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SPATIOTEMPORAL ANALYSIS OF LAND USE AND LAND COVER CHANGES IN THE CITY OF BEIRA, MOZAMBIQUE, BETWEEN 2014 AND 2024

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ABSTRACT

Objective: To analyze land use and land cover changes in the city of Beira, Mozambique, between 2014 and 2024 based on remote sensing data.

Originality/value: This study contributes to the understanding of urban landscape dynamics in a region vulnerable to extreme weather events, providing support for sustainable urban planning and environmental preservation.

Method: A quantitative approach was adopted through the analysis of Landsat 8 satellite images obtained from the USGS database. Supervised classification was performed using the Maximum Likelihood algorithm in QGIS 3.12.3 software. The areas were categorized into four main classes: inhabited zones, vegetation, exposed soil, and water bodies.

Results: The data revealed a significant increase in inhabited zones, from 34.05% to 38.95%, reflecting the intensification of urbanization. Vegetation showed a sharp decline, from 34.14% to 17.31%, indicating human pressure on ecosystems. Exposed soil increased from 29.04% to 39.90%, evidencing environmental degradation. Water bodies showed a slight increase, from 1.77% to 3.84%, possibly related to floods and extreme climate events.

Conclusion: The city of Beira underwent significant changes in land use and land cover between 2014 and 2024, driven by rapid urbanization and extreme climatic events. The results highlight the importance of sustainable urban planning and the use of remote sensing as a key tool for environmental management.

Keywords: Land use. Remote sensing. Landsat 8. Environmental changes. Urbanization.

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ANÁLISE ESPACIO TEMPORAL DAS TRANSFORMAÇÕES NO USO E COBERTURA DO SOLO NA CIDADE DA BEIRA, MOÇAMBIQUE, ENTRE OS ANOS DE 2014 E 2024

RESUMO

Objetivo: Analisar as transformações no uso e cobertura do solo na cidade da Beira, Moçambique, entre os anos de 2014 e 2024, com base em dados de sensoriamento remoto.

Originalidade/valor: O estudo contribui para a compreensão da dinâmica da paisagem urbana em uma região vulnerável a eventos climáticos extremos, oferecendo subsídios para o planejamento urbano sustentável e a preservação ambiental.

Método: Foi utilizada uma abordagem quantitativa, por meio da análise de imagens do satélite Landsat 8 obtidas do banco de dados do USGS. A classificação supervisionada das imagens foi realizada no software QGIS 3.12.3, utilizando o algoritmo de Máxima Verossimilhança. As áreas foram categorizadas em quatro classes: zonas habitadas, vegetação, solo exposto e corpos de água.

Resultados: Os dados apontaram um crescimento significativo das zonas habitadas, que passaram de 34,05% para 38,95%, refletindo a intensificação do processo de urbanização. A vegetação sofreu uma redução expressiva, de 35,14% para 17,31%, indicando pressão antrópica sobre os ecossistemas. O solo exposto aumentou de 29,04% para 39,90%, evidenciando a degradação ambiental. Os corpos de água apresentaram leve aumento, de 1,77% para 3,84%, possivelmente associado a inundações e eventos climáticos extremos.

Conclusão: Constatou-se que a cidade da Beira passou por intensas transformações no uso e cobertura do solo entre 2014 e 2024, impulsionadas pela urbanização acelerada e eventos climáticos extremos. Os resultados reforçam a importância do planejamento urbano sustentável e do uso do sensoriamento remoto como ferramenta para a gestão ambiental.

Palavras-chave: Uso do solo. Sensoriamento remoto. Landsat 8. Mudanças ambientais. Urbanização.

1. INTRODUCTION

Accelerated urban growth has emerged as a characteristic phenomenon of cities in developing countries, driven by demographic factors, rural-to-urban migration, and the expansion of socioeconomic activities. Although this process is often associated with economic development, it leads to significant changes in landscape structure, with direct consequences for urban ecosystems, environmental quality, and socio-spatial resilience (UN-Habitat, 2023; Hansine, 2023).

