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Full Length Research Article

GEOSPATIAL ANALYSIS OF LAND USE CHANGES AND WETLAND DYNAMICS IN KADUNA METROPOLIS, KADUNA, NIGERIA

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ABSTRACT
Wetlands are among the world's most valuable ecosystems, and changes in land use have an impact on their distribution, health, quality, functions, and provision of services. This study assessed how land use change and socioeconomic activities drove wetland conversion in Kaduna Metropolis from 1986--2023. Landsat images (189/053) and SRTM DEMs were obtained from the USGS. The index-based classification was used to identify and map the wetlands in the study area and was also used for land use/land cover analysis classification via eCognition 9.0. A land change modeler on Idrisi Terrset was used to carry out land use/land cover change detection and transition analysis. The analysis of the results revealed an overall accuracy of 92% (0.93 Kappa) for the 1986 classification and 90% (0.88 Kappa) for the 2023 classification. The LULC analysis revealed that built-up areas and vegetation increased by 194.9 km^2 and 60.9 km^{2,} respectively, whereas bare land decreased by 136.5 km^2. With respect to wetland dynamics, marshlands lost a total of 15 km^2, riparian vegetation lost 28.6 km^{2,} and water bodies declined by 2.6 km^2. The study concluded that settlement expansion and agricultural activities are the primary drivers of wetland changes in Kaduna metropolis. The study therefore recommends the creation of buffer zones around the wetlands to prevent further encroachment.

Keywords: Wetlands, Land Use, Nigeria, Kaduna

INTRODUCTION

Ramsar Convention on wetlands (1971) defined wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres." Wetland ecosystems are among the most productive in the world (U.S. Environmental Protection Agency, 2023). They significantly influence the hydrological cycle in a given area (Bian et al., 2024), and they are critical in moderating extreme events such as storms and floods, thereby preventing loss of life and property; they also hold large amounts of water and help maintain the quality of fresh water (Pi et al., 2022).

Wetlands are critical components of the earth, and they play crucial roles in balancing ecosystems, particularly in reducing the adverse effects of human activities and their importance to naturally established ecosystems and their economic, social and environmental functions (Millenium Ecosystem Assessment [MEA], 2005; Yu et al., 2023). Despite the importance of wetlands to the environment, they are lost and degraded globally, although the rates of loss and degradation of wetlands vary widely from one place to another (Wan et al., 2024; Zhao et al., 2024). According to scientific estimates, approximately 64% of wetlands globally have vanished since 1900 (Ramsar Convention Secretariat, 2010), and pollution, intensified agricultural activities, urbanisation and industrialisation have been observed as major threats affecting wetlands worldwide (H. Wang et al., 2023).

In Kaduna Metropolis, similar to other parts of the world, wetlands serve different purposes, ranging from religious services (Verschuuren, 2016). Additionally, floodplain/*fadama* farming is the most common form of crop production during the dry season in Nigeria and has contributed to the livelihoods of people for many centuries (Tanko, 2017). Thus, damage to these wetlands will impact their capacity to support the livelihood of millions of people across the country. Furthermore, the wetlands in Kaduna metropolis provide other services, such as flood regulation (E. B. Baba et al., 2020; Ndabula et al., 2012) and the regulation of land surface temperature (Abubakar, Thomas, et al., 2024). However, many human activities have led to the disappearance and degradation of these previous ecosystems.

Some drivers responsible for the loss of wetlands include the conversion of wetlands to agricultural fields, settlement expansion, hydroengineering projects, oil and mineral exploration, industrial waste, dam construction, overexploitation of wetland vegetation, road construction, and logging (Akumu et al., 2018; Nwankwoala, 2012; Tan & Jiang, 2016; Zhao et al., 2018). Furthermore, climate change adds pressure to these wetlands, altering their distribution by directly affecting the hydrological cycle, thereby increasing their vulnerability (Zhu et al., 2022). Climate change also influences soil moisture and temperature, vegetation dynamics and biogeochemical cycles (Helbig et al., 2016).

