

Assessment of Land Use and Land Cover Change and Urbanization Effects on Gully Erosion in Tunfure, Akko Local Government Area, Gombe State, Nigeria

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Abstract

Urbanization is a major driver of environmental degradation, including erosion with associated socio-economic consequences. This is the case in Tunfure, Akko Local Government, Gombe State, where expansion of urban activities has resulted in increased surface runoff and gully erosion. This study examined the effect of urbanization on Gully Erosion using remote sensing techniques and software such as ArcGIS. Landsat 7 and 8 Imagery of 2002, 2013 and 2022 were downloaded from USGS Earth Explorer. DEM data was used to generate slope map, aspect, Flow accumulation, flow direction, and watershed delineation using the spatial analyst tool on the Arc Toolbox. DEM data was used to generate the erosion Flow path. Results showed that the built-up area increased from 8.5% to 42.6% between 2013 and 2022. Bareland also decreased from 66.30% to 45.02%, vegetation decreased from 20.14% to 1.06%, and sand deposit increased from 5.5% to 11.25% of the total area within the same period (2013 and 2022). Water flow maps of the study area at different periods showed that in 2002, the study area had multiple major erosion pathways known as river tributaries, while in 2013 and 2022, the tributaries had reduced. This disappearance of water flow pathways may be linked to urban expansion as well as the concentration of urban activities on water flow channels. In view of the above, there is a need for a comprehensive urban planning which will prioritize sustainable land use and zoning regulations to limit constructions in gully erosion-prone areas and pathways.

Keywords: *Urbanization, Remote Sensing, GIS, Gully Erosion, Sustainable Landuse, Landsat*

INTRODUCTION

Urbanization is an important indicator of land-use/land cover modification, and uncontrolled urban expansion has raised concerns in developing countries, most especially in sub-Saharan Africa (Aliyu and Amadu, 2017; Abanyam and Dankano, 2019). In these regions, there is usually a rapid population growth and migration from rural to urban areas, which have increased the expansion of towns and cities (Korah and Wimberly, 2024). Urban development is usually associated with economic growth and

improved access to services, but it can bring considerable environmental issues if the approach is not properly planned (Saketta, 2023). Soil erosion is one of the critical environmental problems that is linked to unplanned urban growth. Gully erosion is an advanced stage of soil degradation that is often characterized by the formation of deep and wide channels, which are created by surface runoff (Li *et al.*, 2021). These channels expand rapidly, destroying farmlands, roads, buildings, and other vital infrastructure, thereby posing

serious risks to livelihoods and sustainable development. In Nigeria, the issue of gully erosion is a widespread environmental hazard, which is in the northern and southeastern regions where the soils are fragile, rainfall patterns are intense, and human activities are on the increase (Udumah *et al.*, 2021). States like Anambra, Imo, Enugu, and parts of the North-East, including Gombe State, have experienced severe cases of gully development, which has been intensified by poor drainage systems, sand mining, deforestation, construction of roads and the expansion of impervious surfaces such as concrete pavements and rooftops (Egboka *et al.*, 2025). All these activities alter the natural hydrological cycle by reducing infiltration and increasing the volume and velocity of surface runoff, which in turn enhances the erosive power of flowing water (Obiorah *et al.*, 2025).

Tunfure, a rapidly developing settlement in the Akko Local Government Area of Gombe State, is faced with unregulated urban expansion. The area in recent years has been exposed to population growth, which is noticeable, and accompanied by increased construction of houses, roads, expansion of markets, and the clearing of vegetation for commercial and residential purposes (Sati *et al.*, 2024). These changes have transformed the natural landscape significantly by replacing the soil and vegetative cover with hard and compact surfaces. This has resulted in increased surface runoff, as the rainwater that normally infiltrates into the soil no longer does (Benjamin and Mbursa 2025). The climatic and geological characteristics of Gombe State also influence the problem of gully erosion. The study area experiences distinct wet and dry seasons, with high-intensity storms and rainfall that generate large volumes of runoff within a short period. The Gully erosion experienced in Tunfure is not only an environmental issue, but also a socio-economic challenge. These gullies have cut off access roads, destroyed farmlands,

undermined building foundations, and threatened utilities such as electricity poles and water pipes (Sati *et al.*, 2024). This, therefore, results in financial burdens on households and local authorities, as residents are forced to abandon properties that are threatened, thereby resulting in loss of investments, displacement, and increased vulnerability of already resource-constrained communities (Mbaya *et al.*, 2012). The lost fertile topsoil affects the agricultural productivity, affecting food security and income of households in an area where farming activities are an important source of livelihood (Mbaya 2023).

With the visible severity of gully erosion in Tunfure, there is limited empirical research that focuses specifically on the relationship between the urbanization processes and the development of gully in the area. Understanding how factors such as road layout, drainage design, building density, and land-cover change influence the initiation and expansion of gullies is essential for developing effective control and prevention strategies. Without such data that is location-specific, the interventions may remain reactive rather than preventive, thereby resulting in repeated failures and increased costs in the long-term. This study, therefore, seeks to examine the effects of urbanization on gully erosion in Tunfure, Akko Local Government Area, Gombe State, Nigeria. It aims to achieve this by analyzing the patterns of land-use change, identifying of human activities that can contribute to gully initiation and expansion, and assessing the environmental and socio-economic impacts of gully erosion on the local community. The findings will provide valuable information for environmental managers, urban planners, and policy makers in supporting the design of sustainable drainage systems, improved land-use planning, and effective erosion control measures.

MATERIALS AND METHODS

Study Area Description

Tunfure is located at a latitude $10^{\circ}12'0''\text{N}$ to $10^{\circ}21'00''\text{N}$ and longitude $10^{\circ}54'00''\text{E}$ to $11^{\circ}9'0''\text{E}$ in Akko local government area of Gombe state. The southern part of the area of study is bounded by Billiri LGA, with Gombe LGA, Dukku/Kwami LGA, and Lafiyawo to the east, north, and west, respectively (Figs. 1 and 2). The total land mass of the area is 8.212 km^2 and a population of 337,853 as reported by the 2006 census. It a community consisting of different tribes such as the renowned Hausa and Fulani, Tula, Tera,

Igbo, Tangale, Waja, Yoruba, Jukun, and Tula etc. The state is characterized by the distinct dry season (November-April) and wet season (May-October) as it is located within the sub-Saharan climatic region. The dry season is accompanied by the north-east trade winds, which originate from the Sahara belt. The wind is dry, dust-laden, and accompanied by a low-pressure system. The wet season comes with the south-Westerly wind, which consists of moisture that originates from the Atlantic Ocean high pressure zone to the Saharan region with a low-pressure zone. The average rainfall in this region is 907 mm. (Mbaya *et al.*, 2012).

