



SPATIO-TEMPORAL ANALYSIS OF LAND USE/LAND COVER DYNAMICS USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM IN THE BAGEL ZUNGUR WATERSHED, NORTH-CENTRAL NIGERIA

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ABSTRACT

Land use and land cover (LULC) dynamics are critical indicators of environmental change and watershed sustainability, particularly in ecologically sensitive highland regions. This study analysed the spatio-temporal patterns and dynamics of LULC change in the Bagel Zungur Watershed, North-Central Nigeria, over 30 years (1990–2020) using remote sensing and Geographic Information System (GIS) techniques. Landsat satellite images for 1990, 2000, 2010, and 2020 were obtained from the United States Geological Survey (USGS) and processed using ERDAS IMAGINE and ArcGIS software. A supervised classification approach based on a modified Anderson Level I classification scheme was used to classify the watershed into six land cover categories: bare soil, built-up area, cultivated land, forest/riparian vegetation, rock outcrop, and broad river/waterbody. The results reveal significant LULC changes characterised by a consistent expansion of cultivated land and built-up areas, alongside a marked decline in forest and riparian vegetation. Cultivated land increased from 52.05% of the total watershed area in 1990 to 60.49% in 2020, while forest/riparian vegetation declined from 31.63% to 20.93% over the same period. Built-up areas also showed a steady increase, reflecting population growth and expanding human activities. Water bodies remained relatively stable throughout the study period. The observed LULC changes indicate increasing anthropogenic pressure on the watershed, with implications for land degradation, ecosystem stability, and water resource sustainability. The findings provide a valuable baseline for proactive watershed management, land-use planning, and environmental conservation strategies in the region.

Keywords: Geographic Information System; Land use/land cover; Remote sensing; Watershed

INTRODUCTION

The primary objective of the image classification process is to automatically assign all pixels in an image to specific land-cover classes (Lillesand & Kiefer, 1999). Land use/ land cover changes (LULC) are typically categorized into two main groups: conversion and modification (Baulies & Szejwach, 1997). Conversion signifies a shift from one land cover or land use category to another (e.g., from bare soil to built-up areas). At the same time, modification refers to changes within a single land-use or land-cover category (e.g., from commercial to residential built-up areas) resulting from alterations to its physical or functional attributes.

As revealed by Sadiku et al. (2020), remote sensing and Geographic Information System (GIS) tools have been widely employed throughout Nigeria for land cover and land use mapping over recent decades. These tools and techniques have been utilised in this study to map land use in Alkaleri Local



Government Area, Bauchi State. The research focused on detecting changes across four major land-use categories: vegetation, built-up areas, and bare land. The classified land cover data indicated an overall decrease in forest cover from 1990 to 2013. The study's conclusion highlighted the rising rate of deforestation in Alkaleri, primarily driven by human activities.

The efficacy of land use/ land cover assessment has been significantly enhanced through the development of remote sensing technology and the Geo-Analysis model. This tool has become one of the swiftest, most reliable, and most efficient means of depicting current status and dynamic changes.

Muhammad et al. (2022) reported a 5.3% urbanization rate in Nigeria, which has exerted pressure on altered land use, land cover, and land resources. This has resulted in the occupation of land initially designated for cattle grazing, farming, and construction, leading to conflicts between farmers and herders. The study introduced a unique approach, employing a Geospatial-based method and multi-criteria evaluation for the site selection of cattle ranches in Bauchi State. The findings revealed that approximately 41% of Bauchi State's total land area is suitable for siting cattle ranches, while 33% is unsuitable, and the remaining 26% is moderately suitable. Consequently, there is ample suitable land available for establishing sustainable cattle ranches in Bauchi state, which could help alleviate the ongoing conflicts between herders and farmers. These results underscore the importance of conducting baseline studies of land use and land cover, incorporating relevant themes to mitigate unnecessary conflicts that can affect watershed potential. The study by Cayambe et al. (2023) focused on diversity and life zone (DLZ) classification, offering valuable insights for local and international stakeholders to inform agri-environmental and conservation decisions aimed at mitigating deforestation in the study area. Adapting LULC strategies to address deforestation is crucial for proactive watershed management and overall environmental conservation efforts.