While land use land cover (LULC) is a relatively broad concept that is applicable in every part of the world (Abubakar, 2019), such is not the case for identifying and mapping wetlands. This is because wetland mapping is a relatively new concept, and researchers are gaining interest because of the increasing recognition of the significance of wetlands, their sensitivity and their continuous destruction with respect to climate change and socioeconomic activities. Additionally, considering the diverse nature of wetlands, as well as the variation in soil types and morphological characteristics, there is no universally agreed-upon method of mapping wetlands that can be used in a particular geographic context and is applicable globally. Some of the methods used include the normalised difference vegetation index (NDVI) (Abla et al., 2005; Kahli et al., 2018; Kayastha et al., 2012) and the normalised difference vegetation index (NDVI) and land surface water index (LSWI) (Dong et al., 2014). Other indices used include the normalised difference water index (NDWI) (Dvorett et al., 2016; Jawak & Luis, 2015; Sarp & Ozcelik, 2017); different forms of the NDWI (Feyisa et al., 2014; McFeeters, 1996); the modified normalised difference water index (mNDWI) (Chen et al., 2014; Gautam et al., 2015; Sarp & Ozcelik, 2017; Xu, 2006); and the normalised difference vegetation index (NDVI), land surface temperature (LST) and SAR data (Kaplan et al., 2019). Other studies have used ancillary data such as LiDAR data (Huang et al., 2014), digital elevation models (DEMs) (Li & Chen, 2005), and DEM-derived slopes (Souberou et al., 2017). Furthermore, some studies have employed LULC (land use/land cover) classification via remote sensing and GIS techniques (Abbas, 2008; Obiefuna et al., 2013), unsupervised classification (Abalo et al., 2021; Chouari & Walid, 2015), and supervised classification (Gautam et al., 2015; Mariko et al., 2003).

In Nigeria, there is a paucity of literature on wetland dynamics, especially changes in their spatial extent over time, as most studies have focused on wetland ecosystems and productivity. Furthermore, in Kaduna metropolis, despite the importance of wetlands and their dynamic and sensitive nature, no documented research has identified, classified, and spatiotemporal changes in wetlands. This study intends to provide information to fill this gap.

MATERIALS AND METHODS

Study Area

Kaduna Metropolis covers Kaduna North and Kaduna South Local Government Areas and parts of Chikun and Igabi Local governments (Abubakar, Thomas, et al., 2024). Kaduna Metropolis lies between latitudes 10°20´00˝N and 10°39´00˝N and longitudes 7°20´16˝E and 7°35´00˝E (B. M. Baba et al., 2020). With an area of 3,156 km^2. It is bounded to the north by the Igabi local government area, to the south by the Chikun local government area, and to the east and west by the remaining Chikun and Igabi local government areas (Figure 1). Kaduna is situated in a tropical wet and dry climate (Abdussalam, 2020). The maximum temperature in Kaduna metropolis can be greater than 30°C, with the hottest months being March, April and May. The relative humidity typically ranges between 25% and 90% depending on the month of the year, with the lowest humidity occurring between December and February (Abubakar, Abdussalam, et al., 2024). The metropolis lies on the Kaduna plain, comprising extensive tracts of almost level to gently undulate lightly dissected land, broken in places by groups of rocky hills and inselbergs (Ahmed et al., 2024). The vegetation is a savanna grassland made up of tall grasses, scattered trees and galleries. The area has fringe forests that are constantly exploited for fuel wood (Ajibade & Okwori, 2009). The soils are mainly ferruginous, have a sandy surface and are covered by poorly structured clay soil. The soils have low base levels but high saturation and high pH values. The soil fertility is high, and FAO, (1996) rates them as having good potential. Although soils are highly sensitive to erosion and have low water retention capacity, adequate management practices can help improve their fertility (Mohamed-Saleem, 1986).