According to Baramuge et al. (2023), the rapid transformation of land use and land cover in recent decades has occurred primarily in urbanized and vulnerable tropical areas, where deforestation, urbanization, and environmental degradation reflect increasing anthropogenic pressure on natural ecosystems. This global synthesis, based on remote sensing data and national statistics, revealed that many of the fastest-growing cities are located in tropical regions, especially in Southeast Asia, the Amazon Basin, and parts of East Africa.

The city of Beira exemplifies this context, showing significant transformations in its spatial configuration between 2014 and 2024. These changes have been intensified by extreme climate events, including recurrent floods and tropical cyclones, as well as the unplanned expansion of informal settlements, which often occupy environmentally fragile areas (UNICEF, 2019; Nhangumbe, 2022). This dynamic has generated pressures on urban infrastructure, the degradation of natural resources, and increased population exposure to socio-environmental risks (Hansine, 2022).

In addition to environmental factors, socioeconomic dynamics play a crucial role in intensifying this vulnerability. Limited financial resources and the prioritization of basic survival needs lead the population to adopt unsustainable practices for exploiting natural resources, such as mangrove deforestation and the irregular occupation of risk-prone areas. These actions, combined with unregulated urban growth and the expansion of settlements in ecologically sensitive zones, heighten the city's exposure to disasters and hinder the implementation of effective climate adaptation strategies (Carige et al., 2024).

According to Lepers et al. (2005), the rapid transformation of land use and land cover in recent decades has occurred mainly in urbanized and vulnerable tropical areas, where the advance of deforestation, urbanization, and environmental degradation reflects anthropogenic pressure on natural ecosystems. This global overview, based on remote sensing data and national statistics, highlighted that many of the fastest-growing cities are located in tropical regions, especially Southeast Asia, the

Amazon Basin, and parts of East Africa.

According to FAO (2020), unplanned urban expansion in developing countries has led to the accelerated replacement of vegetated areas with impervious surfaces, directly affecting soil water infiltration, local water balance, and food security. This process is particularly severe in coastal and tropical cities, such as Beira, which face challenges related to rapid urbanization, environmental degradation, and climate vulnerability.

Therefore, the objective is to analyze the land use and land cover changes in the city of Beira between 2014 and 2024. To this end, remote sensing data obtained from the Landsat 8 satellite, provided by the United States Geological Survey (USGS), will be used. This information will enable the detection of patterns and trends of territorial changes over the past ten years

2. METHODOLOGY

2.1. Description of the Study Area

The city of Beira is located in the central region of Mozambique and is the capital of Sofala Province. Its geographic coordinates are 19° 50' South and 34° 51' East, and due to its location, the adopted time zone is CAT (UTC+2). Beira borders the district of Muanza to the north, Dondo district to the west, the Indian Ocean to the east, and the Buzi district to the south.

The city lies along the central coast of the Indian Ocean and is an important port city on the Mozambique Channel. It covers an area of 633 km², with an average altitude of 14 meters above sea level. The city is situated in a swampy region, near the mouth of the Pungue River, and extends over sand dune formations along the Indian Ocean coast. The area's natural vegetation is characterized by lowlands and coastal mangroves, typical of coastal zones (Amaral, 1969).