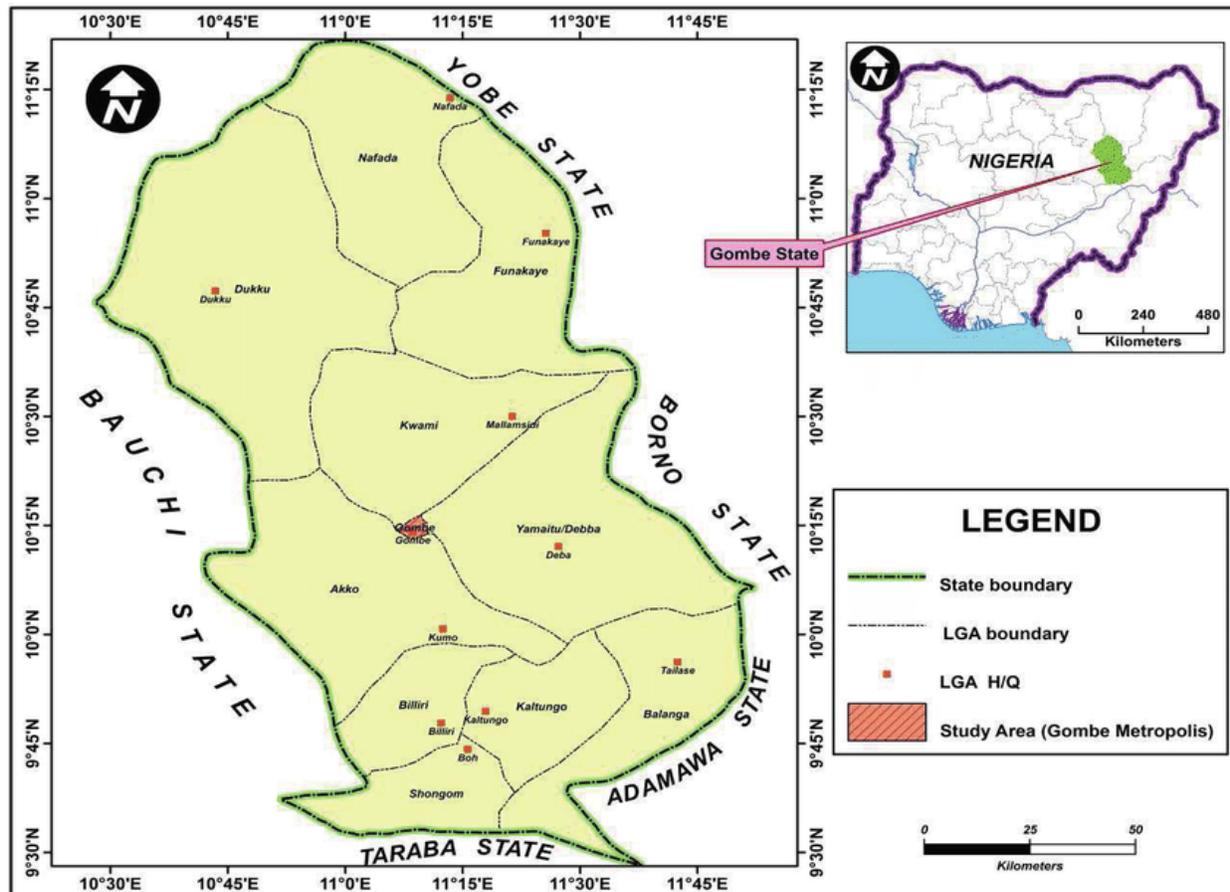


Fig. 1: Gombe Map, Nigeria (Source: Mbaya *et al.*, 2019)