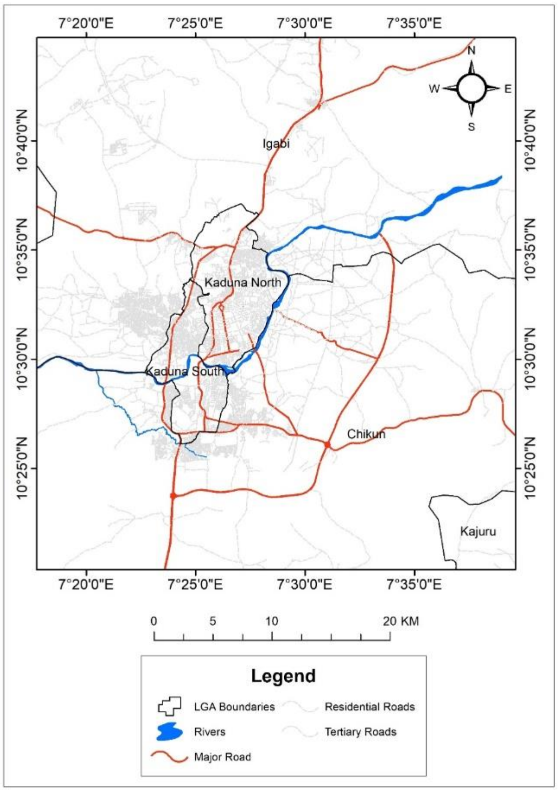


Figure 1: Kaduna metropolis showing rivers, streams, and road networks
Source: GRID3 - Nigeria, 2023

Materials

This study used Landsat TM/OLI (30 m spatial resolution), of which Landsat 5 TM was from January 1986, and Landsat 8 OLI was from February 2023. The images used for analysis were all collected between January and February, a period with no rainfall in the study area. The supplementary data include SRTM data (30 m), which were used to delineate riparian zones. All these images are freely available through the USGS website (https://earthexplorer.usgs.gov). Google Earth images and field observations were also used to determine the classification accuracy.

Methods

Image processing

Landsat 5 (TM) and Landsat 8 (OLI/TIRS) images of the study area were obtained from the USGS portal. The images were homogenised via a histogram algorithm and mosaiced to create a 7-band multispectral image; subsequently, a masking tool in ArcGIS Pro 2.5 was used to extract the study area.

Sample point collection

The current land use and land cover types in Kaduna metropolis were combined with wetland conventions. A total of 180 field samples were collected from the field (30 × 30 m, including built up areas, bare land, marshes, open water bodies, and agricultural land). In addition to the samples from the field survey, points were randomly arranged in ArcGIS Pro 2.5 via the Fishnet tool.

Image classification

In addition to the Landsat image covering the study area, digital elevation model (DEM) and field observation information was also used. This study adapted the wetland definition as defined by the Ramsar Convention (2004). The images were used for calculating the land surface water index (LSWI), normalised differential vegetation index (NDVI), normalised differential water index (NDWI), normalised differential bareness index (NDBI), built-up index (BU) and index-based classification. This entails categorising land cover types via indices generated from remote sensing data. These indices aid in discriminating between various land cover categories on the basis of their spectral properties.

These images were classified into six different land cover types. These include open water, bare surfaces, built-up areas, grass/shrub areas, riparian/fadama areas and marshes. They were sampled and classified. The three land cover classes (bare surface, built-up, grass/shrub/cultivated) were combined into a “nonwet” class, whereas the classes (open water, riparian/fadama, marshes) were combined into a “wetland” class.

The NDVI and LSWI are calculated from the surface reflectances of the Red, NIR, and SWIR bands of the Landsat TM/ETM sensor via the following formulas:

$$NDVI = \frac{(NIR-R)}{(NIR+R)} \quad \text{...} (1)$$

$$LSWI = \frac{(NIR-SWIR)}{(NIR+SWIR)} \quad \text{...} (2)$$

The NDWI is expressed as follows (McFeeters 1996):

$$NDWI = \frac{\text{Green}-\text{NIR}}{\text{Green}+\text{NIR}} \quad \text{...} (3)$$

$$NDBI = \frac{(SWIR-NIR)}{(SWIR+NIR)} \quad \text{...} (4)$$

$$BU = NDBI - NDVI \quad \text{...} (5)$$

where Green is the green band, NIR is the near-infrared band, R is the red band, and SWIR is the shortwave infrared band. A decision tree classification approach was used. This involves machine learning calculations, dividing the informatics space into cells, where every cell has a place with one class.

The steps involved in decision tree classification are shown in Figure 2.

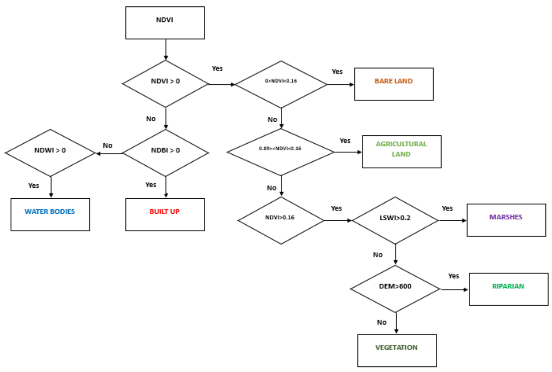


Figure 2: Wetland classification sche

RESULTS

Wetland identification

Using index-based classification, this study was able to identify the following types of wetlands in Kaduna metropolis. The categorisation according to the Ramsar Convention Secretariat was used in this study (Kabii, 1998; Kahli et al., 2018). As shown in Figure 3, three (3) broad categories of wetlands were identified in Kaduna metropolis. These are marshes (labeled as wetlands), riparian vegetation, and water bodies. The names and coordinates of the sites were added to aid in identification. See Figure 3.

