Assessment of The Magnitude and Spatial Pattern of Erosion in Central Part of Katsina State, Nigeria

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Abstract
This study examined the geometric characteristics and spatial distribution of erosion features in central part of Katsina State. The study area comprises of eleven local government areas of the State. The study was conducted using an integrated approach involving field measurements, Geographic Information Systems (GIS), and remote sensing techniques. Field data on erosion features were collected through direct measurement of length, width, depth, slope, and cross-sectional profiles, while Global Positioning System (GPS) was used to record their spatial locations. The results revealed that low severity (depth < 1 m) erosion features are unevenly distributed across the study area. The Moderate severity (depth 1 – 3 m) erosion were found more at the northern part of the State with pronounced hotspots in urban and peri-urban zones and along major drainage channels. Gully erosion was the dominant erosion type, with gully dimensions indicating active expansion and significant soil loss. Areas in the southern part particularly Dutsin-ma and more urbanized areas in the north, exhibited the highest erosion severity. Slope and drainage density were also found to influence erosion development despite the generally gentle terrain of the area. The study concludes that erosion in central Katsina State is driven by the combined effects of natural factors and unsustainable land-use practices. The integration of field-based measurements with GIS and remote sensing proved effective in identifying erosion-prone areas and quantifying erosion severity. The findings provide a scientific basis for targeted soil conservation, improved land-use planning, and sustainable environmental management in central Katsina State. The study therefore, recommends future studies of this type to be put in place and incorporate all erosion-related areas in individual regions for better understanding of erosion processes and that government of Katsina State should initiate regular monitoring of erosion using GIS and remote sensing techniques to track changes over time, evaluate the effectiveness of control measures, and Identify priority areas for intervention.

Keywords: *Erosion, gully erosion, GIS, River geometry, spatial analysis, Cross-section, Central Katsina.*

Introduction
Erosion is a major environmental challenge affecting land resources across the world, particularly in semi-arid regions. It refers to the process by which soil and rock materials are detached and transported from one location to another by agents such as water, wind, ice, and gravity (Lal, 2001). Soil erosion has many severe consequences for agricultural and other type of landscape. At present, it is the single most important environmental degradation problem in the developing world, especially the tropics (Ananda and Herath, 2003). United Nations (UN) Convention to Combat Land Degradation (CCD) opines that soil erosion automatically results in reduction or loss of the biological and economic productivity and complexity of terrestrial ecosystems, including soil nutrients, vegetation, other biota, and the ecological processes that operate therein (Claassen, 2004).
There are reports of accelerated erosion in sub-Saharan Africa between 1960's and 2000, and this is explained by the ongoing land use intensification. According to FAO 1978, many African countries have already lost a significant quantity of their soils to various forms of degradation. Many areas in the continent are said to be losing over 50 tons of soil per hectare per year. In Nigeria, soil erosion is one of the most serious forms of land degradation, threatening agricultural productivity, infrastructure, water resources, and human livelihoods (Adewale et al., 2018). The problem is more pronounced in the northern parts of the country, including Katsina State, where climatic conditions, fragile soils, and human activities interact to accelerate erosion processes.
Katsina State is located in the Sudan–Sahel ecological zone of northwestern Nigeria and is characterized by low and erratic rainfall, sparse vegetation cover, sandy soils, and increasing pressure from farming, grazing, and urban expansion (Olofin, 2008). These conditions make the state highly vulnerable to both wind and water erosion. Seasonal rainstorms often generate intense runoff that washes away topsoil, while prolonged dry seasons expose loose soils to wind action. As a result, large areas of farmland are degraded, reducing crop yields and worsening food insecurity (Abdulkadir et al., 2017).
The causes of erosion in Katsina State can be broadly classified into natural and human-induced factors. Natural causes include high rainfall intensity, strong winds, soil texture, slope gradient, and limited vegetation cover (Morgan, 2005). Human activities such as deforestation, overgrazing,

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bush burning, inappropriate farming practices, road construction, and unplanned urban development significantly accelerate erosion rates (Adewale et al., 2018). In rural communities, continuous cultivation without fallow, removal of crop residues, and cultivation along slopes increase the susceptibility of soils to erosion. In urban areas, poor drainage systems and indiscriminate land clearing contribute to gully formation and surface runoff problems.