Abebe et al. (2022) emphasised the significance of land use and land cover (LULC) analysis for mapping, quantifying changes, identifying drivers of change, pinpointing vulnerable areas for transformation, and designing sustainable ecosystem services. They conducted a comprehensive analysis of 30 years of data using a combination of remote sensing and GIS techniques. The findings revealed that the most extensive LULC types in the study area were cultivated land and settlements. Similarly, studies such as Jidauna et al. (2018) in Dutsinma, Aliero et al. (2022) in Kebbi State, and Mahadi et al. (2023) in Bangladesh conducted spatio-temporal assessments of land cover trends and vegetation degradation. They revealed a decline in dense vegetation, shrubs, and bushes, accompanied by an increase in farmland and bare grassland, while water bodies remained unchanged.

Thus, it is a valuable tool for predicting sustainable land management practices. Against this background, the paper examines the spatio-temporal dynamics of land use/land cover in the Bagel Zungur watershed using Remote Sensing and Geographic Information Systems.

STUDY AREA

The research was conducted in a geographical region that shares boundaries with Bauchi (specifically, Toro, Dass, Bauchi, and Tafawa Balewa) and Jos East in Plateau State. The study area is defined by its geographical coordinates, ranging from latitude 9°50'03"-10°13'31" N and longitude 9°00'44"-9°41'50" E, as depicted in Figure 1. The delineation of this area was achieved using the hydrology extract tool, which was employed to extract the watershed in the ArcGIS workspace. Situated within the North Central Highland of Nigeria, this region boasts an average elevation of 611.38 meters above sea level and covers a total area of 1557.67 square kilometres.

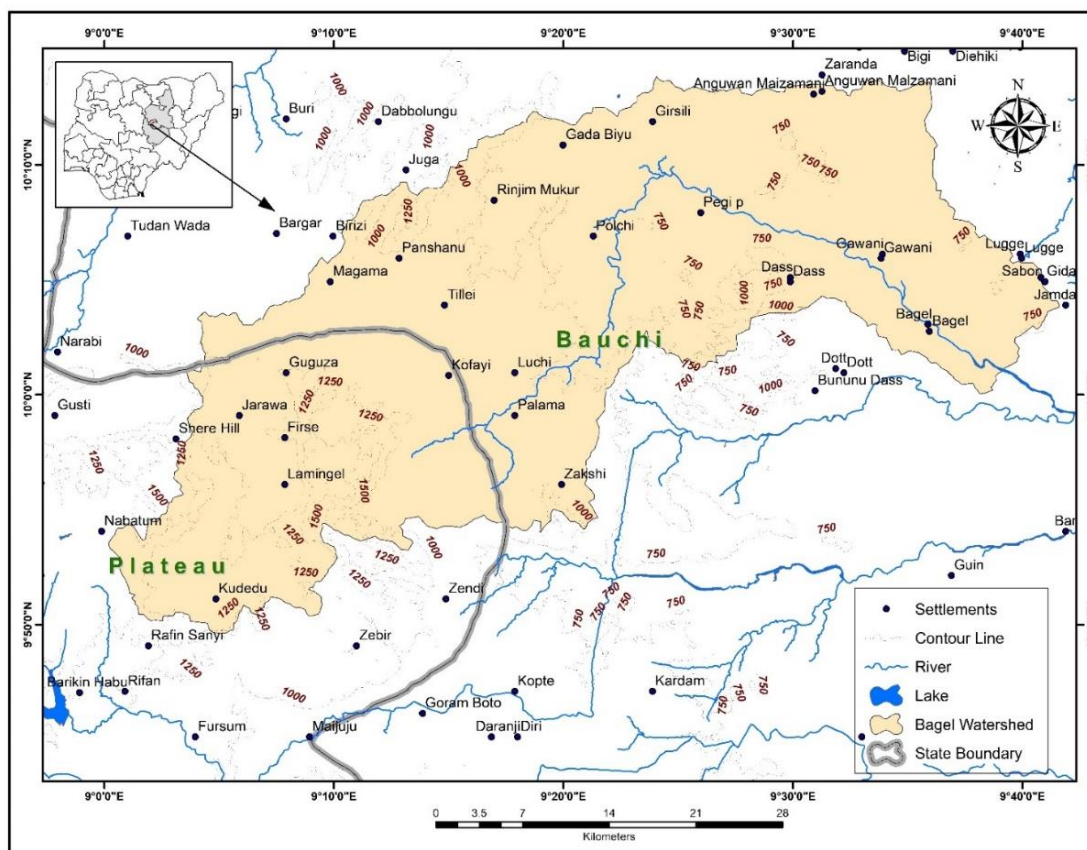


Figure 1: Map showing the Bagel Watershed
Source: Modified from Google Earth, 2022