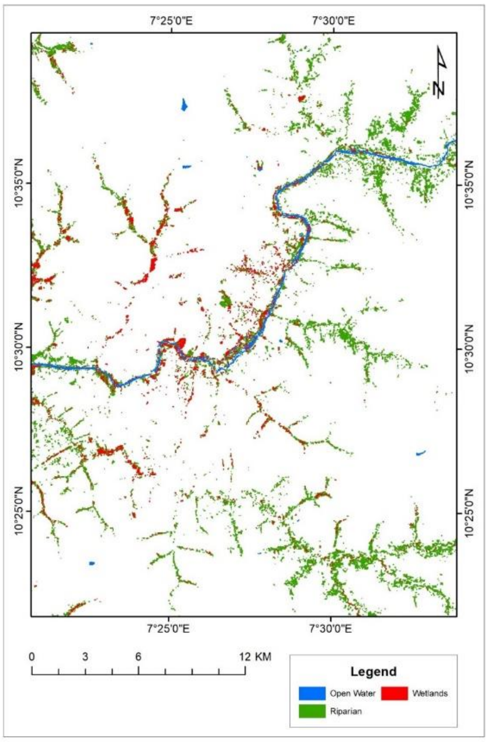


Figure 3: Delineated wetlands in Kaduna metropolis

Table 1: Characterization of wetlands in Kaduna metropolis.

S/N	Location of Wetland	Characteristics	Ramsar Code	Longitude/Latitude	Elevation (m)
1	River Kaduna	Freshwater rivers or streams that are permanent.	M		Average 550
2	Tributaries of R. Kaduna	Rivers that are seasonal or intermittent/irregular rivers/streams/creeks.	N		Average 580
3	Airforce Base	Freshwater lakes that are over 8 hectares and permanent.	O	7.42402 E, 10.59178 N	622
4	Airforce Base II	Freshwater lakes that are over 8 hectares and permanent.	O	7.42304 E, 10.62074	634

5	Rafin Guza	Storage, Reservoirs, dams or impoundments that are generally over 8 hectares.	6	7.46228, 10.59049 N	604
6	Babban Saura	Mining pools, borrow pits and other types of excavations.	7		603
7	Bashama Road	Freshwater marshes that are seasonal or intermittent. *	Ts	7.420799 E, 10.504037 N	574
8	Kabala wetlands	Freshwater marshes that are permanent.	Tp	7.454222 E, 10.501044 N	579
9	Dan Madami Close		Tp	7.461825 E, 10.512863 N	582
10	Gulf course	Freshwater marshes that are seasonal or intermittent.	Ts	7.44503 E, 10.52420 N	608
11	Babban Saura	Freshwater marshes dominated by shrubs	W	7.47512 E, 10.53355 N	587
12	Hayi Rigasa	Irrigation areas and paddy fields.	3	7.405306 E, 10.541503 N	590
13	Stadium	Irrigation areas and paddy fields.	3		576
14	Floodplain Smaller Streams		3, Tp		580

Source: Author's Analysis, 2023

LULC classification in Kaduna metropolis from 1986--2023

LULC accuracy assessment

The accuracy of the land use/land cover analysis was determined. The user's accuracy, producer's accuracy, overall accuracy and kappa coefficients for the land use/land cover analysis of 1986 and 2023 were assessed. The results are shown in Table 2.

Table 2: Accuracy assessment for 1986 LULC

LULC Class	1986		2023	
	PA (%)	UA (%)	PA (%)	UA (%)
Agric Land	92.5	94.87	85	87.2
Bare Land	95	86.36	90	85.7
Built Up	95	95	100	90.9
Marshes	92.5	88.4	93	89.2
Riparian	95	100	90	90
Vegetation	92.5	94.87	82.5	89.2
Water	95	90.47	95	100
Overall	92%		90%	
Kappa	0.93		0.88	

PA: Producer's accuracy **UA:** User's accuracy

Table 2 shows the overall accuracy of the 1986 LULC classification. The overall accuracy was 92%, while the kappa coefficient was 0.926503 (93%). For the 2023 classification, the overall accuracy of the 2023 classification. The total accuracy was 90%, while the kappa coefficient was 0.880089 (88%).