Gully erosion in this study area is dynamic with a high magnitude of increase. The landward movement of gully sides along roads, farmlands and settlements are noticeable and very alarming but yet doesn't seem to be receiving adequate and proper attention by the people and organizations concerned (Ibrahim, 2013). The effects of erosion are wide-ranging and severe. It leads to loss of fertile topsoil, decline in soil nutrients, reduced agricultural productivity, and increased cost of farming (Lal, 2001). In Katsina State, erosion has resulted in the destruction of farmlands, siltation of rivers and reservoirs, damage to roads and buildings, and displacement of communities in severe cases (Abdulkadir et al., 2017).

Understanding the spatial pattern of erosion is crucial for effective environmental management and planning. Spatial analysis helps to identify erosion hotspots, assess the severity and distribution of erosion risk, and determine the relationship between erosion and factors such as land use, slope, soil type, and rainfall (Wischmeier& Smith, 1978; Morgan, 2005). In Katsina State, where resources for land management are limited, studying the spatial pattern of erosion provides a scientific basis for prioritizing areas for intervention, such as afforestation, terracing, gully control, and improved farming practices.

Furthermore, spatial pattern analysis using Geographic Information Systems (GIS) and remote sensing enables policymakers and environmental managers to monitor changes over time, evaluate the effectiveness of control measures, and support sustainable land-use planning (Adewale et al., 2018). By mapping erosion-prone zones, authorities can design targeted strategies to reduce land degradation, protect infrastructure, and enhance agricultural productivity. Therefore, a detailed study of the spatial pattern of erosion in Katsina State is essential for mitigating environmental degradation, improving livelihoods, and achieving sustainable development in the region.

The Study Area

The study area is the central part of Katsina State in the northern part of Nigeria. The area comprises of eleven local government areas which are Katsina, Batagarawa, Rimi Mani, Kurfi, Charanchi, Bindawa Ingawa, Dutsin-ma, Kankia and Kusada. Geographically, the area lies between 12.52^0 and 13.02^0 North of the Equator, and between 07.40^0 and 08.15^0 East of Greenwich (figure 1). Central part of Katsina is characterized by gently undulating plains with elevations ranging between 450 m and 550 m above sea level. The terrain is generally low-lying with occasional inselbergs and rocky outcrops. Slopes are mostly gentle, but localized steep slopes occur along stream channels and in areas affected by gully erosion (Olofin, 2008). The geology of central Katsina State is dominated by Basement Complex rocks, including granite, gneiss, and schist, with some sedimentary formations in the northern parts. These rocks weather to form sandy loam and loamy sand soils, which are generally shallow, porous, and low in organic matter (Olofin, 2008; Abubakar, 2016). The soil type of Katsina region is ferruginous tropical brown and reddish-brown soils derived from basement complex rock. The Aeolian drift materials are mostly derived from the Cretaceous sandstones lying in the area, and the parent material underlying the study area are composed of unconsolidated sands, the nature of which makes part of the area very porous and susceptible to erosion, (Scott, 1985).

The climate of the area is tropical continental, marked by two distinct seasons: the rainy season from May to October and into the dry season, from November to May. The mean annual rainfall ranges between 600 mm and 800 mm, with peak rainfall occurring in August. Rainfall is often intense and short in duration, which promotes surface runoff and soil erosion, especially in areas with sparse vegetation cover (Olofin, 2008; Adefila & Salau, 2012). Temperatures are generally high throughout the year, with mean daily temperatures ranging from 21°C to 38°C. The hottest months are March and April, while the coolest period is during the Harmattan season (December–January). High temperatures and prolonged dry periods contribute to soil desiccation, making the soil more susceptible to erosion when rains begin (Abaje et al., 2014). Most of the Katsina State according to Maxlock Group (1977) lies within the so-called Sudan savannah zone. This is where trees and short grass species (less than one meter) predominate.

