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Mapping land cover changes in the city of Ziguinchor (Southern Senegal) from 2004 to 2025

Hyacinthe SAMBOU[1*], Fodé Amata DRAME[1], Cheikh Sadibou FAYE[3]
1 Institute of Environmental Sciences, Cheikh Anta Diop University of Dakar, Senegal.
3 Civil Engineering Department, Thiès Polytechnic School (EPT).
Corresponding Author ; E-mail: hyacinthe.sambou@ucad.edu.sn
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1 SUMMARY

This study aims to analyse changes in land cover in the city of Ziguinchor over a 21-year period (2004-2025), identifying spatial changes and transformations in land use in this Senegalese urban area. The methodology relies on the use of satellite images and remote sensing techniques to map land use and detect changes over a total area of 4,295 ha. The Normalized Difference Building Index (NDBI) was determined. The results reveal major changes in land use. Housing has expanded dramatically, from 1,035.05 ha in 2004 to 2,359 ha in 2025, an increase of 128% (1,323.95 ha). This urbanization has mainly been at the expense of vegetation, which has fallen by 67.5% (from 1,448.92 ha to 470.68 ha, or 978.24 ha) and agricultural areas, which have been reduced by 41.3% (from 1,179.61 ha to 692.47 ha, or 487.14 ha). Bare land also fluctuated significantly, peaking at 488.57 ha in 2016 before stabilizing at 233.16 ha in 2025. The transition matrix indicates that 2,223.35 ha (51.8%) of the territory remained stable, while 2,071.65 ha (48.2%) underwent land use conversion. This research demonstrates intense urbanization in Ziguinchor, characterized by a doubling of inhabited areas for over two decades. This rapid urban expansion reflects strong demographic pressure and uncontrolled urban growth, resulting in the massive artificialization of natural spaces. The drastic reduction in vegetation cover (67.5%) and agricultural land (41.3%) raises major environmental and food security concerns. The results serve as a warning to local decision-makers and urban planners, highlighting the urgent need to implement sustainable urban development policies. The study recommends the immediate development of controlled urban densification strategies, the protection of peri-urban agricultural areas, and the preservation of remaining vegetation. A system for continuously monitoring changes in land use is essential in order to anticipate and regulate future territorial transformations in Ziguinchor.

2 INTRODUCTION

Urban growth is viewed differently by researchers depending on their discipline. Since the end of the 20th century, urbanization has been seen as an irreversible phenomenon (Ndiaye, 2022). According to UN-Habitat (2010), the urbanization rate rose from 14.5% to 38.7% between 1950 and 2007 and will reach 47.2% and 61.8% in 2025 and 2050, respectively, if projections are to be believed. This phenomenon will be felt more acutely in Africa, where projections predict a doubling of the population by 2100 (Dasylva *et al.,* 2023). In Africa, rapid urban growth is a relatively recent phenomenon. According to Paulet (2006), in 1800 only 2% of the African population lived in urban areas, but by 2000 this figure had risen to over 50%. The urbanization rate in Africa rose from 14.5% to 38.7% between 1950 and 2007 and will reach 47.2% and 61.8% in 2025 and 2050, respectively (UN-Habitat 2010). In Senegal, according to Mbow (1992), "the urban population of Senegal was 697,058 in 1961, or 22% of the total population. Between 1961 and 1988, while the population grew at an average rate of 3% per year, the natural growth rate of the urban population was 5%. In West Africa, according to Gboko (2012), between 1960 and 2010, the urban population increased almost tenfold, from 12 million to over 117 million, while the total population increased fivefold. Ziguinchor city, with only 30,000 inhabitants in 1960, grew to 205,294 inhabitants in 2013 (ANSD/RGPH, 2013) over an area of 4,450 ha. Olvera et al (2002) and Manirakiza (2011) show that cities have faced rapid population growth coinciding with a period of socio-economic crisis, leading to disorderly urban sprawl. Trincaz (1984), Keita (2013), and Sow (2014) have highlighted the various characteristics that accompanied the different phases of spatial growth in the city of Ziguinchor. The drought of the 1970s, which affected much of sub-Saharan Africa, did not spare Senegal. During this period, the region around Ziguinchor became a gathering place for many farmers, herders, and other professionals who came from all over the country to settle in Ziguinchor. In addition, the outbreak of armed conflict in 1982 led to many people being displaced and numerous families from surrounding villages fleeing to the much safer city of Ziguinchor. Added to this are people coming from neighbouring countries (Guinea-Bissau and Gambia), where political instability often reigns. Thus, the municipality of Ziguinchor, with an area of 28.06 km², saw its population increase by more than 139,116 inhabitants between 1988 and 2023. It has grown not only through the expansion and densification of its population and infrastructure, but also through the spontaneous and often poorly controlled occupation of its outskirts and flood-prone areas. This population explosion has caused enormous difficulties in terms of land management, neighbourhood sanitation, and flooding. In addition, population growth and various anthropogenic causes have created significant pressure on natural resources, particularly the degradation of the once dense vegetation cover for housing needs, but also the occupation of areas reserved for urban rice cultivation. Faced with these urbanization and land use issues in the city, several strategies have been developed to reduce the impact of population growth and land use in the municipality and improve the living environment for residents. This led to two major reforms in 1972 and 1996, respectively. In addition, there is the Ziguinchor municipal development plan dating from 2018 (PDC, 2018). This study addresses the issue of urbanization in the municipality, focusing on the link between demographic change and land use in urban areas. The aim of this study is to contribute to better urban land management and to protect marshland areas, which are generally unsuitable for housing. To this end, a study of land use dynamics is essential for a better understanding of the various trends in spatial transformation processes. The development of remote sensing techniques and geographic information systems (GIS) allows for an increasingly accurate approach to land use dynamics (Lu *et al.,* 2004; Lunetta *et al.,* 2006; Niina *et al.,* 2011).