LULC classification and wetland changes in Kaduna metropolis from 1986--2023

This study analysed land use and land cover changes in Kaduna metropolis from 1986--2023. The results of this classification are shown in Table 3 and Figures 4 and 5.

Table 3: LULC change statistics/percentages between 1986 and 2023

LULC Name	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)	Magnitude of Change	Rate of Change
Agric	953.0	44.0	879.9	40.6	-73.1	-2.0
Bareland	387.3	17.9	250.8	11.6	-136.5	-3.7
Built Up	173.1	8.0	368.0	17.0	194.9	5.3
Marshes	35.6	1.6	20.6	1.0	-15.0	-0.4
Riparian	162.2	7.5	133.7	6.2	-28.6	-0.8
Vegetation	436.6	20.2	497.5	23.0	60.9	1.6
Water	19.0	0.9	16.4	0.8	-2.6	-0.1

Table 3 shows the results of the image classification and area coverage for each land use and land cover type. Additionally, the magnitude and rate of change are presented.

Agricultural land

Agricultural land significantly decreased in Kaduna metropolis from 953.0 km^2 (44%) in 1986 to 879.9 km^2 (40.6%) in 2023. This shows that agricultural land has lost approximately 73.1 km^2, with approximately 2 km^2 lost annually within the period.

Bare land

Bare land also significantly decreased in Kaduna metropolis from 387.3 km^2 (17.9%) in 1986 to 250.8 km^2 (11.6%) in 2023. Field observations revealed that most of the bare land within the study area has been taken over by new settlement development. Furthermore, other surfaces have been converted to agricultural land.

Built-up areas

Unlike other land use/land cover types within the metropolis, built-up areas experienced significant expansion within the study period. It covered an area of 173.1 km^2 (8%) in 1986, but it expanded to 368 km^2 (17%) by 2023. The built-up areas had a net gain of 194.9 km^2, increasing at approximately 5.3 km^2 per annum within the study period.

This high expansion in settlements was a consequence of rapid population growth and the development/expansion of infrastructures (schools, hospitals, airport terminals and so on). New settlements were erected within the metropolis, such as the Kaduna millennium city to the east, the NDC (Rigachikun) to the north of the town, the expansion of Rigasa town, and new settlements along the Gonin–Gora axis.

Marshes

Marshy areas significantly decreased from 35.6 km^2 (1.6%) in the year 1986 to 20.6 km^2 (1%) in 2023. The marshes experienced a net loss of almost 50%, with a loss of 15 km^2. Between 1986 and 2023, marshes were losing 0.4 km^2 per annum.

Riparian

Riparian vegetation significantly decreased in Kaduna metropolis from 162.2 km^2 (7.5%) in 1986 to 133.7 km^2 (6.2%) in 2023. The riparian zone has experienced considerable encroachment, losing 28.6 km^2, at 0.8 km^2 per annum.

Vegetation

Table 4 shows that the area covered by natural vegetation in Kaduna metropolis significantly increased. Vegetation covered 436.6 km^2 (20.2%) in 1986 and increased to 497.5 km^2 (23.0%) by 2023. The vegetation area had a net gain of 60.9 km^2, increasing by approximately 1.6 km^2 annually. This shows that many afforested areas occurred within this period.

Water Bodies

The water bodies also experienced a reduction in size. Rivers, streams, dams, reservoirs and excavated grounds covered 19.0 km^2 (0.9%) in 1986 but were reduced to 16.4 km^2 (0.8%) by 2023. Water bodies lost 0.1 km^2 per annum and experienced a net loss of 2.6 km^2 between 1986 and 2023.