The drainage system of central Katsina State is part of the Sokoto River Basin hydrological system. Major rivers and streams include River Gada, River Tagwai, River Ginzo and River Karaduwa, which are mostly seasonal. These rivers flow mainly during the rainy season and dry up or reduce significantly during the dry season (Adefila & Salau, 2012). The hydrology of the study area could be depicted from the information on rainfall characteristics of the study area given above. Runoff from arid and semi-arid catchments is often characterized by short and high-peaked hydrographs (Raghunath, 1990). The temporal parameters of the flood hydrographs (time of start, time of concentration) follow each other without delay. This is partly due to the rainfall occurring at short but high-intensity bursts and partly due to the characteristics of soil type.

Central Katsina State is one of the most densely populated zones in the state. The high population pressure has led to intensive land use, deforestation, overgrazing, and

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encroachment on marginal lands. These human activities significantly accelerate erosion processes and land degradation (Abubakar, 2016). The combination of fragile soils, climatic

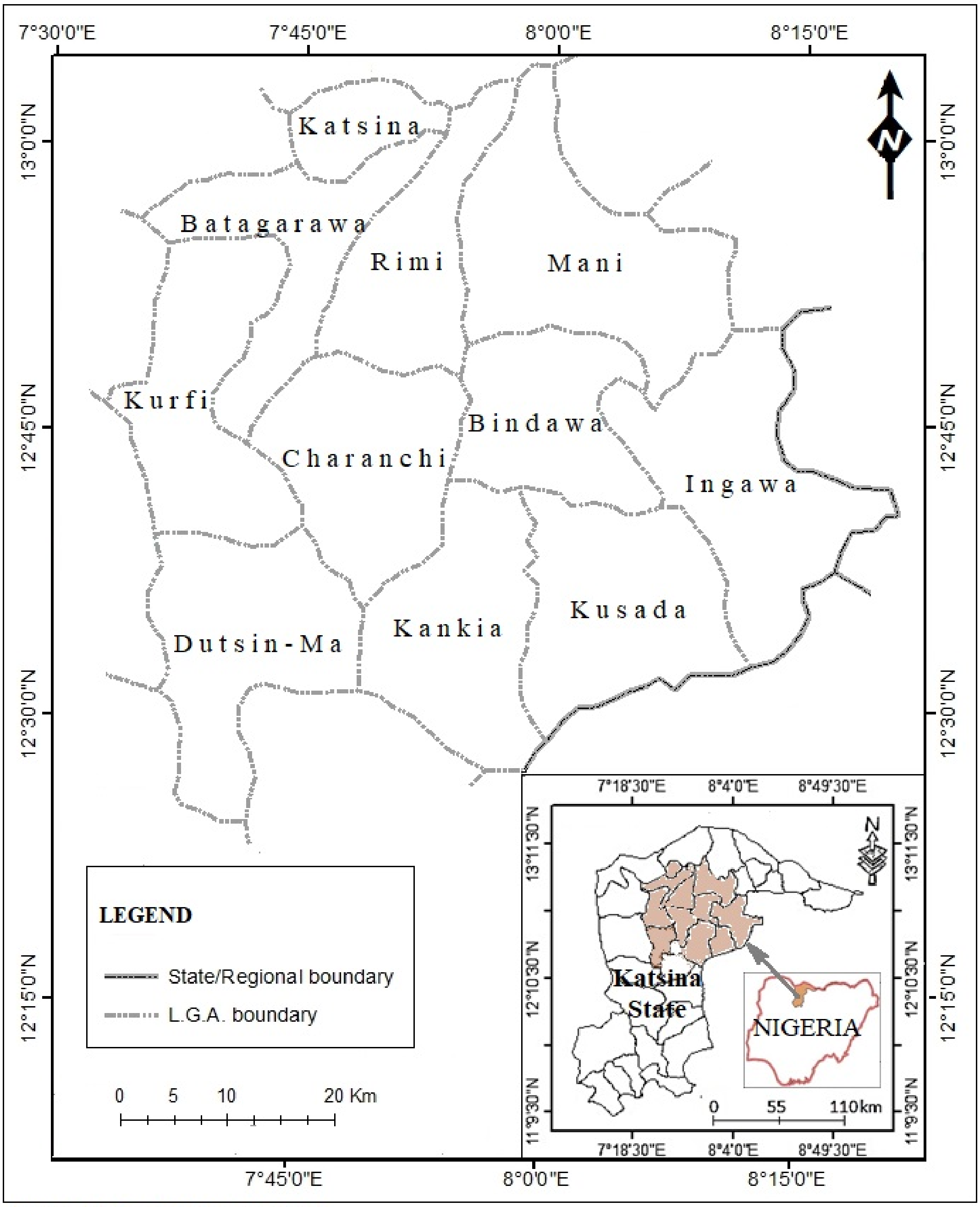

Figure 1: Map of the Study Area
Source :- National Aerounotic and Space Administration Spot Image 2026

variability, and human pressure makes central part of Katsina State highly vulnerable to erosion, necessitating detailed spatial and field-based studies for effective management and control.

Methodology

Study Design and Approach

This study adopted a field-based survey approach combined with geospatial techniques to determine the geometric characteristics of erosion features. Field measurements were carried out to obtain accurate data on the length, width, depth, slope angle, and cross-sectional shape of erosion features, while Global Positioning System (GPS) was used to record their spatial location. This method is widely used in erosion and geomorphological studies because it provides direct, reliable measurements of erosion features in their natural environment (Morgan, 2005; Goudie, 2013).

Materials used