3 MATERIALS AND METHODS

3.1 Study area : The municipality of Ziguinchor is located in the Ziguinchor region, in southwestern Senegal (Figure 1). It is located between 12°34'N and 16°18'W. The municipality of Ziguinchor is characterized by a southern Sudano-coastal climate (Dasylva, 2017). Rainfall is around 1300 to 1500 mm per year. With such high rainfall, it is considered the rainiest region in Senegal. The high rainfall, vast expanses of agricultural valleys (Dasylva; 2019) and fertile soils (ANSD, 2015) provide this city with favourable conditions for agriculture and other socio-economic activities. According to demographic projections, the city of Ziguinchor had a population of 232,217 in 2017 and is expected to reach 281,915 by 2023 (PAM, 2012).

It is a cosmopolitan city, with 26% of households engaged in agriculture (Ba, 2007). It is mainly populated by the Diola people (35%), who practice agriculture in urban interstices and in peri-urban lowlands (Robineau, 2018).

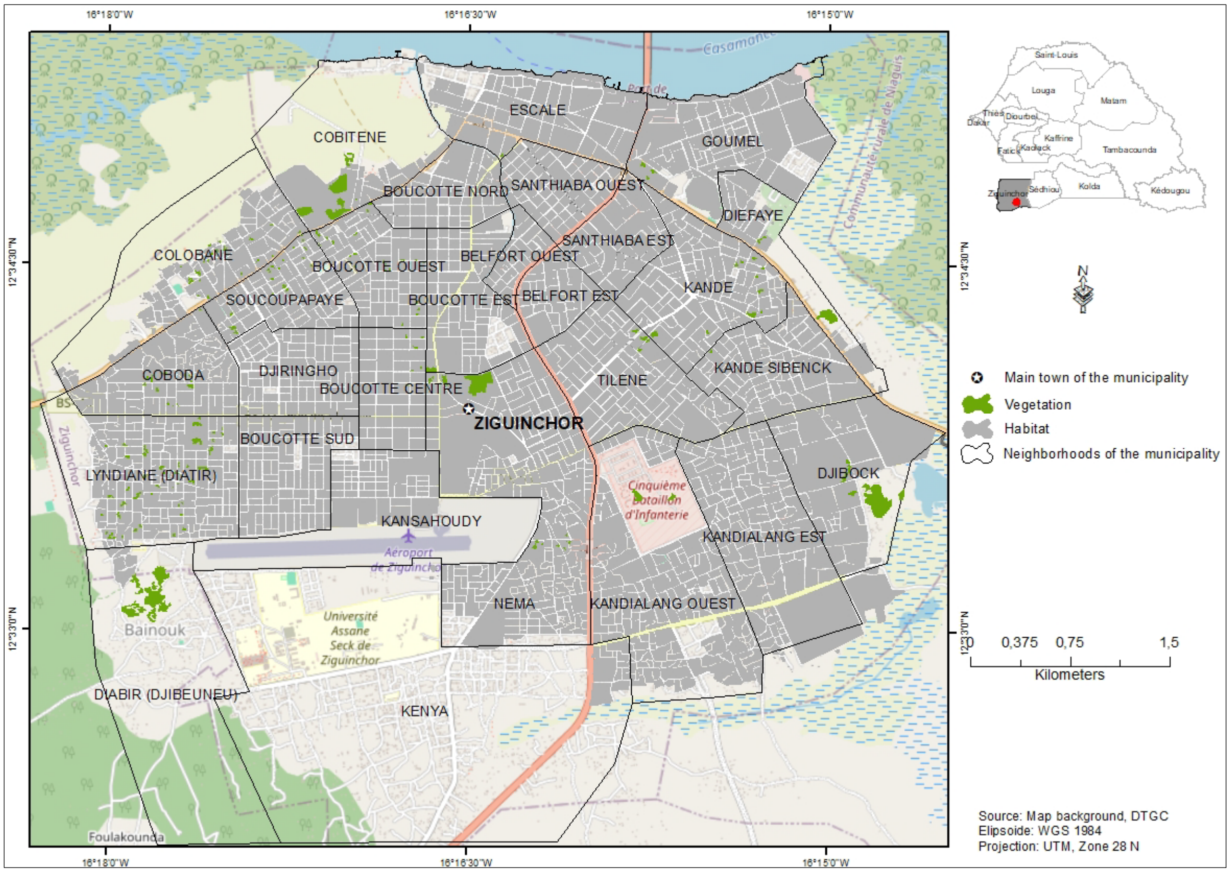

Figure 1: Location map of the study area

3.2 METHODS

3.2.1 Acquisition and Preprocessing of Satellite Images: Three categories of satellite images from scene 205-51 of the Landsat ETM+ (Enhanced Thematic Mapper Plus) sensor from February 2004 and the OLI (Operational Land Imager) sensor from February 2016 and February 2025 were used to map and monitor land use dynamics in the municipality of Ziguinchor. These images were downloaded from the United States Geological Survey (USGS) website. To avoid discrepancies due to differences between Landsat sensors and optimize image overlay for diachronic analysis, the 2004 and 2016 data were calibrated against the 2025 image taken as a reference based on landmarks identified on the topographic map. This made it possible to render the spatial entities present in the images close to the real world (Caloz & Collet, 2001). This correction was made possible using ENVI 5.6 software. The correction method used was the nearest neighbour method, and the geometric correction was performed using a first-order polynomial transformation. Validity was checked by estimating the standard error, RMSE (Root Mean Square Error) or Mean Square Error (Tendeng *et al.,* 2016). As RMSE is only one indicator, the validation of geometric corrections was supplemented by a visual check carried out by superimposing the images. The spatial accuracy threshold used was an error of less than one pixel. They will then be enhanced by spreading the dynamics and false colour compositions (5-4-3) for ETM+ sensor images and (6-5-4) for OLI sensor images will be created for better interpretation of the image themes. The choice of channels was based on near infrared (channel 4) and middle infrared (channel 4) because vegetation reflects better in these channels.

3.2.2 Classification of satellite images: Knowledge of the study area facilitated fieldwork and the characterization of land use units in the municipality. Since this objective was to group all the pixels in the image based on a number of samples called training sites determined on the basis of field knowledge, supervised classification was chosen. Thus, the different land cover units were referenced and used, thanks to the maximum likelihood algorithm, to classify the multispectral images of the study area. This algorithm was chosen because it is widely used in remote sensing and is mathematically very satisfactory, as the pixels are classified according to a probabilistic method.(Biga *et al.,* 2020). The probability of each pixel in the image belonging to a land cover unit was calculated. The calculation of the probability of a pixel belonging to a class was based on the average of the training area, the spectral signature of the pixel, and the standard error margin of the covariance matrix of the pixels in the training area. The pixel is thus classified in the land cover unit with the highest probability. In addition, this algorithm assumes that the statistics of the training site for each class follow a Gaussian distribution (Duminili, 2007).