The study area exhibits a two-season climate pattern, with distinct dry and wet seasons. It falls within the Guinea savannah bioclimatic zone, characterised by a rainfall period spanning 6-7 months, from April to October. The annual precipitation in this locality spans from about 1200 mm in the South to less than 700 mm in the North. The source of this rainfall can be traced to Atlantic maritime air masses that converge on the leeward side of the North Central Highland of the Jos Plateau (Ejeh et al., 2020). The temperature in the study area is relatively high, with an average annual temperature of 26°C. (Dass Local Government DLG, 2022)

The study area, an extension of the Mambila Plateau, is situated on the basement complex rocks of the North Central Highland. The predominant minerals in the area include tin, quartz, feldspar, aquamarine, zinc, iron, manganese, and kaolin (Umar, 2014). These rocks consist of plutonic formations that solidified at considerable depths within the Earth's crust, resulting in large rock crystals or coarse-grained structures. Common rock types in the region include granite, gabbros, migmatite, gneisses, and diorite. These plutonic rocks, now exposed at the surface, have emerged through denudation and erosion. They typically contain acid rocks, characterised by the presence of silicate and aluminium components, contributing to their lighter colouration.



The region's topography, characterised by ridges and hills, gives rise to a range of soil types and profiles. Soil types include azonal soils found in and around the hills, characterised by immature profiles with distinct layers and structures resulting from recent sediment deposition, such as alluvial and peat soils. On the other hand, zonal soils, like laterites, are also prevalent in the area. The study area's vegetation falls under the Guinea Savannah type, receiving more than six months of rainfall. This vegetation is lush and green for much of the year, characterised by fresh leaves and tall grasses. During the dry season, the landscape appears patchy and arid, with trees shedding their leaves to conserve water. These trees often have an umbrella-like shape because they face minimal competition for sunlight. Their thick bark helps them resist the adverse effects of the dry season and bushfires. Prominent tree species in the area include locust-bean, ashiwali, tamarind, acacia, and baobab, alongside various shrubs and herbs (Udo 1970 and Iloeje, 2009)

The North Central Highland of Nigeria ranges in elevation from 700 to 900 meters above sea level in the low-lying eastern part to 1000 to 2000 meters above sea level in the plateau-like western region. The undulating terrain is a prevalent feature across the area, characterised by hills, ridges, and scattered boulders (Iloeje, 2009). Some of these ridges extend into neighbouring local government areas, particularly Toro Local Government, which forms the boundary between Bauchi and Plateau States. The region is characterised by standout rock formations, including plutonic hills formed through tectonic activity and later exposed by denudation, resulting in rugged mountains (DLG, 2021). Due to its rugged landscape, Dass has earned the nickname "A Dangerous Area Surrounded by Stones.

The primary water system in the study area is the River Bagel, a perennial river. However, due to the area's extreme conditions, the river may not have water year-round. River Bagel is classified as a class H (Hydrographic) stream in Nigeria and is situated at an elevation of 521 meters above sea level (Dan'azumi & Olasunkanmi, 2018). It originates from the Jama'are River, also known as the Bunga River, in its upper reaches. The River Bagel originates in the highlands near Jos, Plateau State, Nigeria, and flows northeastward.

MATERIAL AND METHOD

Data Sources

Remote sensing data were sourced from the United States Geological Survey (USGS) from 1990 to 2020 (30 years). The GIS approach was adopted to analyse the delineated images of the Bagel Zungur watershed. The study's objective is to produce Land Use/Land Cover (LULC) thematic maps of the watershed for 10-year intervals spanning 1990, 2000, 2010, and 2020. These processes were executed using Erdas IMAGINE 14 and ArcGIS (10.7). The generated images were used to analyse the Land Use/Land Cover (LULC) of the watershed, as outlined in Table 1.