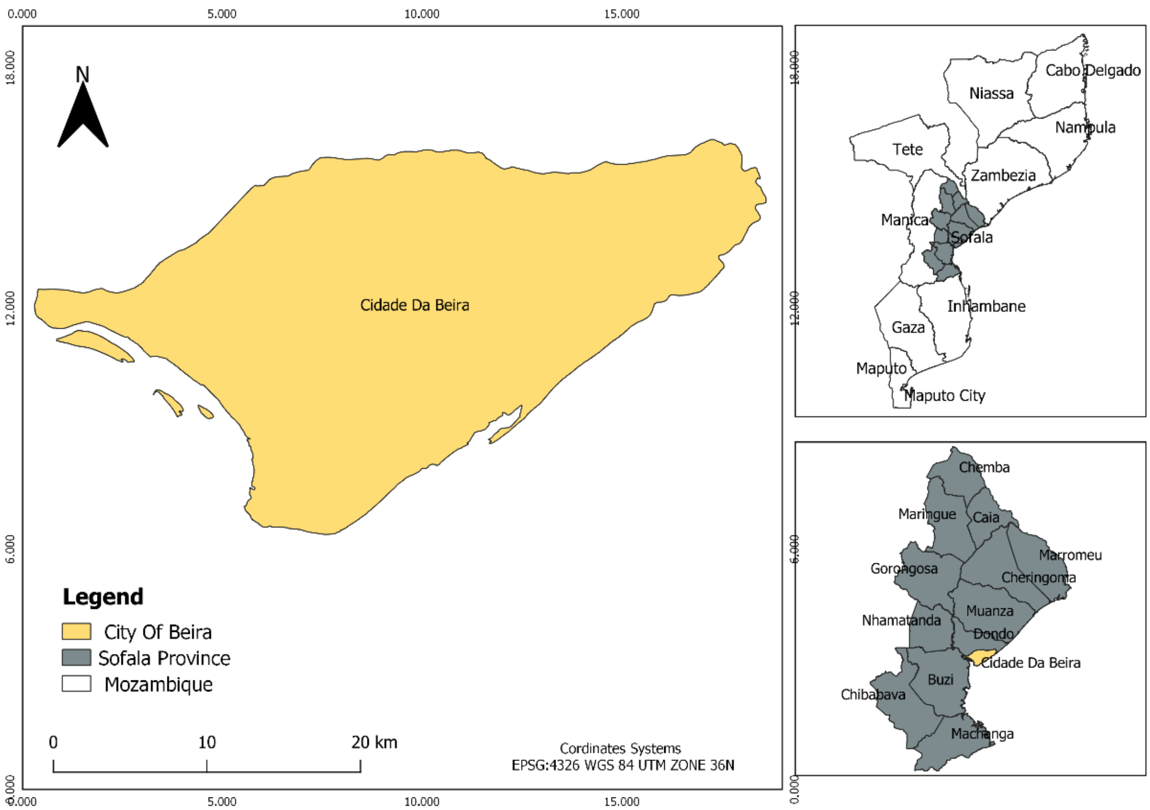


Figure1. Location of the study area

Source: CENACARTA, 2022

2.1.1. Image Acquisition and Processing

Landsat 8 OLI satellite images were used to analyze land use and land cover changes between the years 2014 and 2024. The images were obtained from the United States Geological Survey (USGS) repository, selecting those corresponding to the dates of June 17, 2014, and June 7, 2024. Images with the least cloud cover were prioritized to ensure analysis quality. The study area was delimited using a shapefile provided by Cenacarta (2024), enabling accurate clipping of the satellite imagery for the region of interest.

The image processing was carried out using QGIS version 3.12.3, where radiometric and geometric corrections automatically provided by the USGS were applied. Subsequently, spectral band composition was performed using bands B2 (blue), B3 (green), B4 (red), B5 (near-infrared – NIR), B6 (shortwave infrared 1 – SWIR1), and B7 (shortwave infrared 2 – SWIR2). This composition highlighted spectral differences among features, facilitating the identification of the classes of interest.

A false-color RGB composition was used to enhance the visualization of landscape elements, highlighting areas of vegetation, water bodies, urban surfaces, and bare soil.

2.1.2. Land Use and Land Cover Classification

A supervised classification approach was adopted, implemented in QGIS 3.12.3 using the Semi-Automatic Classification Plugin (SCP). The Maximum Likelihood algorithm was used for pixel categorization, considering the probabilistic distribution of spectral values, which resulted in greater classification accuracy. Representative samples of each class were manually collected to calibrate the model, ensuring accurate identification of the defined categories.