3.2.3 Classification validation: To assess the accuracy of the classification of the different land cover units, the pixel confusion matrix was determined for each of the satellite images. The overall accuracy is 87.21% and the Kappa coefficient is 0.89. Thanks to these matrices, it was possible to evaluate the conversion rates of land use classes (Schlaepfer, 2002) over a period of thirty years. This made it possible to obtain the overall accuracy of the results obtained (i.e., the total number of correctly classified pixels, Kappa coefficient) and the accuracy of each classified category, in particular individual accuracy (Gao and Skillcorn, 1998). The classification results are considered acceptable when the total number of correctly classified pixels is greater than or equal to 80%. The individual accuracies of the categories are of the same order (Anderson *et al.,* 1972), and the Kappa coefficient must be greater than 0.80 (Tso & Mather, 2001). The accuracy of the 2018 image was determined using GPS control points collected in the various land use categories during field investigations. In addition to the supervised classification of Landsat satellite images, human settlements were identified by calculating urbanization indices. As part of this study, we determined the normalized difference built-in index (NDBI). The NDBI uses shortwave infrared (SWIR) and near-infrared (NIR) bands according to the following formula:

$$\mathbf{NDBI = (SWIR)\text{-}(NIR)/\ (SWIR)+(NIR)}$$

3.2.4 Statistical analysis: The analysis of land use dynamics in the municipality of Ziguinchor is essentially based on calculating the average annual spatial rate of expansion of land use units. In this study, the equation from Bernier, 1992 was used.

$$\mathbf{Tc = ((\ln S2 - \ln S1)\ /\ (TS2 - TS1) \times \ln e) \times 100}$$

where Tc = average annual change rate, S1 = the area of a land use unit at time t1; S2 = the area of the same land use class at time t2; ln = natural logarithm; e = the base of natural logarithms (e = 2.71828). This equation enabled us to evaluate the percentages of progression, regression, or stability of the different land use units for the study period considered.

4 RESULTS

4.1 Analysis of land cover and land use dynamics: Three maps were produced to illustrate land use in 2004, 2016, and 2025 (Figure 2).

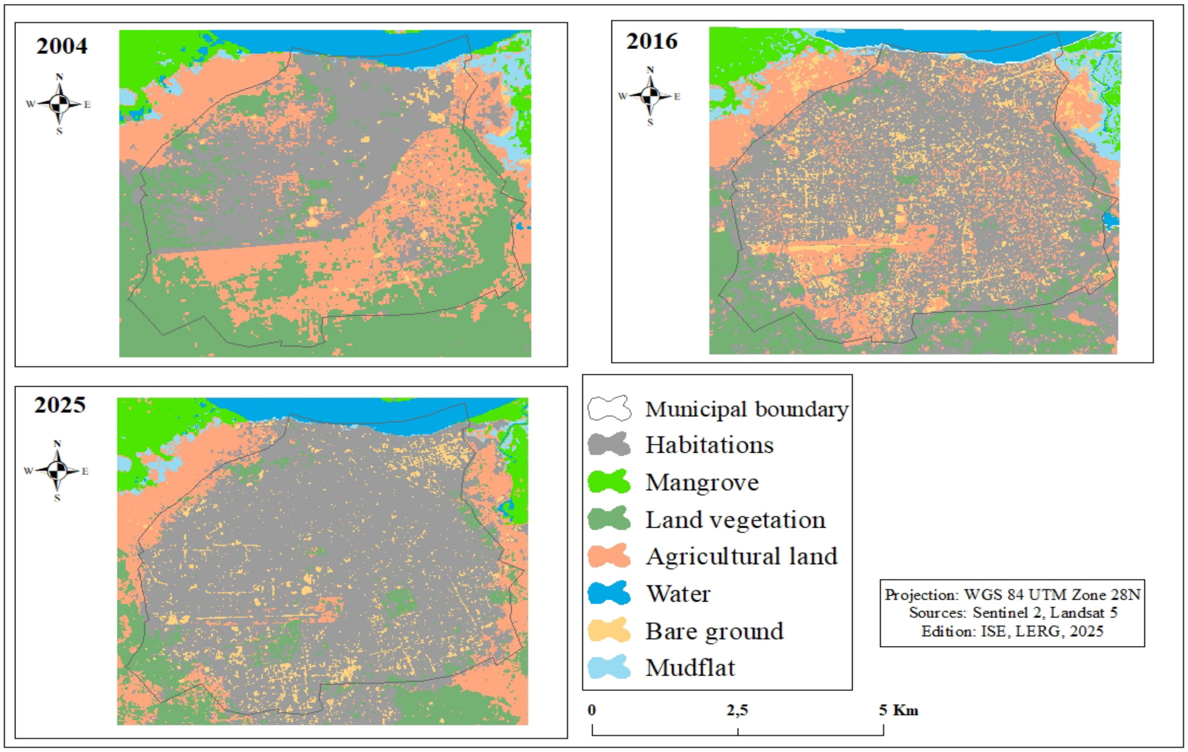

Figure 2: Changes in land use in the municipality of Ziguinchor between 2004, 2016, and 2025