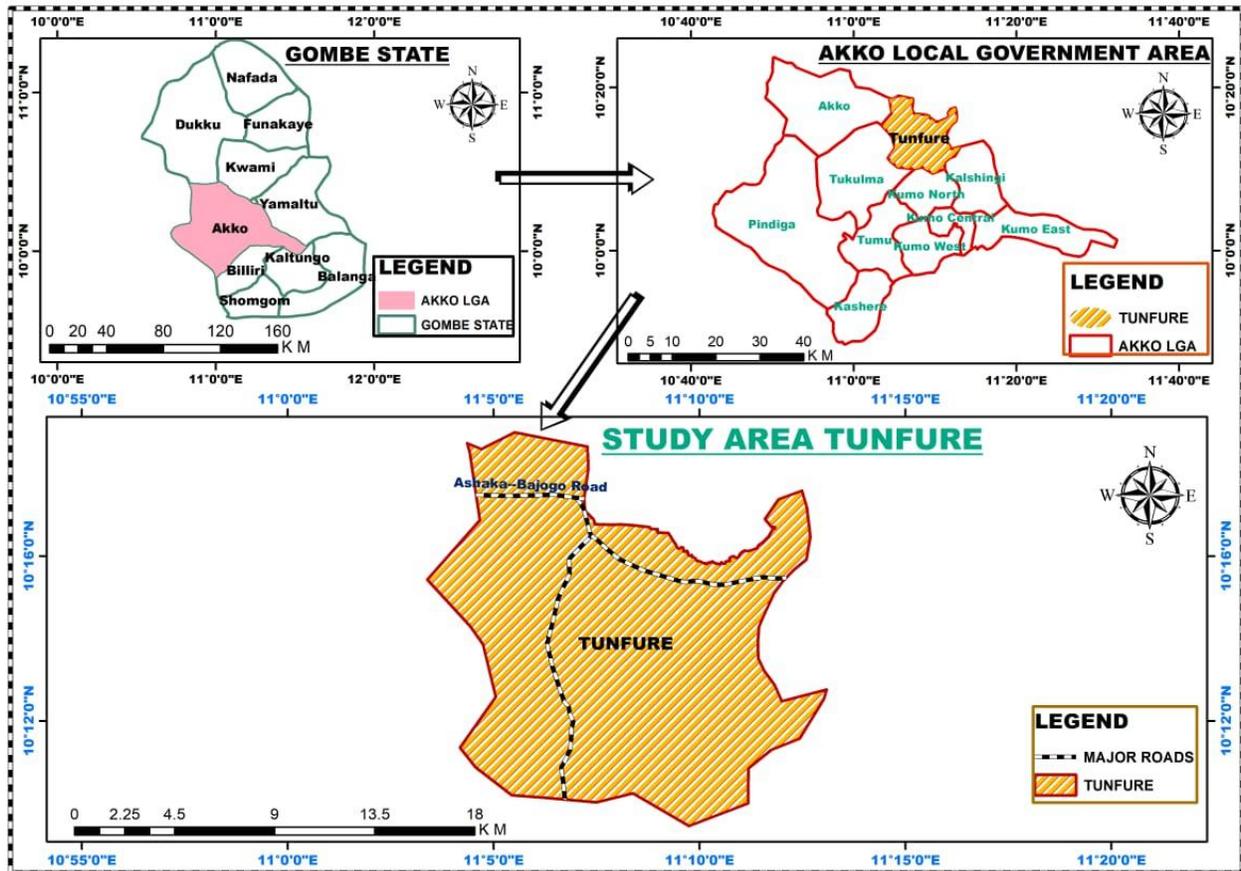


Fig 2. Tunfure, Tunfure in Akko LGA, Akko in Gombe State (field work 2023)

The study area has a geological formation mainly of Cretaceous sandstones with several deposits. The Gombe metropolis has a low-lying and undulating landscape that slopes from the Akko escarpment in the west to Liji hill in the east, which is the highest point of about 500m. The area is drained by some ephemeral streams and ravines, which take their sources from the Akko escarpment and flow eastwards. The vegetation is of the Sudan savannah type, characterized by shrubs, scattered trees, and grasses (Amos, et al., 2015). The predominant tree species in this area include Parkia (*Parkia clappertoniana*), Baobab (*Adansonia digitata*), Tamarind (*Tamarindus indica*), date palm (*Phoenix doctylifera*) and Neem (*Azadirachta indica*) (Abaje, 2007). The area has a population projection of about 337,435 2006 and projected to 509,122 in 2022 with a growth rate of 3.18% (National population commission, 2009).

Data Acquisition and Sources

Landsat 7 and 8 Imagery of 2002, 2013 and 2022 were downloaded from the United States Geological Surveys (USGS) Earth Explorer platform. Landsat 7, launched in 1999 and Landsat 8, launched in 2013 as part of the joint NASA-USGS Landsat programme, provide medium-resolution multispectral imagery widely applied in land use/land cover studies (Landsat Missions, 2024). The raw data on land use and cover were gotten from Landsat 8 Operational Land Imager (OLI) from year 2022 and 2013, with Landsat 7 Enhanced Thematic Mapper Plus imagery for data in the year 2002. These specifications made Landsat 7 & 8 particularly suitable for monitoring urban expansion, vegetation dynamics, water resources, and thermal anomalies such as those associated with land degradation (Roy et al., 2014).

Image Processing, Manipulation and Classification

ArcGIS 10.8: This was used for the supervised maximum likelihood image classification of the study area and the other GIS-based functions that were carried out.

Microsoft Office software: This was used basically for plotting charts and report writing

Google Earth Pro: This software was used as a digital alternative to ground truthing while performing an accuracy assessment of land use land cover classification, and the elevation and measurement tools were used for the measurement of erosion pathways.

Image Pre-Processing

This involved the use of radiometric corrections and geometric corrections. Preprocessing of acquired Imagery was done to remove distortion, degradation, and noise that may be introduced during the process of acquisition of imaging. Prior to the image pre-processing, the selected bands were stacked using the ArcGIS combine clipping was done.

Image classification

Image classification was done using the maximum likelihood method while also taking 20 training samples per land use and land cover class. The training samples were then converted to KML format for ground truthing on the Google Earth application.

Erosion Path Generation

The erosion Flow path was generated after the DEM data was used to generate a slope map, aspect, flow accumulation, flow direction and watershed delineation using the spatial analyst tool on the Arc Toolbox.

Data Analysis

GIS analysis was done using Microsoft Excel to compare land use and land cover classes and generate charts. Further analysis of erosion pathways was done on Google Earth Pro and image-based analysis was done on ARCGIS 10.8.

RESULTS AND DISCUSSION

Spatio-Temporal Patterns of Land Use/ Land Cover Changes (LULCC)

The built-up areas in the study area had a progressive linear increase throughout the years with a dense form of development in 2022, as opposed to the sparse and decentralized development observed in 2002 and 2013 (Figs. 3-5) and these rapid growth and land use changes may be due to increased commercial interest in the area and cheaper rates of residency when compared to Gombe metropolis. Figs. 3-5 also illustrate that the bare land got more exposed between 2002 and 2013 which is mainly due to the reduced Vegetation cover experienced within that time frame. The Vegetation cover continued to reduce between the years 2013 and 2022 and the bare land exposure reduced because more buildings were built on the bare land created by vegetation loss. The sand deposit and sand materials accumulation increased progressively throughout the years, which is indicative of erosion because the top layer of the soil in the study area is being washed away, making the sand deposit more visible around erosion Pathways. This implies that over the years, as urban development grew in the study area, there have been exponential changes in LULC because of urban expansion.