The analyzed classes included four main categories: Urban Area, Vegetation, Bare Soil, and Water. The definition of these classes was based on standard land use and land cover mapping references, ensuring consistency in the comparison between the analyzed periods.

The quantitative analysis of land use and land cover changes was performed by calculating spatial metrics using the LecoS (Landscape Ecology Statistics) plugin in QGIS. Detailed statistics such as total area per class, number of fragments, vegetation area connectivity, and diversity and dominance indices were extracted. These metrics enabled an in-depth

assessment of landscape structure and the spatial dynamics of the changes observed over the temporal series.

Validation of the results was conducted through visual inspection using Google Earth, with high-resolution imagery employed to verify classification accuracy (Table 1). The comparison between the classified data and the reference images allowed the identification of potential inconsistencies and adjustments to class boundaries. Based on the results obtained, thematic maps were produced for the years 2014 and 2024, enabling the analysis of spatial changes in land occupation and providing a foundation for understanding the environmental dynamics in the city of Beira.

As part of the study area characterization, a hypsometric map of the city of Beira was generated using data from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), with a spatial resolution of 30 meters, provided by the USGS. Data processing and map generation were performed using QGIS 3.12.3, employing a gradient color scale to highlight the different altitude ranges. This map aims to represent the region’s topography, supporting the visualization and interpretation of the spatial distribution of land use and cover classes.

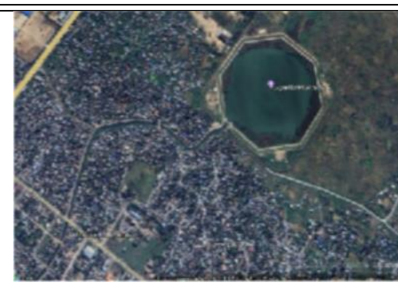
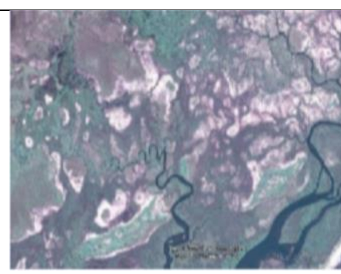
Classes e Descrição	2014	2024
Urban Area – Areas with a significant density of buildings and roads, including open spaces without buildings and infrastructure.		
Vegetation – Areas of non-permeable surfaces (infrastructure, urban expansion, or mining) not mapped in their respective classes.		
Water – Rivers, lakes, dams, reservoirs, and other bodies of water.		
Exposed Soil – Areas of soil without vegetation cover, vulnerable to erosion.		

Table 1. Land Use and Land Cover Classes and Descriptions Extracted from Google Earth.

Source: Author(s), 2025.

3. RESULTS AND DISCUSSION

The results of the temporal analysis of land use and land cover changes in the city of Beira are presented in Figures 1, 2, and 3, covering the period from 2014 to 2024. The comparison between the maps generated from Landsat 8 OLI images highlights significant transformations in the territory, especially in the main categories analyzed: urban areas, vegetation, exposed soil, and water surfaces. These changes reflect the effects of urban growth and environmental changes that occurred over the studied period.