Land use in 2004: In 2004, the ecological landscape of the municipality of Ziguinchor was mainly dominated by vegetation cover, which occupied 1,448.92 ha, and agricultural land, which occupied 1,179.61 ha (Figure 2). Proportionally, these two land use types occupied 33.74% and 27.46% of the municipality's total area, respectively. Together, they covered more than half of the municipality. Descriptive statistics for the areas of the different land cover units obtained after processing the 2004 Landsat satellite image are shown in (Table 1).

Table1 : Statistics on land use and occupation in Ziguinchor

Land use units	2004		2016		2025	
	Areas (ha)	%	Areas (ha)	%	Areas (ha)	%
Habitations	1,035.05	24.10	1,638.39	38.15	2,359	54.92
Mangrove	202.54	4.72	195.65	4.56	243.82	5.68
Land vegetation	1,448.92	33.74	753.01	17.53	470.68	10.96
Agricultural land	1,179.61	27.46	788.54	18.36	692.47	16.12
Water	248.02	5.77	238.06	5.54	238.92	5.56
Bare ground	58.95	1.37	488.57	11.38	233.16	5.43
Mudflat	121.91	2.84	192.78	4.49	56.95	1.33

4.2 Land use in 2016: Unlike in 2004, the appearance of the vegetation landscape in the study area in 2016 differs significantly from that of 2004. The Figure 2 and Table 1 show a decline in the area covered by vegetation, from 33.74% in 2004 to 17.53% in 2016, representing a loss of 17.41% between 2004 and 2016. Similarly, agricultural areas also experienced a 9.1% loss in surface area between 2004 and 2016. On the other hand, residential areas have increased in size from 1,035.05 ha in 2004 to 1,638.39 ha, representing a gain of 14.05%. This increase in residential areas has been at the expense of agricultural land and vegetation. Mangroves also declined slightly between 2004 and 2016.

4.2 **Land use in 2025:**The visual interpretation of the results of the 2025 image processing shows a densification of residential areas throughout the municipality of Ziguinchor, except for a few sites that are not yet heavily exploited. In addition, the decline in vegetation cover and agricultural land has accelerated in 2025. These two land use categories recorded losses of 6.57% and 2.24% respectively. This downward trend is also observed in the area of bare land, which fell from 488.57 ha in 2016 to 233.16 ha in 2025.

4.5 Synthesis of land use types in 2004, 2016, and 2025: Figure 3 highlights the summary of changes in the various land use categories. It shows that natural formations (vegetation cover, agricultural areas, and bare soil) have declined significantly across the municipality, by 22.78%, 11.34%, and 5.95%, respectively. In contrast, residential areas have grown considerably between 2004 and 2025, by 30.82%.