Table 1: Satellite Images Acquisition Data

SN	Year	ROW	PATH	Land Satellite Image	Date of Acquisition
1	2020	053/57	187/188	Landsat 8 OLT	December 08 th , 2020
2	2010	053/57	187/188	Landsat 8 ETM	December 22 th , 2010
3	2000	053/57	187/188	Landsat 7 ETM	December 29 th , 2000
4	1990	053/57	187/188	Landsat 4 TM	November 29 th , 1990

To classify the regions of interest, a modified version of the level 1 classification scheme described by Anderson et al. (1976), as cited in Burian et al. (2002) and Jidauna et al. (2018), was adopted. This scheme categorizes the study area into six (6) classes, namely: Bare Soil, Broad River/Waterbody, Built-Up Area, Cultivated Land, Forest/Riparian Vegetation, and Rock Outcrop.

Data Analysis

The study analyses land use/land cover within the study area. This was achieved by examining the satellite images. Land Use/Land Cover analysis from satellite imagery is intended to provide valuable insights into the current condition of the watershed to support the implementation of a proactive management strategy geared towards watershed conservation and against degradation. The basic classes of land use/land cover are presented in Table 2.

Table 2: Land Use/ Land Cover Class and Description

LULC Class	Description
Bare Soil	Regions with no dominant cover or open spaces.
Built-Up Area	Areas with built-up infrastructures.
Broad River/ Water bodies	The natural course of river flow and an artificial waterbody.
Cultivated Land	Cultivated farmland for rain-fed and irrigated.
Forest/ Riparian Vegetation	Woody shrubs and vegetation cover.
Rock outcrop	Underlying and exposed rocks.

Source: Author compilation, 2023

RESULTS AND DISCUSSION

Landuse/Landcover Analysis

Based on the results, the study area covers 1557.67 square kilometres. The findings presented in Table 3 summarise the area coverage (km²) and the corresponding percentages for each of the six (6) classes. In 1990, it was evident that cultivated areas and forest/riparian vegetation areas occupied the largest portions. An increase in cultivated land was observed, indicating its dominance in 2000. There was also a notable loss of vegetation, with a few scattered built-up areas emerging in patches in 2010, while cultivated land continued to expand. In 2020, the analysis reveals an increase in cultivated land, built-up areas, and bare soil, accompanied by a noticeable loss of forest/riparian vegetation. However, the stable presence of broad rivers and water bodies remained consistent, while built-up areas showed a consistent increase, consistent with the work of Jidauna et al. (2018).

Table 3: LULC changes in square kilometres and percentage of the study area (1990 – 2020)

SN	LULC	1990		2000		2010		2020	
		Km ²	%	Km ²	%	Km ²	%	Km ²	%
1	Bare soil	11.48	0.74	16.13	1.03	2.56	0.16	6.39	0.41
2	Broad River/Waterbody	0.56	0.035	0.50	0.320	0.50	0.320	0.50	0.320
3	Built-up Areas	18.87	1.21	20.11	1.29	24.20	1.55	37.44	2.40
4	Cultivated Area	810.82	52.05	902.23	57.92	933.29	59.91	942.36	60.49
5	Forest/ Riparian	492.75	31.63	351.43	22.56	346.32	22.23	326.12	20.93

Vegetation									
6	Rock out Crop	223.19	14.33	267.27	17.16	250.80	16.10	244.86	15.71
	Total	1557.67	100	1557.67	100	1557.67	100	1557.67	100

Source: Author compilation, 2023

Land Use/Land Cover Change (1990)

As depicted in Table 3, the Land Use/Land Cover (LULC) classification for the TM 1990 image reveals the following distribution within the study area: cultivated area covered approximately 810 km², constituting 53.02% of the total area. Forest/Riparian vegetation in this class encompassed about 492.75 km², accounting for 31.63% of the total area. The rock outcrop covered an area of 223.19 km² (14.33%) and was characterised by rock outcrops, extending the Mambila plateau. The built-up area in this classification covered 18.87 km², accounting for 1.21% of the total area. Bare soil, covering 11.48 km² (0.74%), was identified. Broad River/waterbody class had the smallest area coverage, totalling 0.56 km², representing 0.035% of the total area. For a visual representation of the study area in 1990, Figure 2(a) provides a clear overview.