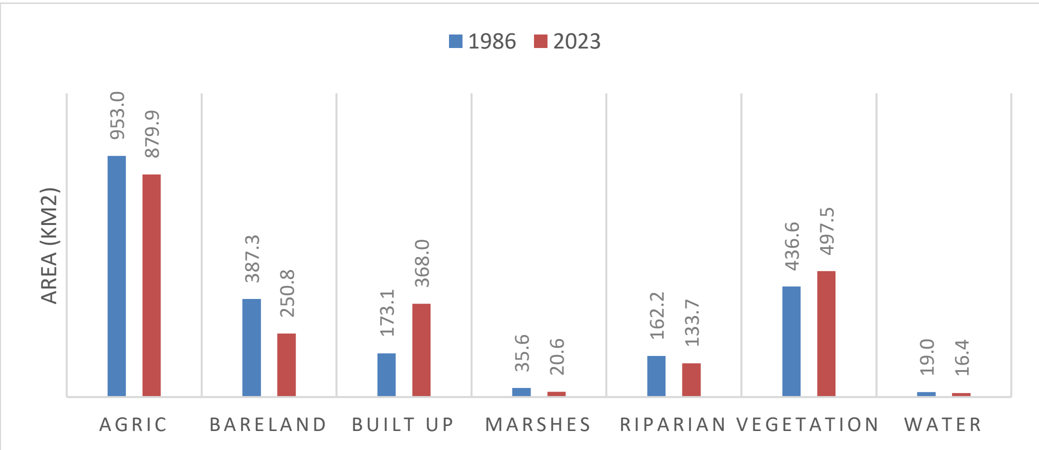
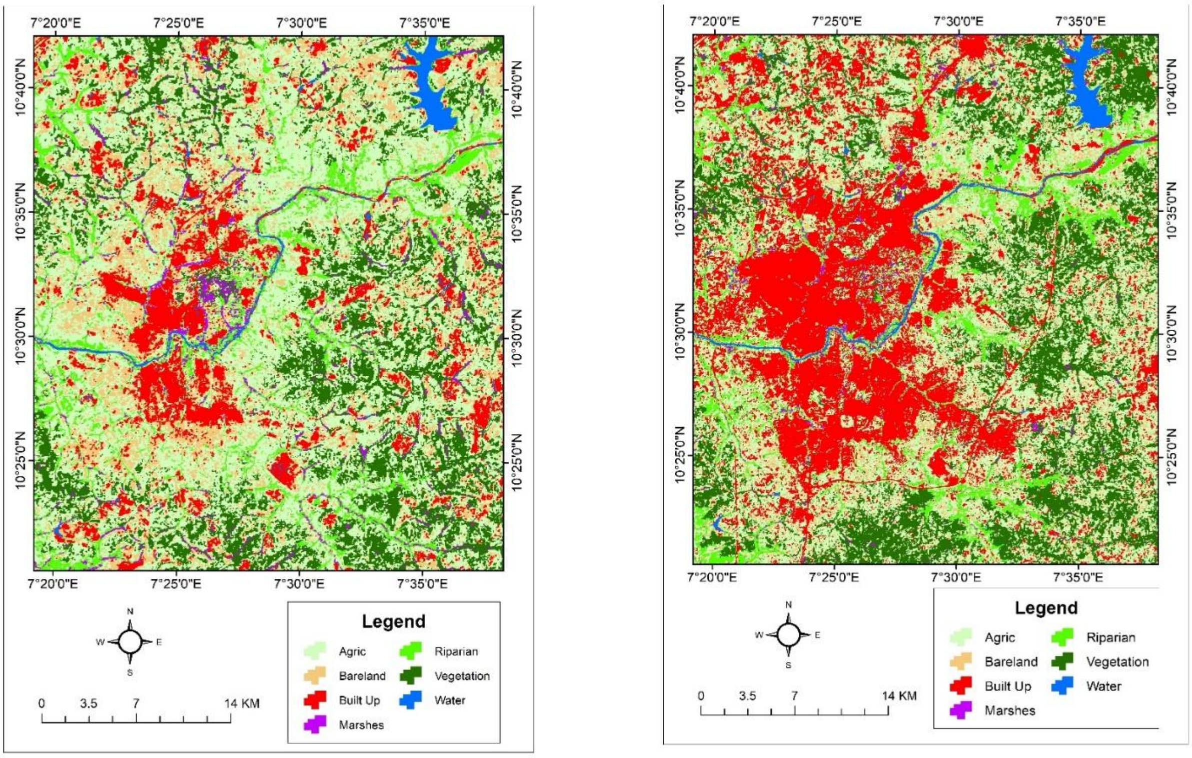


Figure 4: Land use/land cover change analysis between 1986 and 2023



a. LULC 1986 **b. LULC 2023**

Figure 5: (a) Land use land cover of Kaduna metropolis in 1986 and (b) land use land cover of Kaduna metropolis in 2023

Wetland dynamics
The wetland areas in Kaduna metropolis have experienced a decline as a result of settlement expansion and increased agricultural activities along flood plains. For this study, only marshes, water bodies and riparian zones are considered wetlands. The results are shown in Table 4.