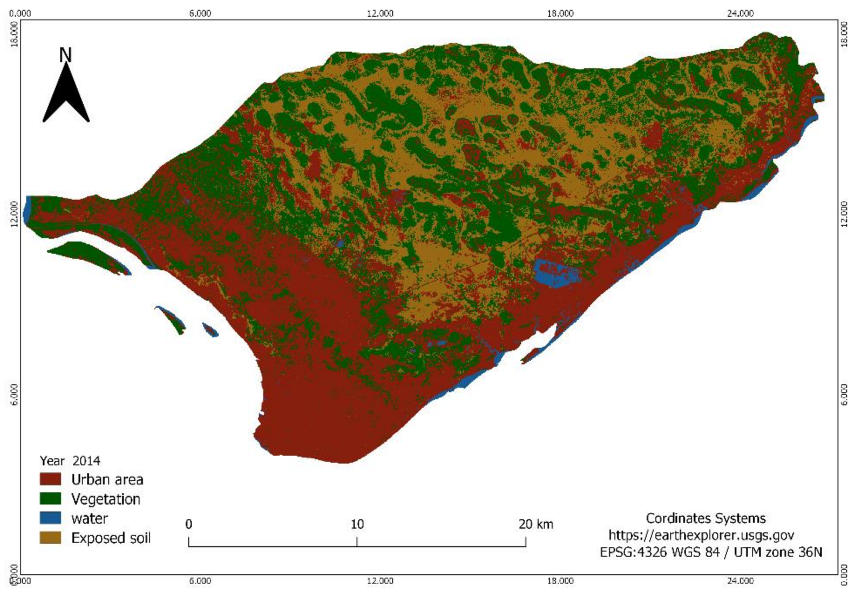


Figure 1: Land cover and land use for the year 2014.
Source: Author(s), 2025.

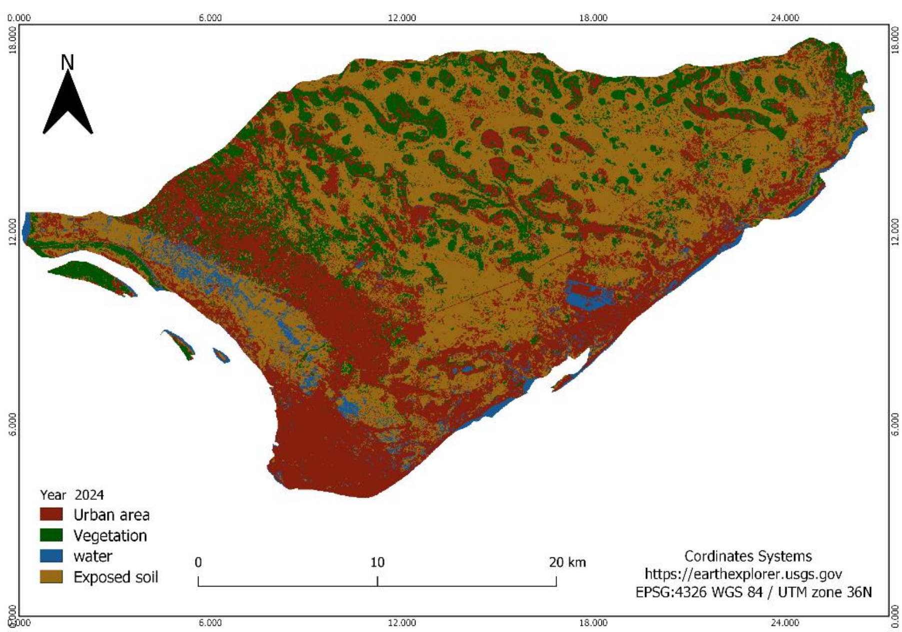


Figure 2: Land cover and land use for the year 2024
Source: Author(s), 2025.