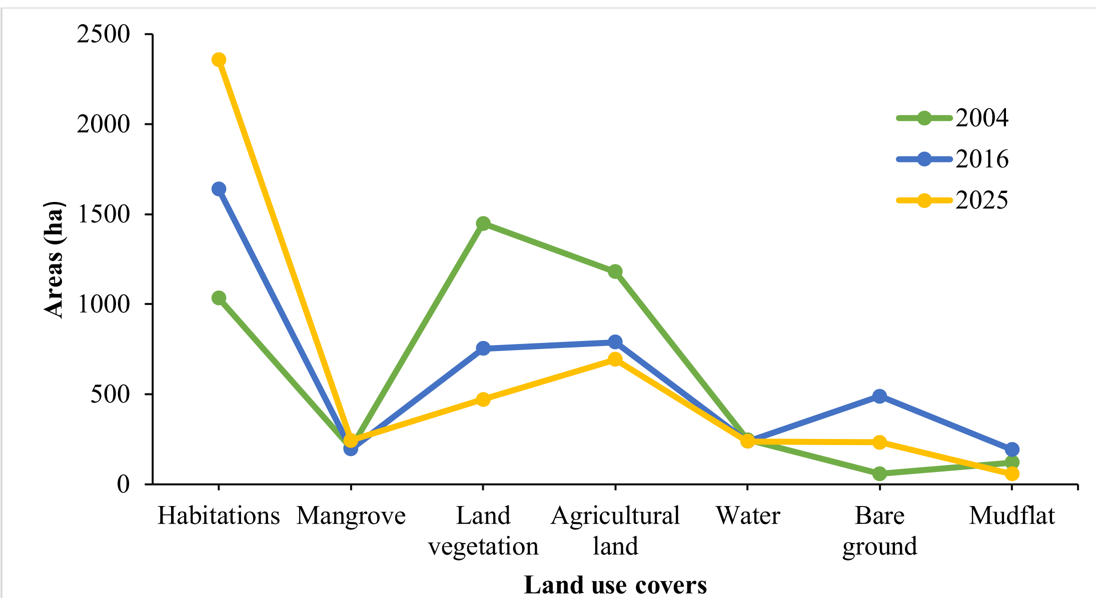

Figure 3: Synthesis of changes in land use units from 2004, 2016, and 2025

However, because older neighbourhoods such as ESCALE, BOUCOTTE, and SANTHIABA are almost completely saturated in terms of housing, development has mainly increased in the southwestern part of the municipality. This growth is mainly concentrated in the KENIA and DIABIR neighbourhoods, as shown by the Normalized Difference Building Index (NDBI) in Figure 4. These neighbourhoods are home to Assane Seck University in Ziguinchor, which began operations in 2007. The presence of the university has sparked keen interest in this area among the local population. Since then, these neighbourhoods and surrounding areas have been under increased pressure from residents and real estate developers for housing and commercial activities. Numerous housing developments have sprung up in the area and land prices have risen significantly.