Table 4: Wetland dynamics between 1986 and 2023

Wetland Type	Loss (km²)	Gain (km²)	Net Change
Marshes	30.6	15.7	-15.0
Riparian	94.2	65.6	-28.6
Water	5.2	2.6	-2.6

The results in Table 4 revealed that marshy areas and water bodies in Kaduna metropolis were reduced by almost 50%. The area of riparian vegetation also experienced a significant decline, with a loss of 28.6 km² within the study area.

Wetland conversion to other land cover classes
The conversion of marshes, riparian vegetation and water bodies into different land cover types is presented in Table 5.

Table 5: Conversion of wetlands to other classes

Marshes >	Area converted (km²)	Riparian >	Area converted (km²)	Water >	Area converted (km²)
Agric	6.3	Agric	52.6	Agric	2.0
Bareland	1.3	Bareland	13.0	Bareland	0.4
Built Up	2.2	Built Up	12.9	Built Up	1.1
Water	0.0	Water	0.4	Riparian	0.8
Riparian	7.4	Vegetation	9.8	Vegetation	0.6
Vegetation	13.5	Marshes	5.5	Marshes	0.4
Total Loss	**30.6**		**94.2**		**5.2**

As shown in Table 5, 6.3 km² of marshes were converted for agricultural use, 1.3 km² was converted to bare land as a result of drying, 2.2 km² was converted to built-up areas, 7.4 km² was converted to riparian vegetation due to the loss of water, and 13.5 km² was converted to dense vegetation. This result is shown in Figure 6a.
The conversion of riparian vegetation to agricultural land has the greatest contribution to its loss, with 52.6 km². A total of 13.0 km² dried up and was converted to bare land, followed by built-up areas of 12.9 km², which resulted from settlement expansion. A total of 9.8 km² of riparian vegetation was converted to vegetation, whereas 5.5 km² of riparian vegetation was converted to marshes. This result is shown in Figure 6b.

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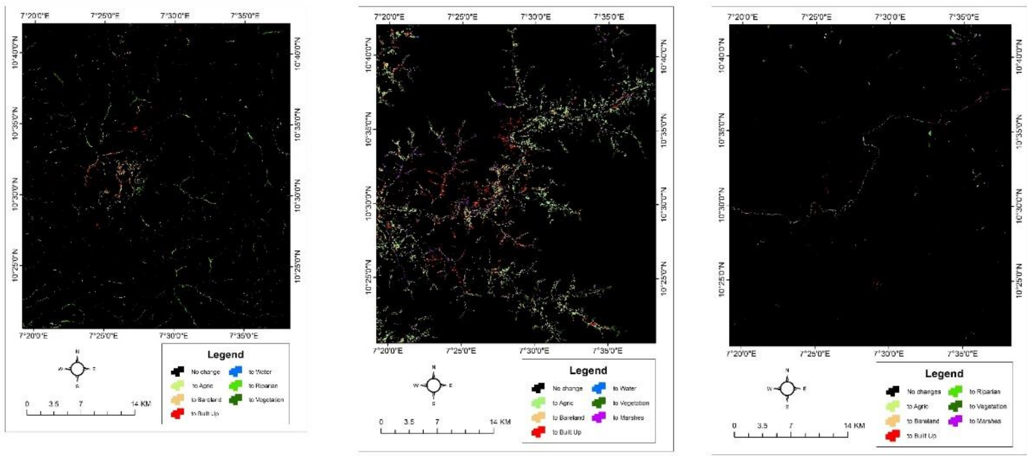

a. b. c.

Figure 6: (a) Conversion of marshes, (b) loss/conversion of riparian vegetation, (c) conversion of water bodies

DISCUSSION

This study successfully identified and mapped wetlands in Kaduna metropolis via remote sensing techniques. Three (3) classes of wetlands were identified in this study (Figure 3) via the Ramsar wetland criteria: open water bodies, riparian wetlands and fresh water marshes. This is because Kaduna metropolis is considered a plain with gentle slopes (Bennett et al., 1979). Furthermore, the distribution of the wetlands in Kaduna metropolis is influenced by its hydrology.