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The materials used therefore, involved Ranging poles/arrows, Measuring tape, Staff and survey arrow, Global Positioning System (Garmin 76csx GPS model), and GIS software (Arc-GIS 9.3 version). This was also supported by the use of Google Earth Imagery and Toposheets. Smartphone was also used in the study for photographic documentation.

Sampling and Site Selection

Erosion sites were selected using purposive sampling based on severity, accessibility, and representativeness of the area. Preliminary identification of erosion-prone areas was done using satellite imagery and local knowledge. Selected sites included areas showing visible gully erosion. This approach ensures that different stages of erosion are adequately represented based on assertion of Morgan, 2005.

Method of data collection

On field exercise, the co-ordinates of the major gully sites were taken using handheld Ground Positioning System (GPS) receiver. Each erosion feature was geo-referenced using a **handheld GPS receiver**. Coordinates were recorded in degrees, minutes, and seconds (or decimal degrees). The spatial data were later transferred to a Geographic Information System (GIS) environment for mapping and spatial analysis (Adewuyi & Salami, 2018).

The exercise for collection of the geometric data of gully dimensions was conducted in the dry season of 2025 at accessible clean sections of gullies for convenience and where the edges could be easily identified. At each and every location selected, the width and depth of the valley was measured. This was done by fixing a measuring tape at one banks of the river, using a survey arrow, and stretched across the stream to the other end. The valley width of the gulley was measured by dividing the width into 10 equal intervals. At each interval a Staff was used to measure the depth of the channel and the results were recorded. Using the readings obtained from the measurements, the cross-sectional area was computed based on the technique outlined by Gregory and Wailings (1973).

Methods of Analysis

The coordinates of the erosion points taken during the fieldwork were imported into the ArcGIS 9.3 as text file, then converted to shape file to show the spatial distribution on the digital using Points dots).

Field data were organized in tables and used to compute: Mean width and depth as well as Cross-sectional area.