Land Use/ Land Cover of the Watershed (2000)

Table 3 presents the results of the Land Use/ Land Cover (LULC) classification for the 2000 image. The findings are as follows: the cultivated area class covered the largest portion, totalling 902.23 km², which represents 57.92% of the total area. Forest/Riparian vegetation covered approximately 351.43 km², accounting for 22.56% of the total area. A persistent change was observed between cultivated areas and forest/ riparian vegetation. Rock outcrops characterised 267.27 km² (17.16%) of the area. The built-up area covered 20.11 km², comprising 1.29% of the total area. Bare soil similarly covered 16.13 km², representing 1.03% of the total area. Broad River/waterbody had the smallest area coverage, measuring 0.50 km² (0.320%). It is noteworthy that cultivated areas and forest/riparian vegetation cover the largest areas, suggesting land conversion elsewhere. Figure 2(b) provides a thematic map of the study area for the year 2000.

Land Use/Land Cover of the Watershed (2010)

In 2010, as indicated in Table 3, the Land Use/Land Cover (LULC) classification results show the following distribution: yet again, the largest portion of cultivated land, covering an area of 933.29 km², accounts for 59.91% of the total area. Forest/Riparian vegetation covered approximately 346.32 km², constituting 22.23% of the total area. The broad river/waterbody had the smallest area coverage, at only 0.50 km² (0.320%). Rock outcrops characterised an area of 250.80 km² (16.10%). Built-up areas covered 24.20 km², accounting for 1.55% of the total area. Bare soil covered 2.56 km² (0.16%). Once again, cultivated area and forest/riparian vegetation were the dominant land cover classes in 2010, accounting for about 80% of the total area. Figure 2 (c) illustrates the thematic map for the period.

Land Use/Land Cover of the Watershed (2020)

In the Land Use/Land Cover (LULC) classification for the 2020 image, as presented in Table 3, the study area exhibited the following distribution: cultivated area was the largest land cover category, covering 942.36 km² and accounting for 60.49% of the total area. Forest/Riparian vegetation covered approximately 326.12 km², constituting 20.93% of the total area. The rock outcrop covered an area of 244.86 km² (15.71%). The built-up area covered 37.44 km², accounting for 2.40% of the total area. Bare soil: Covering an area of 6.39 km² (0.41%). Broad River/waterbody had the least area coverage,



totalling 0.50 km² (0.32%). Figure 2(d) presents a thematic map of land use and Land Cover in the study area for 2020.