Land use/land cover change

This study revealed that built-up areas are the primary driver of land use and land cover change in Kaduna metropolis, which gained 194.9 km^2 between 1986 and 2023. This increase in built-up areas is similar to the findings of Ishaya et al. (2008), who revealed an unprecedented increase in built-up areas in Kaduna Metropolis. Additionally, (Akpu et al., 2017) revealed an increase in built-up areas in Kaduna metropolis between 1973 and 2009. However, in contrast to their findings, which revealed a significant decline in vegetation cover, this study revealed a significant increase in built-up areas, probably due to insecurity, which forced people to move close to the city center. The increase in vegetation is expected to improve living conditions within the Kaduna metropolis because it helps reduce the intensity of land surface temperatures and urban heat islands (Abubakar, Thomas, et al., 2024). Furthermore, some of the impacts of increases in built-up areas include the loss of urban agricultural lands (Saleh et al., 2014), encroachment on floodplains (Ndabula et al., 2012), and increases in waste generation (Sawyerr & Tanko, 2018; Yahya & Uba, 2021).

Wetland dynamics and conversion

This study revealed that approximately 15 km^2 of marshes have been lost. As shown in Table 6, 13.5 km^2 of marsh lands were converted to vegetation. This conversion can be a result of ecological succession, where marshlands convert to forests (R. Zhao et al., 2024), human intervention through drainage and reclamation (H. Wang et al., 2023), and climate change, which can alter water levels and soil conditions (Salimi et al., 2021; R. Wang et al., 2023). Previous studies have revealed that the loss of marshes can add stress to adjacent wetlands. Additionally, the loss of marshes results in degraded ecosystem function (Bian et al., 2024; Hedman, 2019) and the loss of habitats for different plant and animal species (H. Wang et al., 2023).

The conversion of riparian vegetation to built-up areas in Kaduna metropolis has previously been reported by Ndabula et al. (2012) and E. B. Baba et al. (2020). This encroachment on riparian vegetation disrupts their ability to regulate floods by slowing and dissipating floodwater, enhancing infiltration, and preventing soil erosion (Olokeogun et al., 2020). Thus, low infiltration has been identified as a contributing factor to floods in Kaduna metropolis due to increased surface runoff (Ibrahim & Abdullahi, 2016). Other environmental problems caused by the removal of riparian vegetation include increased riverbank erosion (Croke et al., 2017) and increased sediment transportation (Baniya et al., 2019).

Finally, the degradation of open water bodies (rivers, streams) affects the water supply to other wetland types through drying and fragmentation. Specifically, the degradation of water bodies will alter the hydrological cycle through increased surface flow and reduced infiltration (Abubakar, 2021). Water bodies are converted to bare land as a result of long-term sediment deposition (Stenfert Kroese et al., 2020). On the basis of the LULC classification, most of the encroachment on water bodies occurred mostly along streams (tributaries on the Kaduna River) because they are close to the Central Business District (CBD).

Conclusion

Wetlands in Kaduna metropolis are constantly threatened by human activities, causing significant changes in LULC dynamics between 1986 and 2023. Built-up areas and natural vegetation increased sharply over the three decades. However, agricultural land, riparian vegetation, bare land, marshlands and natural water bodies experienced significant net declines over 34 years. The decline in bare land and agricultural land was also driven by settlement expansion within the study period. These changes are responsible for the conversion and pollution of the wetlands, invasion by plant species such as Typha grass, shrinking of the area cultivated and, overall, degradation of the wetlands, limiting their provisioning and regulatory functions.

Finally, from the findings of this study, it can be concluded that the major threats faced by wetlands in Kaduna metropolis are settlement expansion, wetland cultivation, and high sedimentation due to inadequate irrigation practices put in place along the courses of the River Kaduna, which flows into the wetlands.
Thus, actions should be taken by regulatory agencies to prevent further encroachment and degradation of the wetlands in Kaduna metropolis. This can be through:

i. Creation of a policy and establishment of a legal framework governing the management of wetlands.
ii. Imposition of a levy for pollution (both land and water);
iii. Encouraging wetland restoration; and
iv. Revision of land allocation and land use policies to protect wetlands.

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