The cross-sectional area (A) was calculated using:

$$A = \frac{(\text{Top width} + \text{Bottom width})}{2} \times \text{Depth}$$

This method is commonly used in gully erosion studies to estimate erosion severity (Morgan, 2005; Thomas et al., 2009).

- *For erosion Severity Classification, Erosion features were classified into low, moderate, and severe categories based on depth and width measurements. For example:*

  - Low severity: **depth < 1 m**
  - Moderate severity: **depth 1–3 m**
  - Severe: **depth > 3 m**

This classification aids in prioritizing areas for intervention and is consistent with erosion risk assessment practices (Adewuyi & Salami, 2018).

Result

Geometric Characteristics of Selected Gullies in the Study Area

The basic geometric variables of the gullies were obtained using appropriate techniques in the field alongside their absolute and relative locations. Table 1 presents the results of the selected and measured erosion features and the relative locations of the selected gully sites.

Table 1: Geometric Characteristics of Selected Gullies in the Study Area

S/N	Site	Local Govt Area	Lat. Location	Long. Location	Elevation (m)	Mean Width (m)	Mean Depth (m)	Cross Section (m^2)	Gully Shape
1	S1	Mani	12°83'75"	7°88'52"	522	04.5	02.2	09.9	V- Shape
2	S2	Dutsin-ma	12°42'64"	7°51'90"	504	14.6	06.1	87.6	U- Shape
3	S3	Kankia	12°52'34"	7°83'21"	528	04.8	08.6	41.28	V- Shape
4	S4	Rimi	12°84'81"	7°72'38"	513	03.6	03.2	11.5	V- Shape
5	S5	Batagarawa	12°94'97"	7°66'75"	532	13.0	05.5	71.5	U- Shape
6	S6	Katsina	13°01'44"	7°61'68"	573	05.0	03.7	18.5	V- Shape
7	S7	Charanchi	12°65'91"	7°71'72"	635	08.8	02.8	24.6	U- Shape
8	S8	Bindawa	12°69'55"	7°85'63"	486	11.0	04.5	49.5	V- Shape
9	S9	Kurfi	12°67'26"	7°45'81"	507	08.0	04.4	36.0	V- Shape
10	S10	Ingawa	12°67'62"	8°02'85"	546	13.2	05.2	68.6	U- Shape
11	S11	Kusada	12°47′57′	8°00′31″	567	06.4	07.6	48.64	U- Shape

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Source: Author's field work 2025

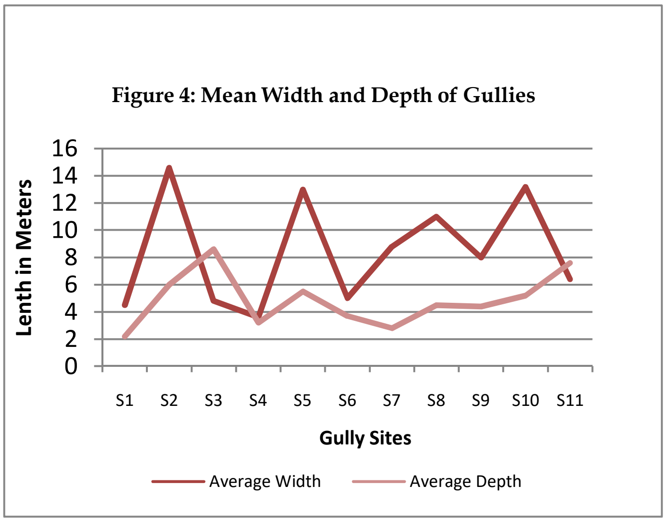
The information in the table represents selected gullies from each local government area under this study. Although a number of gullies were sampled and measured from the local government areas, but only the most spectacular ones are selected based on severity and presented in the table.