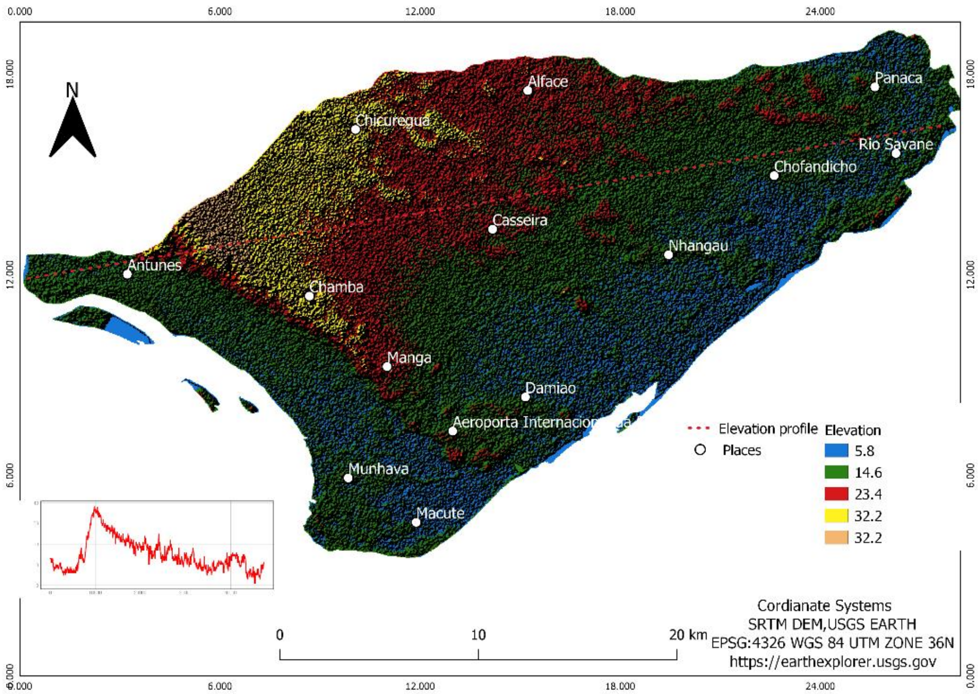


Figure 3 – Hypsometric map of the city of Beira, Mozambique.
Source: Author(s), 2025.

Table 2 shows the mapping results, containing the area values and the respective percentages for each land use and land cover category.

Classes	2014 (m²)	2014%	2024 (m²)	2024%
Urban Area	213.412.500	34,05%	244.076.300	38,95%
Vegetation	220.212.900	35,14%	108.481.500	17,31%
Water	11.100.600	1,77%	24.054.300	3,84%
Exposed Soil	182.024.100	29,04%	250.138.000	39,90%
Total	626.750.100	100,00%	626.750.100	100,00%

Table 2. Spatio-temporal variation of land cover and land use.
Source: Author(s), 2025.

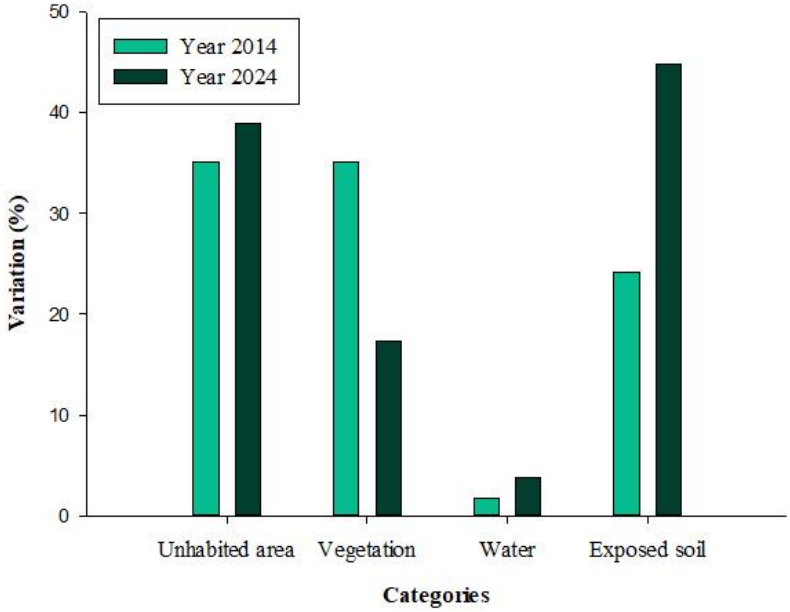


Figure 4. Spatio-temporal variation graph of land cover and land use.
Source: Author(s), 2025.