This was similarly confirmed by Abubakar et al., (2023), who reported that there has been a rapid expansion in Gombe metropolis from 13.812 km² in 2000 to 44.105 km² between 2000 and 2020. This report also indicated that the area will continue to expand at a rate of 3.48% per year, to a size of 77.623 km² of urban land use by 2030 (Abubakar et al., 2023). Mbaya et al., (2019) also corroborated this statement on expansion, and reported that the bare surfaces in Gombe metropolis have increased to 17% in 2016, as against 13% in 1996 and 11% in 1976. Similarly, the vegetation area cover decreased to 11% in 2016 from 62% in 1976 to 27% in 1996. Due to the conversion of farmlands into structures, farmland increased from 25% in 1976 to 43%

in 1996 and decreased to 17% in 2016 (Mbaya et al., (2019). Gombe metropolis has been reported to experience spatial growth as the study by Gadiga and Galtima (2017) revealed that the spatial extent of the metropolis in 1984 was estimated at 1104.03 hectares. However, a growth trend of 62% increase (1792.44 hectares) in built-up areas between 1984 and 1991 was observed. This increase in growth

trend was attributed the metropolis as the capital city of the newly created Gombe state in 1996. This led to the establishment of government ministries, extra-ministerial departments and agencies, added commercial functions and the influx of new jobs, which all attracted scores of people from the neighboring settlements (Gadiga and Galtima, 2017), leading to further expansion in built-up areas.

