random forest classifier-the role of image composition. *Remote Sensing*, *12*(15), 1–22. https://doi.org/10.3390/RS12152411.

Omar, H., Afizzul Misman, M., and Musa, S. (2019). GIS and Remote Sensing for Mangroves Mapping and Monitoring. *Geographic Information Systems and Science*, *January*. https://doi.org/10.5772/intechopen.81955.

Pan, L., Xia, H., Yang, J., Niu, W., Wang, R., Song, H., Guo, Y., and Qin, Y. (2021). Mapping cropping intensity in Huaihe basin using phenology algorithm, all Sentinel-2 and Landsat images in Google Earth Engine. *International Journal of Applied Earth Observation and Geoinformation*, 102, 102376. https://doi.org/10.1016/j.jag.2021.102376.

Quevedo, J. M. D., Uchiyama, Y., and Kohsaka, R. (2022). Community perceptions of long-term mangrove cover changes and its drivers from a typhoon-prone province in the Philippines. *Ambio*, *51*(4), 972-989. https://doi.org/10.1007/s13280-021-01608-9.

Ragheb, A. E., and Ragab, A. F. (2015). Enhancement of Google Earth Positional Accuracy. *International Journal of Engineering Research and Technology*, 4(1), 627–630. www.ijert.org.

Rwanga, S.S. and Ndambuki, J.M. (2017) Accuracy Assessment of Land Use/Land Cover Classification Using Remote Sensing and GIS. *International Journal of Geosciences,* 8, 611-622. https://doi.org/10.4236/ijg.2017.84033.

Saoum, M. R., and Sarkar, S. K. (2024). Monitoring mangrove forest change and its impacts on the environment. *Ecological Indicators*, *159*, 111666. https://doi.org/10.1016/j.ecolind.2024.111666.

Sciortino, M., De Felice, M., De Cecco, L., and Borfecchia, F. (2020). Remote sensing for monitoring and mapping Land Productivity in Italy: A rapid assessment methodology. *Catena*, *188*(November 2019), 104375. https://doi.org/10.1016/j.catena.2019.104375.

Seto, K. C., and Fragkias, M. (2007). Mangrove conversion and aquaculture development in Vietnam: A remote sensing-based approach for evaluating the Ramsar Convention on Wetlands. *Global Environmental Change*, 17(3–4), 486–500. https://doi.org/10.1016/j.gloenvcha.2007.03.001.

Srikanth, S., Lum, S. K. Y., and Chen, Z. (2016). Mangrove root: adaptations and ecological importance. *Trees*, *30*(2), 451-465. DOI 10.1007/s00468-015-1233-0.

Sofue, Y., Quevedo, J. M. D., Lukman, K. M., and Kohsaka, R. (2025). Identifying changes in mangrove landscapes in the Philippines and Indonesia using remote sensing and community perceptions: Towards ecosystem services management. *Regional Studies in Marine Science*, *82*, 104023. https://doi.org/10.1016/j.rsma.2025.104023.

Somayajula, V. K. A., Ghai, D., and Kumar, S. (2021). Land Use/Land Cover Change Analysis using NDVI, PCA. *Proceedings - 5th International Conference on Computing Methodologies and Communication, ICCMC 2021*, *May 2023*, 849–855. https://doi.org/10.1109/ICCMC51019.2021.9418025.

Tempa, K., Peljor, K., Wangdi, S., Ghalley, R., Jamtsho, K., Ghalley, S., and Pradhan, P. (2021). UAV technique to localize landslide susceptibility and mitigation proposal: A case of Rinchending Goenpa landslide in Bhutan. *Natural Hazards Research*, *1*(4), 171–186. https://doi.org/10.1016/j.nhres.2021.09.001.

Tuholske, C., Tane, Z., López-Carr, D., Roberts, D., and Cassels, S. (2017). Thirty years of land use/cover change in the Caribbean: Assessing the relationship between urbanization and mangrove loss in Roatán, Honduras. *Applied Geography*, *88*, 84–93. https://doi.org/10.1016/j.apgeog.2017.08.018

Vahtmäe, E., Kotta, J., Lõugas, L., and Kutser, T. (2021). Mapping spatial distribution, percent cover and biomass of benthic vegetation in optically complex coastal waters using hyperspectral CASI and multispectral Sentinel-2 sensors. *International Journal of Applied Earth Observation and Geoinformation*, 102, 102444. https://doi.org/10.1016/j.jag.2021.102444.

Valderrama-Landeros, L., Flores-de-Santiago, F., Kovacs, J. M., and Flores-Verdugo, F. (2018). An assessment of commonly employed satellite-based remote sensors for mapping mangrove species in Mexico using an NDVI-based classification scheme. *Environmental Monitoring and Assessment*, 190*; 23*. https://doi.org/10.1007/s10661-017-6399-z.

Wang, P., Li, L., Xu, C., Zhang, Z., and Xu, X. (2022). An open source inventory and spatial distribution of landslides in Jiyuan City, Henan Province, China. *Natural Hazards Research*, *2*(4), 325–330. https://doi.org/10.1016/j.nhres.2022.10.004.

Wartman, M., Palacios, M. M., Nourice, B., Macreadie, P. I., Constance, A., Waryszak, P., and de Paula Costa, M. D. (2025). Assessing blue carbon in mangrove ecosystems of Seychelles. *Journal of Environmental Management*, *374*, 123967. https://doi.org/10.1016/j.jenvman.2024.12396.

Wu, J., Kurosaki, Y., Gantsetseg, B., Ishizuka, M., Sekiyama, T. T., Buyantogtokh, B., and Liu, J. (2021). Estimation of dry vegetation cover and mass from MODIS data: Verification by roughness length and sand saltation threshold. *International Journal of Applied Earth Observation and Geoinformation*, 102, 102417. https://doi.org/10.1016/j.jag.2021.102417.

Yan, M., Fan, S., Zhang, L., Mahmood, R., Chen, B., and Dong, Y. (2022). Vegetation dynamics due to urbanization in the coastal cities along the maritime silk road. *Land*, 11(2), 164. Doi:10.3390/land11020164.

Zhai, J., and Pu, L. (2025). Urban–Rural Differences in Cropland Loss and Fragmentation Caused by Construction Land Expansion in Developed Coastal Regions: Evidence from Jiangsu Province, China. *Remote Sensing*, 17(14), 2470.https://doi.org/10.3390/rs17142470.

Zhao, L., Zhang, P., Ma, X., and Pan, Z. (2017). Land Cover Information Extraction Based on Daily NDVI Time Series and Multiclassifier Combination. *Mathematical Problems in Engineering*, *2017*. https://doi.org/10.1155/2017/6824051

Zhen, J., Jiang, X., Xu, Y., Miao, J., Zhao, D., Wang, J., Wang, J., and Wu, G. (2021). Mapping leaf chlorophyll content of mangrove forests with Sentinel-2 images of four periods. *International Journal of Applied Earth Observation and Geoinformation*, *102*. https://doi.org/10.1016/j.jag.2021.102387.