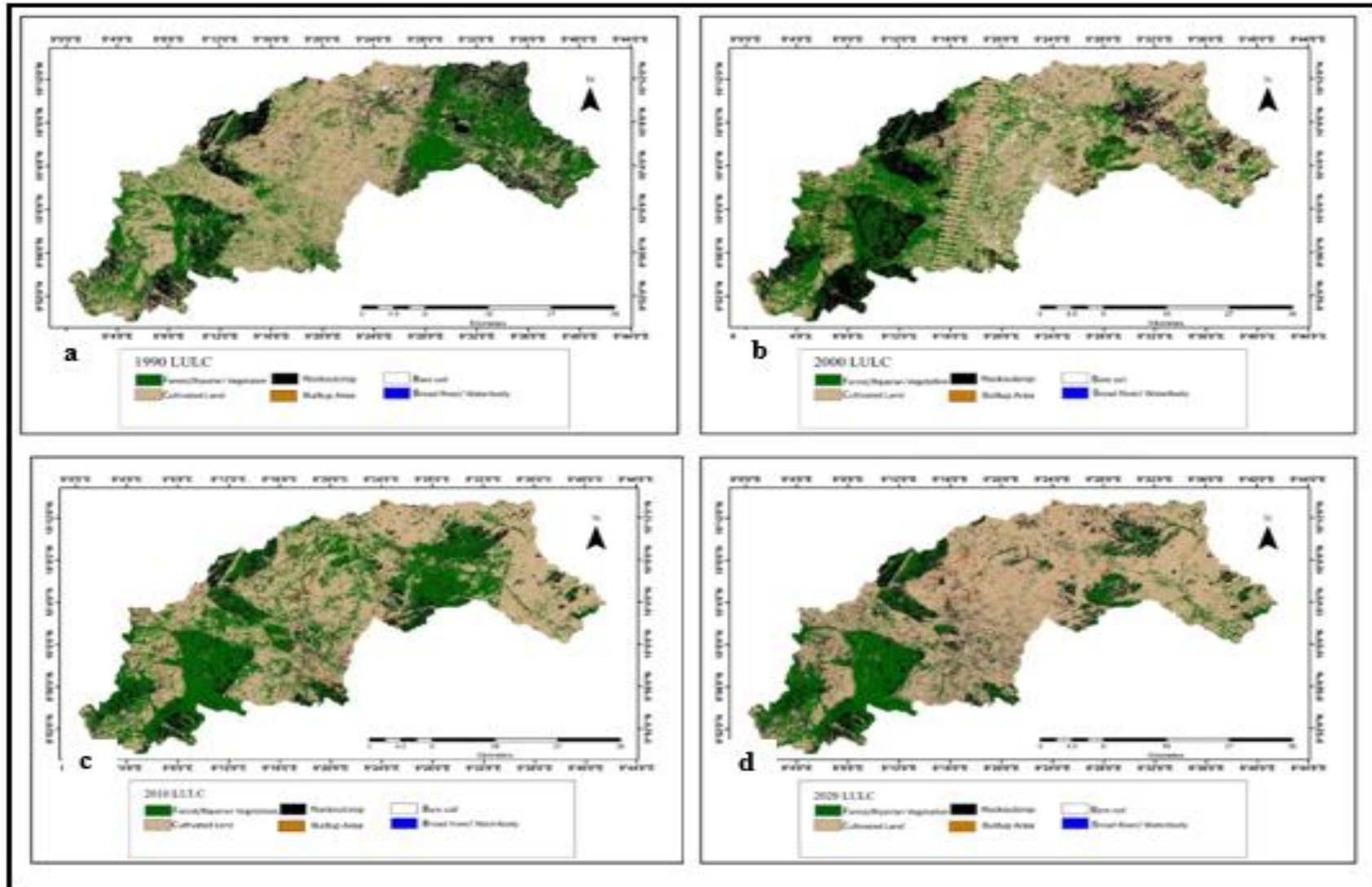


Figure 2: Land Use/Land Cover of the Study Area

Annual Growth Rate of LULC (1990-2020)

The results in Table 4 provide an overview of the land use/ land cover changes for the periods 1990-2000, 2000-2010, and 2010-2020, including the difference in area coverage and the annual rate of change:

The results from 1990 to 2000 show that cultivated land increased by 91.42 km² at an annual rate of 8.31%, based on the watershed as presented in the work of Jidauna et al. (2020) and Jidauna, Kwando, and Ndabula (2023). Bare soil and broad river/waterbody had area coverage and annual rate of 4.65 km² (0.42%) and 0.06 km² (0.005%), respectively. Forest/riparian vegetation was observed by 141.32 km² at an annual rate of 12.84%. A rock outcrop is observed covering 44.08 km², with an annual rate of 4.01%, reflecting an intertwining of the two classes due to the rugged nature of the study area. Lastly, the built-up area increased by 1.24 km² annually at a rate of 0.11%.

For the period from 2000 to 2010, cultivated land increased by 31.06 km² at an annual rate of 2.83%, representing a 5.48% decline from the previous period. Bare soil had an area coverage of 13.57 km² (1.23%) and an annual rate of 1.23%. The broad river/waterbody remained stable, with no significant change (0%); the region does not show any significant waterbody, as observed from the imagery. The built-up area increased by 4.09 km² annually, at a rate of 0.37%. Rock outcrop covered 16.47 km² at an annual rate of 1.49%. Forest/riparian vegetation observed a change of 5.11 km² per year, or 0.46%.

A well-defined pattern was observed from 2010 to 2020, cultivated land increased by 9.07 km² at an annual rate of 0.82%. Bare soil observed a difference of 3.83 km² at an annual rate of 0.34%. Broad River/waterbody remained stable with no change (0%). The rock outcrop had an area difference of 5.94 km² at an annual rate of 0.54%. Forest/riparian vegetation decreased by 20.16 km² at an annual rate of 1.83%.