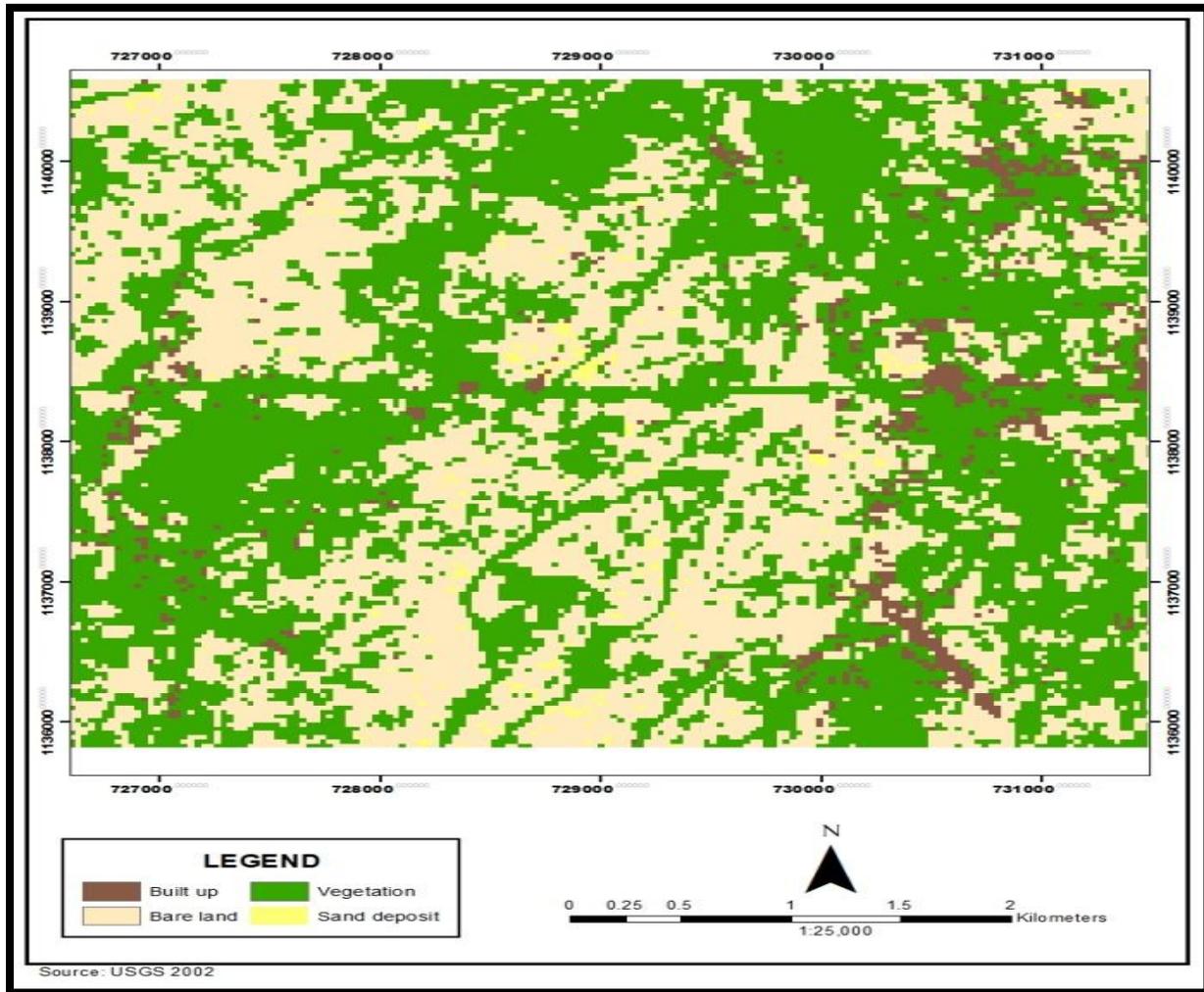


Fig 3: Land use and Land cover of Tunfure in 2002

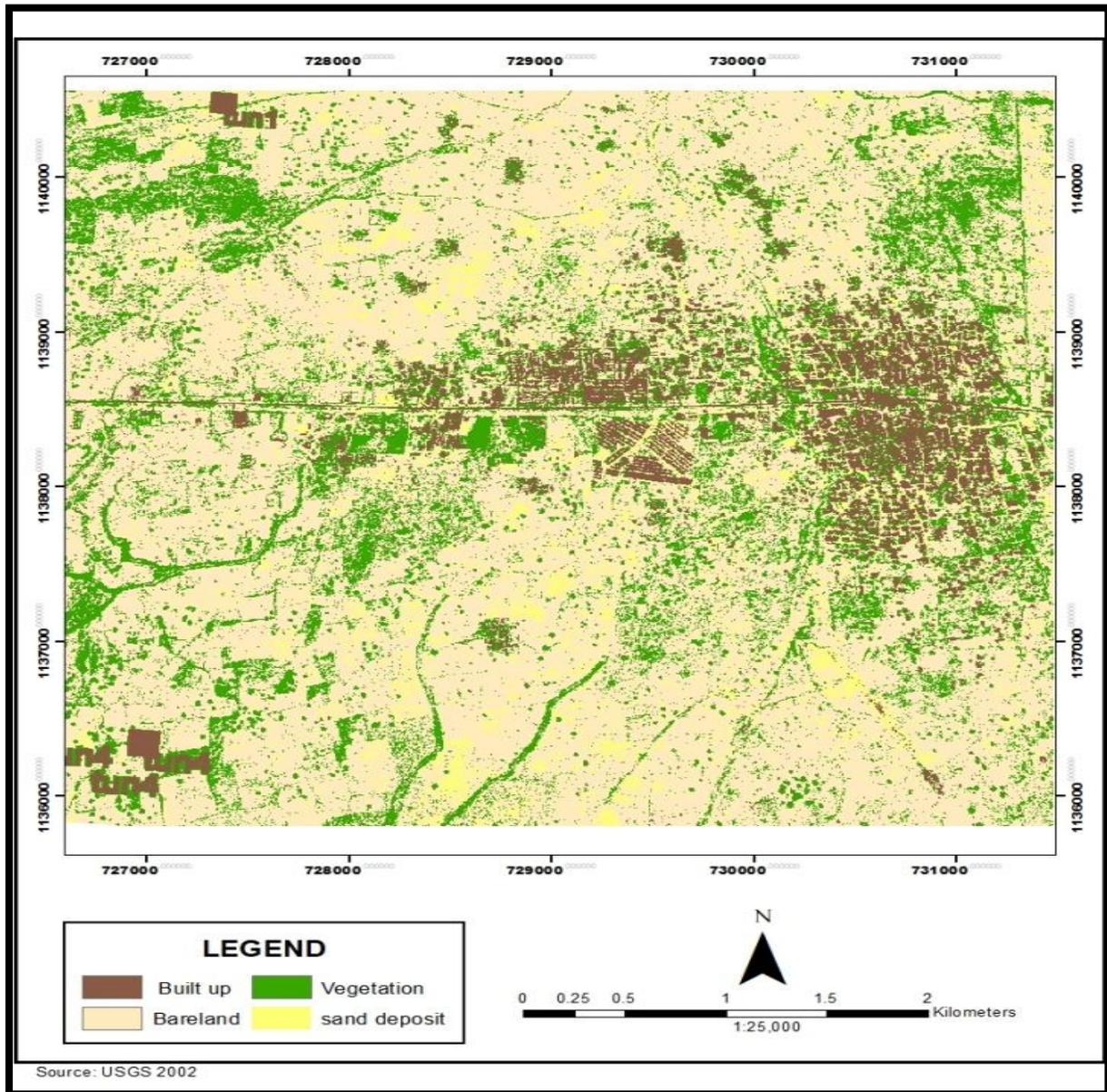


Fig 4: Land use and Land cover of Tunfure in 2013

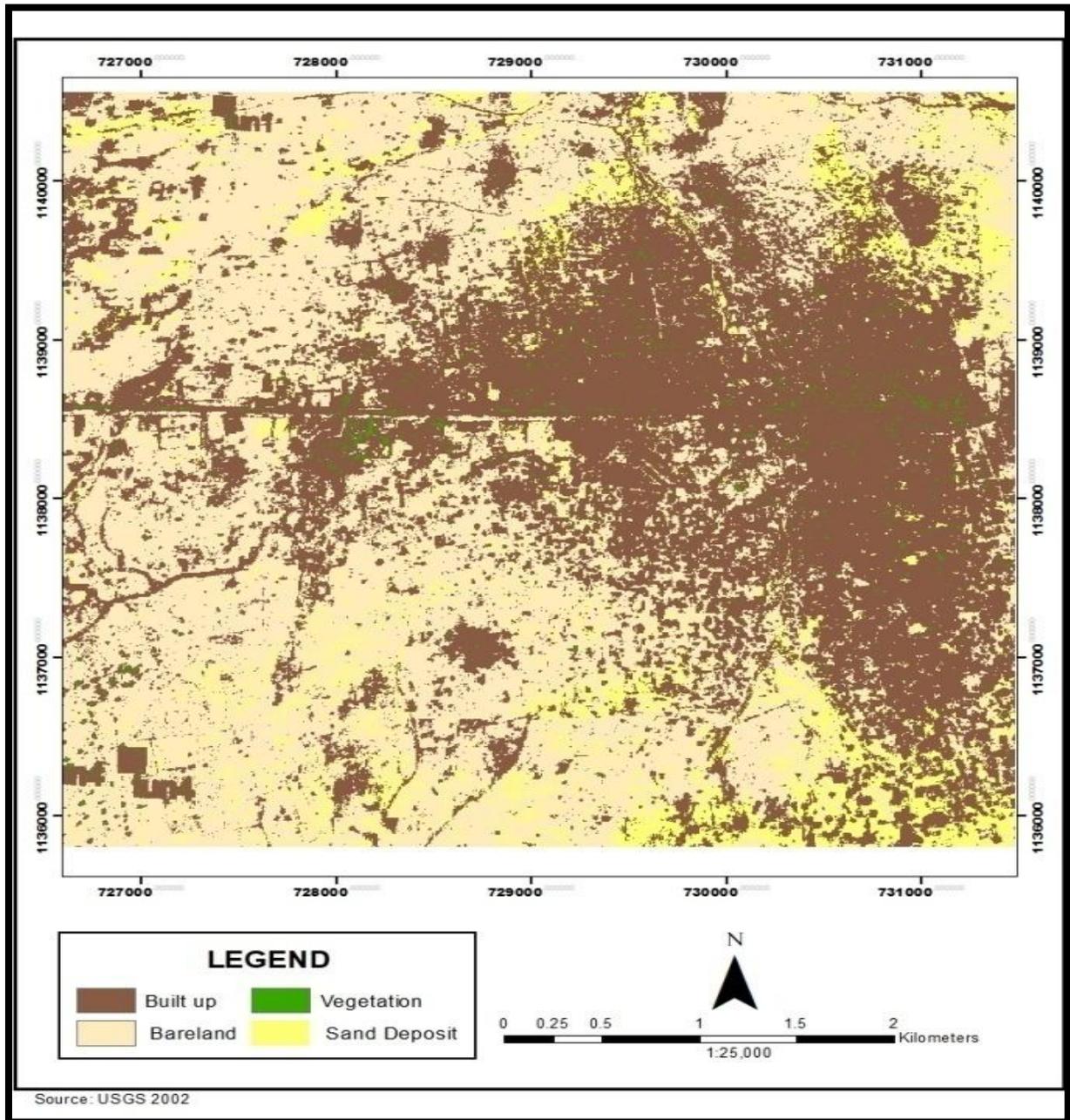


Fig 5: Land use and Land cover of Tunfure in 2022

Table 1 indicates the area distribution in square kilometers (Km²) of land use land cover (LULC) in Tunfure, Gombe State, and the percentage variations (%) over the years 2002, 2013 and 2022. The evaluation of Land use/Land cover (LULC) revealed marked variation at different periods. In 2002, the built-up area occupied about 4.18% of the study area, while bare land, Vegetation and sand deposit