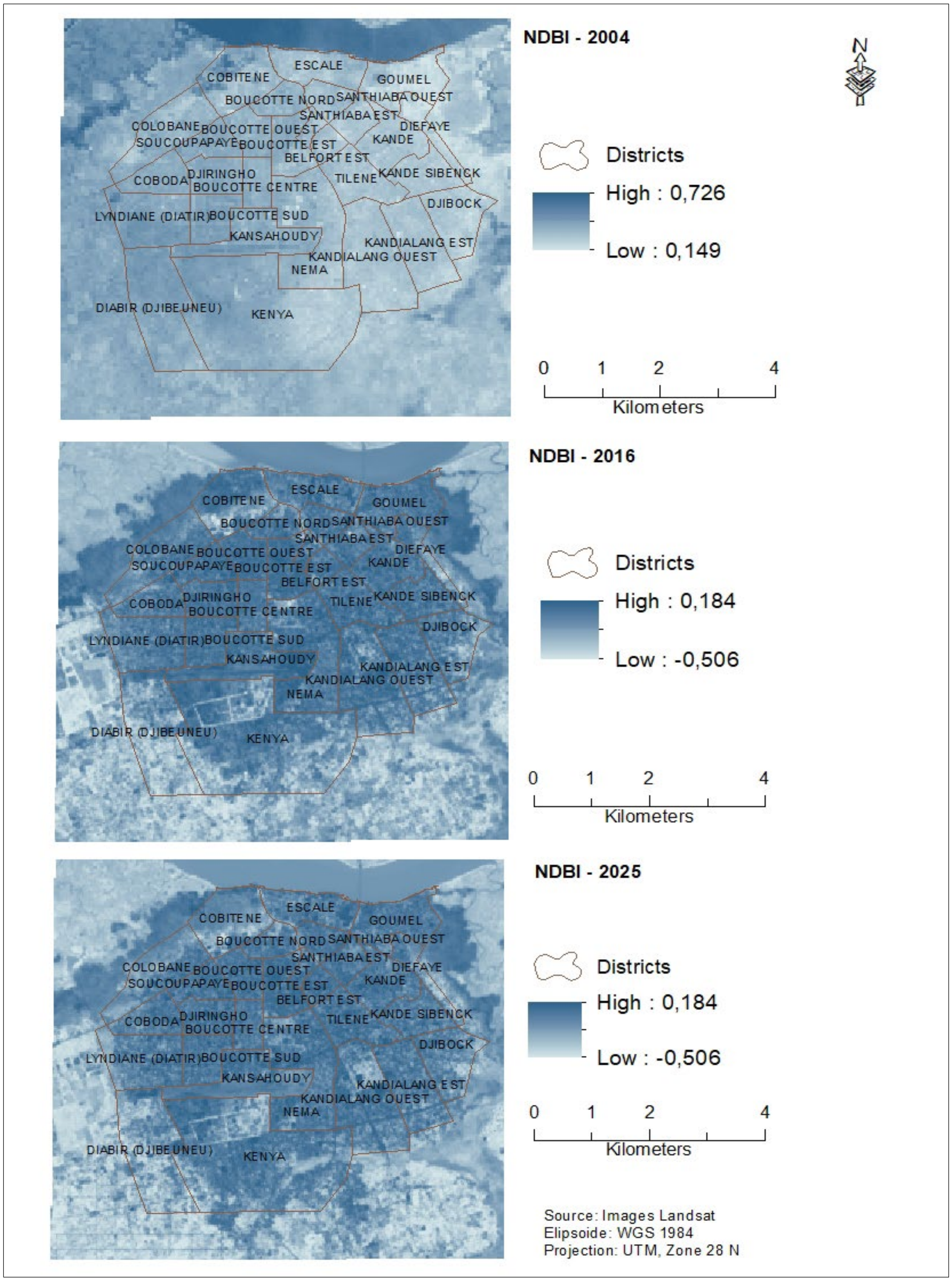

Figure 4: Normalized Difference Built-up Index (NDBI) Map

4.6 Changes in land use units: Changes in land use units in the municipality of Ziguinchor are presented in one stage between 2004 and 2025. Statistics on land use dynamics between 2004 and 2025 are shown in Figure 4.

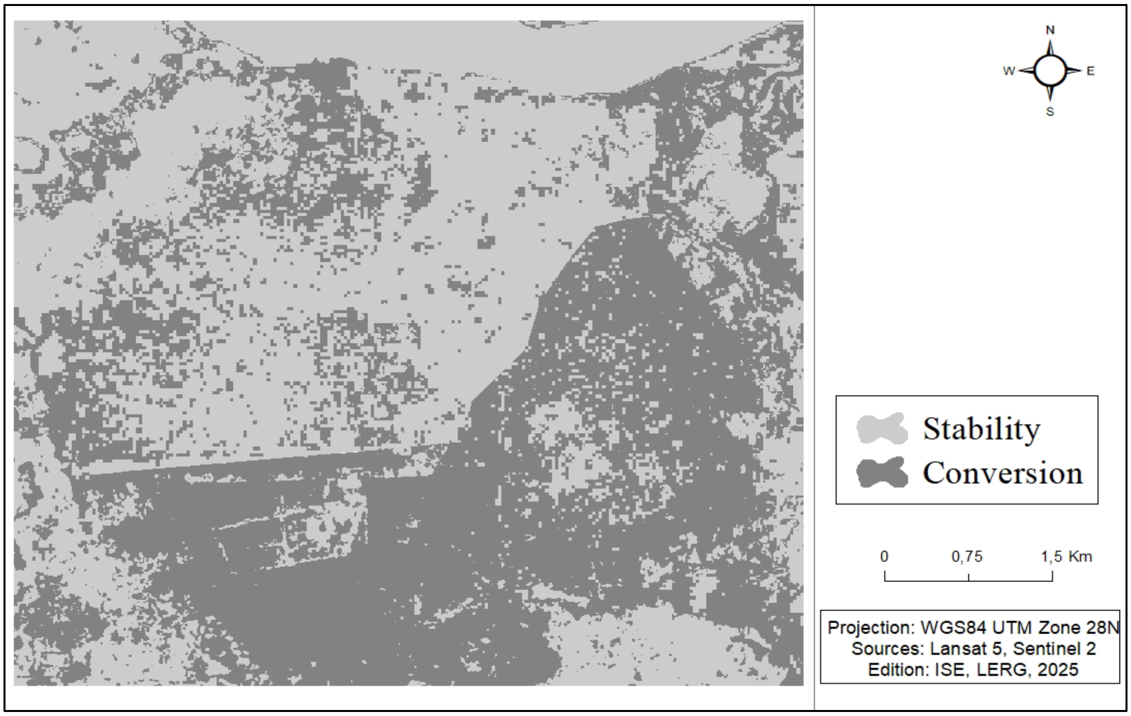

Figure 4: Change detection 2004–2025

Analysis of Table 2 shows that residential areas have grown to cover an area of 1,323.95 ha (an annual growth rate of 60.17%). In contrast, agricultural areas and terrestrial vegetation declined by 467.13 ha (a rate of decline of 21.23%). Overall, 2,223.35 ha remained stable between 2004 and 2025, compared with 2,071.65 ha that underwent conversion. The most significant conversion is the conversion of terrestrial vegetation into residential areas.