Figure 2: (S3) Moderate-Severity Gulley Erosion at Kankia

Figure 3: (S2) Severe Gulley Erosion along at Dutsin-ma along Wakaji Road

Table 1 shows that among the gullies studied in the field, site S_2 at Dutsin-ma is the largest in size and in both mean depth and width. It appears to be a spectacular u-shaped gully with sides more or less like a cliff with a depth of up to 6 metres. This is a typical severe gulley in the study area. The second largest is S_{10} which has 68.6 meters cross sectional area and yet is the widest but very narrow in proportion to its width. The smallest gully in cross sectional area is S_1 with only 4.7 meters square, a typical of moderate-severity erosion.

These characteristics of the gullies are also depicted in figure 4 below with a clear inter-relationship between gullies and intra-relationship between average depth and average width in each gully.



Spatial Distribution of Gullies and Erosion Sites

The results indicate that erosion within the study area can be classified into three distinct categories based on their dimensions: small, medium, and large erosion features. This classification highlights variations in both the spatial distribution and severity of erosion processes across the study area.

The spatial distribution of the gullies identified and studied is shown in figure 5. The map shows only the two categories of erosion, that is, the medium-severity erosion and severe erosion. This is because small erosion features are evenly distributed across all the eleven local government areas, suggesting that minor erosion processes are widespread and relatively uniform throughout the region. This widespread occurrence may be linked to common environmental factors such as rainfall intensity, soil characteristics, and land surface exposure, which affect the entire study area uniformly.

In contrast, medium-sized erosion features show a clear spatial pattern, with higher concentrations observed in the northern local government areas and a gradual decrease in frequency toward the southern parts of the study area. Large erosion features are more spatially restricted and occur only in specific locations rather than being evenly distributed. Although they are present across the study area, they are more prevalent in the southern regions than in the north. There is also concentration of the large erosion features around Katsina and Batagarawa in the northern part of the study area where urbanization is concentrated being the capital city of the state.

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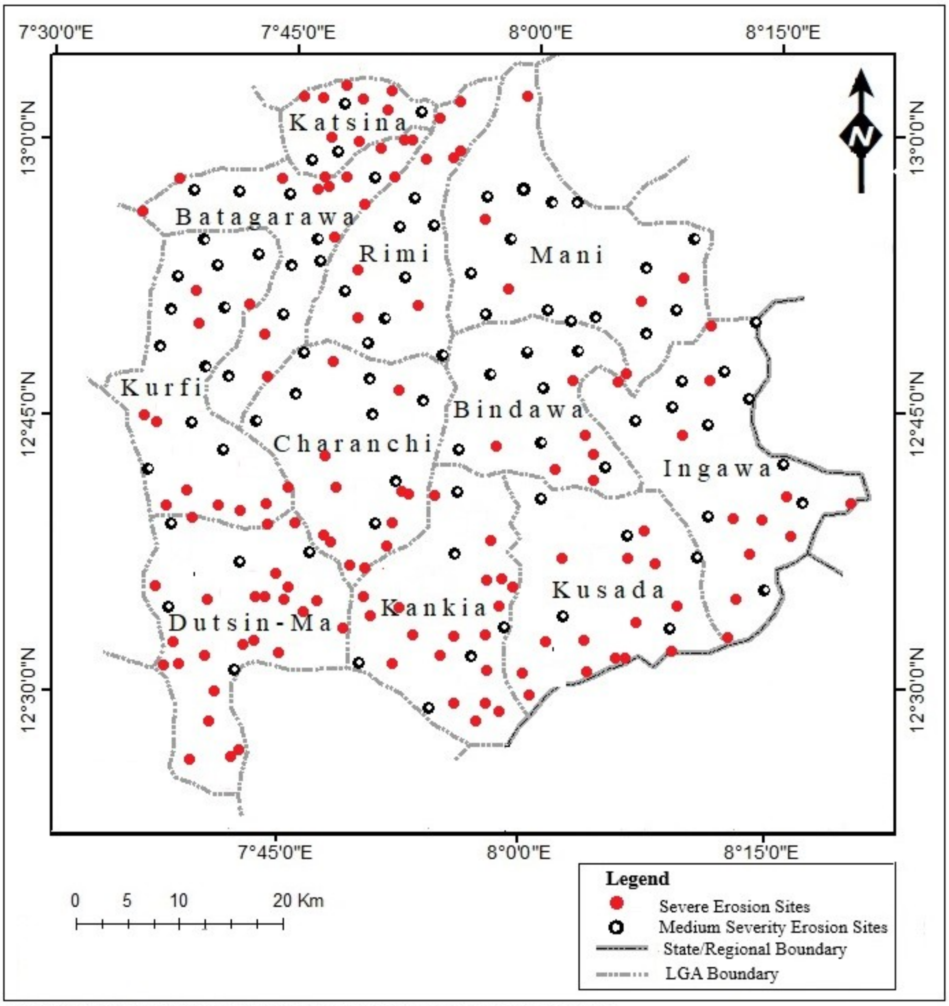