occupied 44.02%, 50.90%, and 1.04% respectively within a total area coverage of 27.30 square kilometers. In 2013, built up area increased from about 4.18% in 2002 to 8.05% of the study area. The result further revealed that bareland increased from 44.02% to 66.30%, vegetation decreased from 50.90% to 20.14%, and Sand Deposit increased from 1.04% to 5.50% for the same period. In 2022, built up area increased from 8.5% to 42.6%

between 2013 and 2022 of the study area, bareland decreased from 66.30% to 45.02%, vegetation decreased from 20.14% to 1.06% and sand deposit increased from 5.5% to 11.25% of the total area within the same period. The information in the figures above reveals the level of change during the period of study for Table 1: Land cover distribution

each time interval. This goes to show that over the period of 2002-2022, the study area has been heavily affected by urbanization as the percentage of land used for urban expansion has increased while vegetation and bareland have drastically reduced.

S/N	LULC CLASS	2002		2013		2022	
		Km ²	%	Km ²	%	Km ²	%
1	Built up	1.14	4.18	2.20	8.05	11.65	42.6
2	Bareland	12.02	44.02	18.10	66.30	12.29	45.02
3	Vegetation	13.89	50.90	5.50	20.14	0.29	1.06
4	Sand Deposit	0.2826	1.04	1.50	5.50	3.07	11.25
Total		27.30	100.0	27.3	100.0	27.3	100.0

Source: field work (2023)

Lengths and Depths of Gully Erosion Pathways in the Study Area

The impacts of the land use changes in the study area were related to erosion gully pathway and the results revealed increased water flow pressure, deepening, widening, and

lengthening of the paths at different periods (2002, 2013, and 2022) as shown in 6-8. Tables 2 and 3 also showed the maximum width and depth on each path, denoted in units of meters as measured using the measurement tool on Google Earth Pro.