These changes reflect dynamic patterns in land use and land cover within the study area, with land conversion from forested/ riparian vegetation to cultivated land becoming a prominent trend. It is important to note the interrelationships among different land-use/land-cover classes, often influenced by topographic characteristics, which can lead to coherent land conversion. Proactive management strategies are essential for addressing environmental challenges and promoting sustainable land-use practices while considering the consequences of these changes on the local ecosystem.

Table 4: Decadal Difference in Square kilometres showing Annual Rate of LULC change

SN	LULC CLASS	1990 – 2000		2000 - 2010		2010 – 2020	
		Km ²	Annual Rate%	Km ²	Annual Rate%	Km ²	Annual Rate%
1	Bare soil	4.65	0.42	13.57	1.23	3.82	0.34
2	Broad River/ Waterbody	0.06	0.005	0	0	0	0
3	Built-up Areas	1.24	0.11	4.09	0.37	13.24	1.20
4	Cultivate Area	91.42	8.31	31.06	2.82	9.07	0.82
5	Forest/riparian vegetation	141.32	12.84	5.11	0.46	20.16	1.83
6	Rock outcrop	44.08	4.01	16.47	1.49	5.94	0.54

Source: Author compilation, 2023

Land Use/ Land Cover Change Dynamics.

Table 5 provides an overview of the change dynamics of the six (6) land use/ land cover classifications in the study area. Here are some key observations: the built-up area has gradually increased over the years. This suggests population growth, especially in regions close to the stream channels. Small-scale irrigational activities characterise these patches of settlement. Cultivated land has increased over the years, attributable to factors such as deforestation for domestic use, income generation, changes in rainfed agricultural practices, and small-scale irrigation activities. This has led to an obvious land conversion from forest/ riparian vegetation to an increase in cultivated land, which aligns with the findings from studies of Jidauna et al. (2016), Dan’azumi and Olasunkanmi (2018), and Usaku (2021), highlighting the need for vegetation conservation and protection to counteract desert encroachment and future land degradation. Rock outcrops remain a significant feature, particularly for construction quarrying. This strongly contributes to weathering, erosion, and land degradation, resulting in sediment yield. These findings underscore the complex interplay between natural features and environmental changes in the study area. The need for sustainable land management practices and conservation becomes essential.

Table 5: Land Use/ Land Cover Dynamics (1990-2020)

SN	LULC CLASS	1990 – 2000		2000 - 2010		2010 – 2020	
		Km ²	Changes	Km ²	Changes	Km ²	Current Change
1	Bare soil	4.65	Gain	13.57	Loss	3.82	Gain
2	Broad River/ Waterbody	0.06	Loss	0	Stable	0	Stable
3	Built-up Areas	1.24	Gain	4.09	Gain	13.24	Gain
4	Cultivate Area	91.42	Gain	31.06	Gain	9.07	Gain
5	Forest/riparian vegetation	141.32	Loss	5.11	Loss	20.16	Loss
6	Rock outcrop	44.08	Gain	16.47	Loss	5.94	Loss

Source: Author compilation, 2023

CONCLUSION

This study provides a comprehensive assessment of land-use and land-cover dynamics in the Bagel Zungur Watershed over 30 years using remote sensing and GIS techniques. The results indicate a clear and persistent trend of land conversion, particularly from forest and riparian vegetation to cultivated land and built-up areas. The continuous expansion of agricultural land reflects increasing dependence on land-based livelihoods, while the growth of built-up areas highlights rising population pressure and settlement expansion within the watershed. Conversely, the steady decline in forest and riparian vegetation suggests heightened vulnerability to land degradation, erosion, and potential hydrological imbalance. Although water bodies remained largely stable, overall LULC dynamics underscore increasing anthropogenic stress on the watershed. These changes have significant implications for ecosystem services, watershed hydrology, and long-term environmental sustainability. The study emphasizes the need for integrated land-use planning, vegetation conservation, and sustainable land management practices to mitigate further degradation. The findings serve as a critical baseline for future monitoring, predictive modelling, and policy interventions to promote sustainable watershed



management and environmental resilience in the Bagel Zungur Watershed and similar ecological settings in Nigeria.

RECOMMENDATIONS

Appropriate stakeholders' participation is critical in the watershed degradation management plan. Hence, there should be community inclusivity in raising awareness of the dynamics, impacts, and changes posed by major projects. This initiative aligns with Nigeria 2030 and Sustainable Development Goal Target 15.

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