Figure 5: Distribution of Severity Erosion Sites in the Study Area
Source :- National Aerounotic and Space Administration Spot Image 2026

Conclusion

The classification of erosion features into small, medium, and large dimensions reveals clear spatial variability in erosion intensity across the study area. Such dimensional categorization is also opined by Morgan, 2005; Lal, (2015), and is widely used in erosion and geomorphological studies to distinguish between background surface erosion and more advanced stages of land degradation. The uniform distribution of small erosion features across all eleven local government areas studied suggests that low-magnitude erosional processes are pervasive throughout the region. The dominance of moderate erosion in the southern areas indicates that these locations may represent transitional zones where natural susceptibility is amplified by land-use pressure, leading to the escalation of erosion severity.

Large erosion features which are found spatially limited and occur only in specific locations aligns with existing studies that show that large gullies and severe erosion forms tend to develop where multiple predisposing factors converge, including steep terrain, concentrated surface runoff, weak soil structure, and inadequate land management practices (Boardman, 2006; Nyssen et al., 2008). The restricted distribution of large erosion sites suggests that extreme erosion is not solely controlled by regional location but is strongly dependent on site-specific conditions.

Notably, the results indicate that the most severe erosion sites across the study area are predominantly triggered by anthropogenic activities. Apparently, human-induced factors such as deforestation, poorly designed road networks/constructions, improper drainage systems, urban expansion, burrow pits/ponds and poor agricultural practices significantly accelerate erosion and defines distinct erosion hotspots, particularly along major drainage channels, road corridors, and intensively cultivated farmlands in the study area. This finding is consistent with previous research such as Montgomery, (2007); Vanmaercke, (2016), that identifies human disturbance as a primary driver of severe erosion, often exceeding the impacts of natural geomorphic processes alone.

The spatial pattern and severity of erosion observed in this study have serious implications for agricultural productivity, infrastructure stability, and sustainable development**.** Loss of fertile topsoil threatens food security, while gully expansion endangers roads, buildings, and farmlands.

Recommendations

The higher concentration of medium and large erosion features in the southern part of the study area underscores the

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need for targeted erosion control and land-use management strategies, particularly in zones exhibiting greater environmental vulnerability and anthropogenic pressure. With this therefore, this study recommend the following:

- The authorities concerned should put in place appropriate soil conservation measures and Large-scale tree planting and re-vegetation programmes, especially in erosion-prone areas.
- Farmers should be sensitized and supported to adopt **sustainable farming practices**, including crop rotation, agroforestry, conservation tillage, and maintenance of crop residues on farmlands.
- Local communities should be actively involved in erosion control programmes through environmental education and community-based initiatives**.** Public awareness campaigns will help promote responsible land use and long-term sustainability.
- The government of Katsina State should initiate regular monitoring of erosion using GIS and remote sensing techniques to track changes over time, evaluate the effectiveness of control measures, and Identify priority areas for intervention.
- Future studies of this type should be put in place and incorporate all erosion-related areas in individual regions so as to enhance better understanding of erosion processes and predict future trends under climate variability.

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