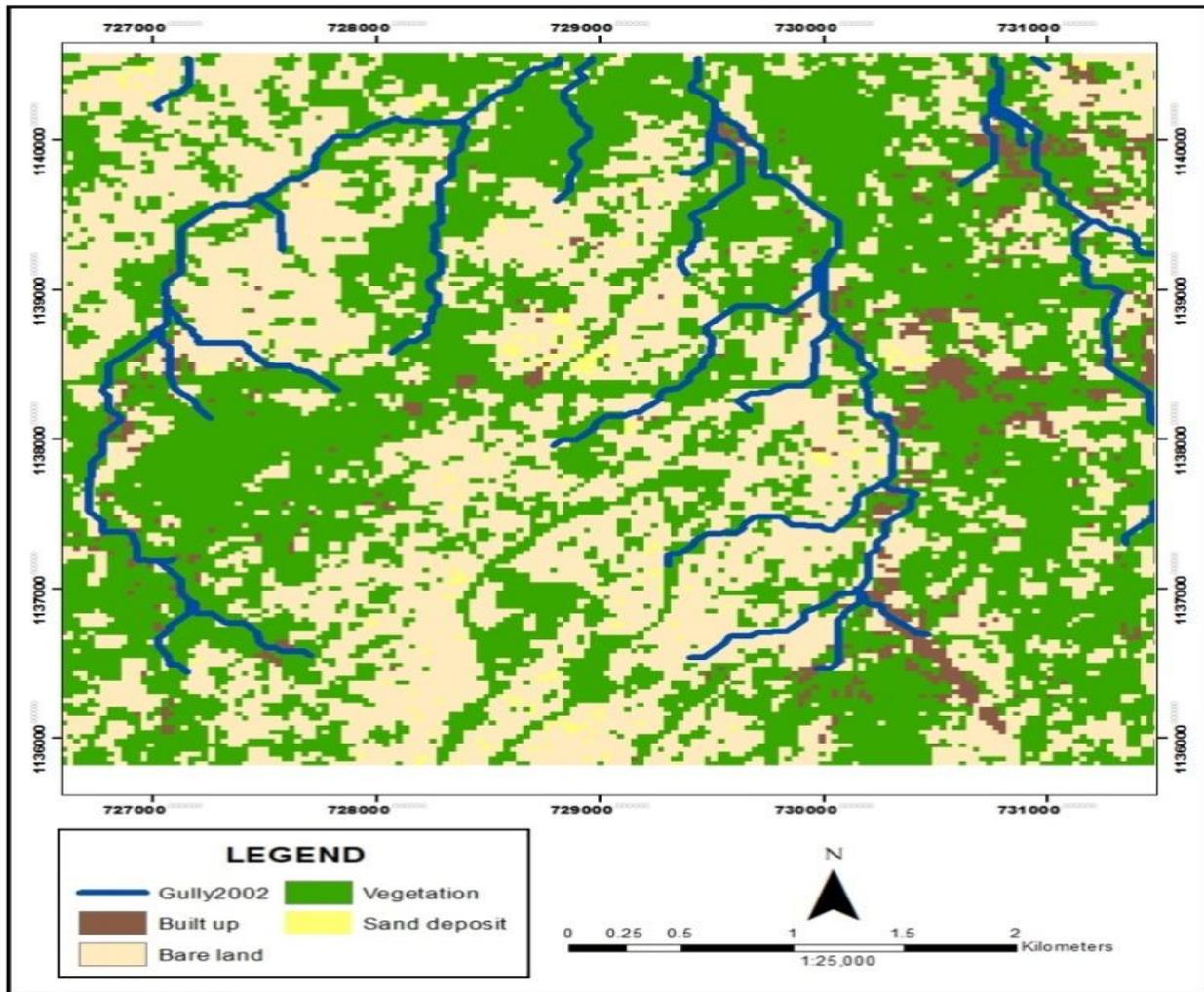


Fig 6: Water flow map of the study area in 2002

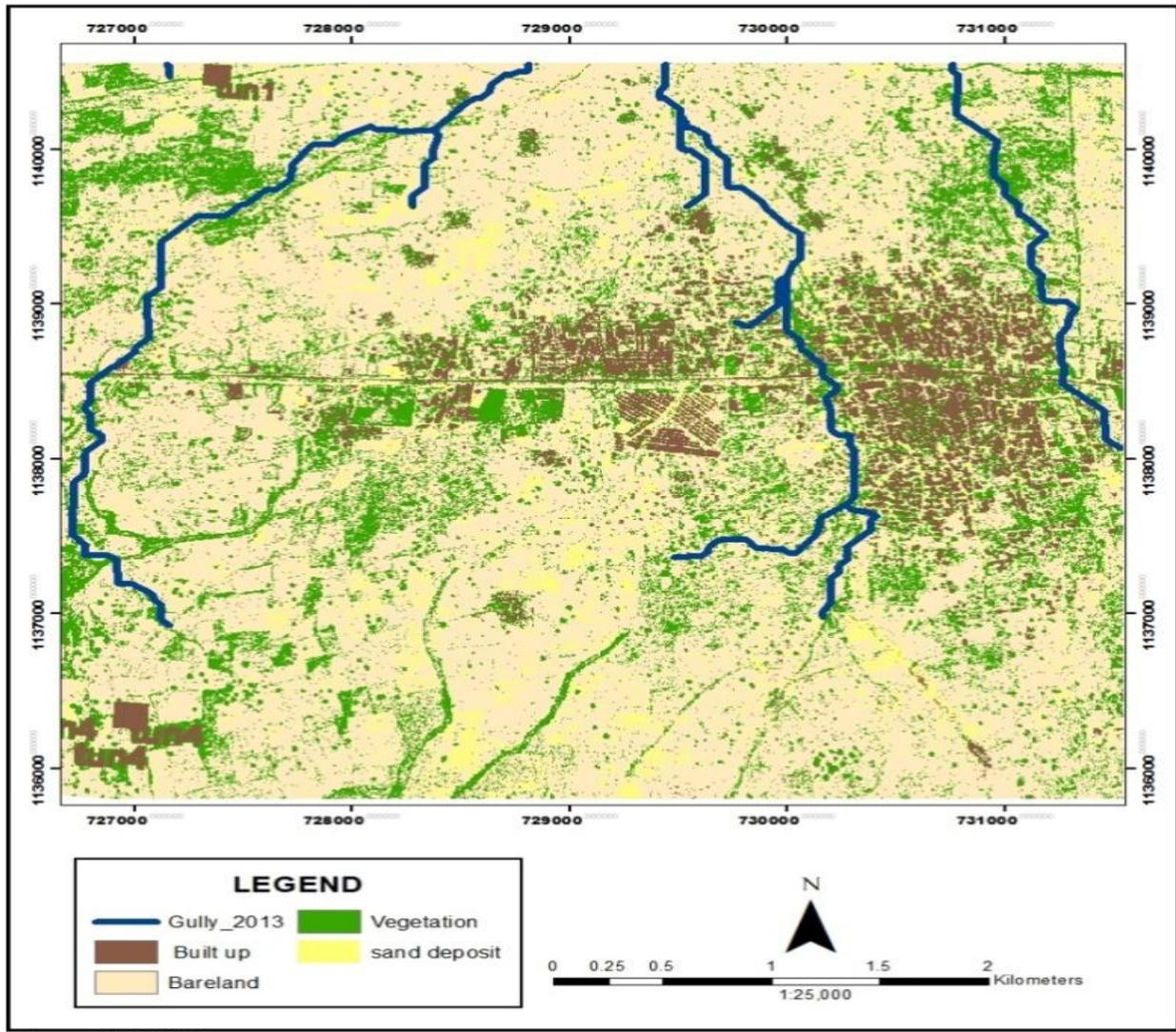


Fig 7: Water flow map of the study area in 2013

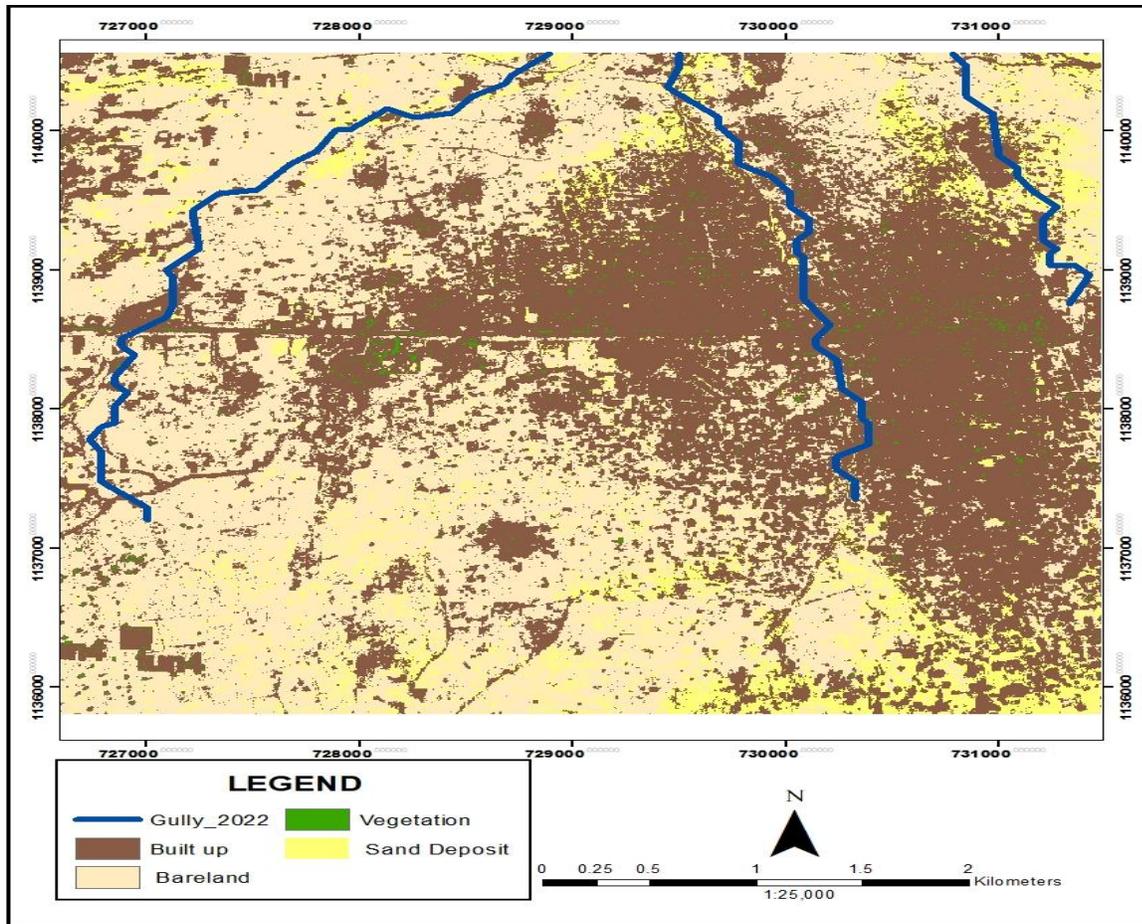


Fig 8: Water Flow map of the study area in 2022

These water flow maps of the study area at different periods show that the study area in 2002 had multiple major erosion pathways known as river tributaries, while in 2013 and 2022, the tributaries had reduced. This disappearance of water flow pathways may be linked to urban expansion as well as the concentration of urban activities on water flow channels. River tributaries are freshwater streams that contribute its flow to a larger stream or river, known as the main order basin. Tributaries serve as important habitats and carry various sediments, chemicals, organic matter and volumes of water that contribute to unique conditions that support various species (Water Education Foundation, 2025). As tributaries merge to the mainstem, they can become a source of water for various water resources planning and development such as

irrigation, water supply as well as support marine life.

An adverse impact of urbanization on the flow of water includes the implications for quality of river flow, which will deteriorate because of the disposal of untreated industrial and domestic sewage in the river. Similarly, the flooding events resulting from urbanization can increase as the drainage system will be clogged due to indiscriminate disposal of refuse and siltation. The effects of urbanization were similarly reported by Kumar, et al. (2019) on the river Yamuna basin in northern India. In the Taihu Region, China, Deng et al., (2015) revealed that the number of river systems decreased drastically in the region in the last 50 years due to urban expansion. Apurba and Susmita (2022) also argued that due to urbanization,

forestation constantly decreased, causing river variability in Cachar District, Assam, India. In Nigeria, Fombo et al., (2024) reported a gradual deterioration of the water quality of rivers on mangrove wetland at Eagle Island, River State as a result of human-mediated activities. A study by Abali and Nkii (2024) revealed a significant positive link between channel morphology, discharge, and urbanization index. Similarly, Alayande and Agunwamba (2010) reported that along the Kaduna River

floodplain the situation of increasing urbanization being responsible for flooding issues along the river floodplain. Also, they reported that encroachment into the traditional flood-prone areas of the Kaduna River has attained a level of 85.31%, 68.47% and 67.54%, respectively in Reach 2, Reach 3 and Reach 1 respectively over the period 1962 and 2009. The maximum width of each erosion pathway across the timeframe is presented in Table 2.

Table 2: The maximum width of erosion pathways