Table 2: Changes in different land use units between 2004 and 2025

2004-2025 (ha)	**Classes 2004**							**Total 2025**	**Gained areas**
Classes 2025	**Habitation**	**Mangrove**	**Land vegetation**	**Agricultural land**	**Water**	**Bare ground**	**Mudflat**		
Habitation	1035.05	2	537.69	724.61	0.78	43.18	15.68	2359	1323.95
Mangrove		184.73			14.35	0.18	44.56	243.82	59.09
Land vegetation			429.09	41.06	0.41	0.12		470.68	41.59
Agricultural land		6.07	345.47	309.79	1.66	2.08	27.4	692.47	382.69
Water		5.69		0.57	225.47	0.06	7.14	238.92	13.46
Bare ground		0.05	136.67	81.88		13.34	1.23	233.16	219.83
Mudflat		4		21.71	5.35		25.89	56.95	31.06
Total 2004	1035.05	202.54	1448.92	1179.61	248.02	58.95	121.91		
Lost areas		17.81	1019.83	869.82	22.56	45.62	96.02		

5 DISCUSSION

The spectacular expansion of housing in Ziguinchor (128% between 2004 and 2025) is part of a remarkable historical trend. It echoes the observations of Dramé *et al* (2025). who already documented a sharp increase of more than 85% in inhabited areas in Kaour between 1990 and 2006. This population growth can be explained in particular by the population movements documented by Dièye (2009). who in March 2009 recorded populations originating from 23 villages in the municipality of Ziguinchor. totalling 995 families and approximately 10.522 people. These migratory flows are part of the broader context of the armed conflict in Casamance. which over the past three decades has led to the exodus of 60.000 to 80.000 people (ANSD. 2014) and the abandonment of nearly 231 villages (Sakho. 2016). The drastic decline in vegetation (67.5%. or 978.24 ha) observed between 2004 and 2025 continues an alarming trend already identified by Dramé (2025). who reported a sharp decrease in vegetation cover from 3.646 ha in 2000 to only 505 ha in 2010 in the Bakoum watershed. This is mainly due to the felling of trees to meet families' firewood needs and. according to Chave (2000) and Sané (2003). creates a difficult situation where prolonged periods of drought cause the death of large trees. The significant reduction in agricultural areas (41.3%. or 487.14 ha) confirms the conversion of peri-urban agricultural land into residential areas. a phenomenon that Tabopda and Fotsing (2010) had observed in other regions of West Africa under demographic pressure. This transformation can be explained by the massive migration flows linked to the Casamance conflict. which has been ongoing for nearly 40 years. and the severe drought of the 1970s. factors that drove rural populations towards Ziguinchor. The conversion of 48.2% of the territory (2.071.65 ha) illustrates the extent of artificialization. a problem raised by Mballo (2019) who argues that land pressure is also responsible for changes in rural areas that were once agricultural. This conversion raises crucial issues of food security and environmental sustainability. as suggested by Thiaw *et al* (2022). land use and vegetation cover maps are valuable decision-making tools. particularly in urban areas where the advance of urbanization poses a significant problem for urban planning. especially in developing countries. In light of these challenges. recommendations for controlled densification and protection of peri-urban agricultural areas appear to be urgent imperatives for ensuring sustainable urban development in Ziguinchor.

6 CONCLUSION

This study highlighted the spatial and temporal dynamics of the municipality of Ziguinchor between 2004 and 2025 using Landsat data. remote sensing tools. and fieldwork. Interpretation of Landsat satellite images revealed that residential areas. terrestrial vegetation. and agricultural areas underwent major changes during the study period. The built-up area has doubled in size. As for terrestrial vegetation and agricultural areas. their surface areas have declined significantly between 2004 and 2025. Thus. only 41.59% of the land area covered by vegetation remained stable between 2004 and 2025. During the same period. 58.31% of the vegetation was replaced by buildings. Similarly. only 41.30% of agricultural areas were preserved. However. Landsat images (30 m) resolution are suitable for an overview. The percentages found may contain minor errors related to the assessment of image pixels. which depend on the spatial resolution of the images. Therefore. to minimize errors and assessment errors. we recommend using higher resolution drone images. This work is of major interest. because it will enable administrative and local authorities to take appropriate measures and decisions with a view to implementing sustainable and planned land management strategies and ensuring effective environmental protection for the city.

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