Urban areas recorded growth from 34.05% to 38,94%, indicating an expansion of housing infrastructure and urban development. This increase may be related to the need for reconstruction and restructuring of the city after extreme climatic events, such as Cyclone Idai in 2019, which required the construction of new housing and modernization of existing infrastructure. In contrast, vegetation was the category most negatively affected, with a decrease from 35.14% to 17.31%, demonstrating an accelerated process of replacement of these areas by other land uses.

Carvalho et al. (2021), in their study, found a significant increase in urban area in Uberlândia-MG, resulting from urban expansion over natural areas over recent decades. This process led to a reduction in vegetation cover, evidencing intense anthropic pressure on natural ecosystems and the conversion of green areas into urban spaces, corroborating the patterns observed in the city of Beira.

Exposed soil showed a significant increase, rising from 29,04% to 39,91%, suggesting activities such as deforestation, expansion of construction sites, and environmental degradation resulting from urban pressure and possible changes in the region's hydrologica regime.

Andrade et al. (2022) observed in their study that the growth of exposed soil areas is an indicator of environmental vulnerability, as it is directly related to increased erosion rates, decreased soil water infiltration capacity, and increased surface runoff. These factors combined may raise the risk of flooding, especially during intense rainfall periods.

Water bodies increased from 1.77% to 3.84%, which may be associated both with natural changes in the hydrographic system and urban interventions related to drainage and water management. This increase could also reflect reconstruction efforts of hydraulic infrastructure following Cyclone Idai, including the creation of new reservoirs or drainage channels. Abreu (2024) identified that water bodies in the municipality of Miranda present significant seasonal variations, resulting from natural flood and drought cycles typical of the Pantanal biome. These hydrological fluctuations can partly explain the increase in water body areas over time. Additionally, the author noted that the expansion of agricultural activities, especially livestock grazing and the cultivation of soy and rice, has altered local water dynamics, favoring the formation of artificial reservoirs, such as ponds and small lakes, used for irrigation and animal supply.

Dimuna et al. (2024) observed that in West African cities, unplanned urban growth has led to a reduction in green areas and an increase in impervious surfaces, significantly raising the risks of flooding and environmental degradation. Similarly, Magang et al. (2024) reported that expanding urban centers in Southern Africa are placing growing pressure on natural ecosystems, especially in peri-urban areas, where unregulated land occupation intensifies socio-environmental vulnerability.

Echendu (2023) highlights the worsening of extreme weather events in African coastal cities, emphasizing the urgent need for integrated territorial management and climate adaptation policies.

In this context, the findings of this study, conducted in the city of Beira, reinforce the importance of establishing regional and continental dialogues to address the consequences of urbanization and climate change. Such efforts are essential to strengthen urban resilience strategies capable of responding to the common challenges faced by African cities.

4. CONCLUSION

This research highlighted significant transformations in land use and land cover in the city of Beira between 2014 and 2024. The growth of inhabited areas, combined with the sharp reduction in vegetation and increase in exposed soil, reflects an accelerated urbanization process and growing human impact on the environment. Moreover, the expansion of water bodies indicates the influence of extreme climatic events, such as floods and cyclones, common in the region.

The results reinforce the importance of public policies directed toward sustainable urban planning, including environmental preservation actions and strategies to mitigate the effects of climate change. The use of remote sensing techniques, such as satellite image analysis, proved to be a fundamental tool for continuous monitoring of these changes, contributing to territorial management and the development of more effective measures for the conservation of natural resources in the city of Beira.

Therefore, it is recommended to adopt initiatives such as reforestation programs, control of disorderly occupation, and development of resilient infrastructure, aiming to minimize the environmental and social impacts resulting from the observed changes. Future studies could further analyze the causes of these transformations and assess the socioeconomic impacts associated with land use and land cover changes in the region.

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