Year	Path 1 Maximum width(m)	Path 2 Maximum width(m)	Path 3 Maximum width(m)	Path 4 Maximum width(m)	Path 5 Maximum width(m)	Path 6 Maximum width(m)
2002	22.40	22.30	16.52	14.44	16.40	8.5
2013	23.50	34.60	11.01	0	0	0
2022	45.3	32.50	46.3	0	0	0

Source: field work (2023)

Over the years, due to urbanization, erosion paths became reduced, and the gullies became deeper due to increased water pressure and volume in the limited erosion pathways. An assessment of the erosion Path of major pathways was carried out using the elevation profile tool on the Google Earth Pro application, and the elevation loss data was obtained. For the year 2002, the overall maximum elevation loss across all erosion pathways was 19.0m. By the year 2013, the maximum elevation loss was 21.2m, which is about an 11.6% loss in elevation in comparison

to 2002 and a 23.5% loss in elevation by the year 2022 when compared to 2013 (Table 3). Also, from table 3 it can be seen that the number of erosion paths was highest in 2002, with a number of up to 6 major tributaries which were relatively shallow when compared to the pathways created by erosion in 2013 and 2022 that had deeper and lesser number of tributaries. These findings show that urbanization has played an active role in the increase in the width and length of the erosion pathways.

Table 3: Elevation loss

OBJECT ID	Erosion Path	Elevation loss(meters) 2022	Elevation loss(meters) 2013	Elevation Loss(meters) 2002
1	Path 1	20.3	19.3	2.76
2	Path 2	26.2	21.2	0.45
3	Path 3	9.11	5.84	1.06
4	Path4	0	0	19.0
5	Path 5	0	0	3.45
6	Path 6	0	0	4.65
7	Max elevation loss	26.2	21.2	19.0

Source: field work (2023)

CONCLUSION AND RECOMMENDATIONS

This study assessed the effect of urbanization on gully erosion in Tunfure, Gombe State. The study established that urbanization has indeed had an impact on gullies in the study area. As the rate of urban expansion increased, drainage pathways became fewer in number and concentrated into 3 main pathways. This activity led to the widening and deepening of gully erosion, which has in turn led to the destruction of buildings, access roads, farm lands and a loss of a lot of money. It also showed that the rate of expansion of gully erosion in the study area is directly related to urban expansion, as shown in the maps provided and if effective measures are not taken, the rate of expansion of gullies will increase with time, leading to greater risk. In view of the study findings, there is a need for a comprehensive urban planning which will prioritize sustainable land use and zoning regulations to limit construction in gully erosion-prone areas. This also recommends the utilization of water harvesting structures so that floodwater can be collected and used for productive purposes. Flooding, when properly managed, can be opportunities rather than a hazard. Finally, there is a need for afforestation programme in the study area to create canopies over exposed surfaces and reduce sediment movement.

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