



## Geomorphological Characteristics of the Karadua River Basin Dutsin-Ma, Katsina State, Nigeria

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### ABSTRACT

*The presentation here so far analyses the geomorphology of the Karadua basin which is the study area. Three (3) major geographical regions were identified and mapped out. These are the upland plains, Lowland plains and the Riverine plains which formed the major division of the Geomorphological map of the area produced for the purpose of this work. Within these major divisions, other smaller landforms were identified and studied. They ranges from the highest hill or rock outcrop to the lowest lying borrow pit or quarry which are the common feature of the area. The geomorphology of the Karadua Basin, which is generally classified as homogenous undulating plains, was found to be a reflection of many natural as well as anthropogenic processes of the past and in current times. The common processes in operation were identified and the most spectacular features resulted were identified and studied. The common geomorphologic processes are denudation and the most common are rill and gully erosion. These were found to have wrecked many places and affected land use surfaces to the extent that over 1.6% of the total land area has been damaged by gully erosion. The rate of retreat in sampled gullied amount to as high as 36cm/yr and averaged more than 19cm/yr. The natural properties of the local soils and the tropical climate type greatly contribute to the spread of soil erosion, particularly the gully erosion, in the study area.*

### ARTICLE INFO

#### Article History

Received: November, 2024

Received in revised form: February, 2025

Accepted: March, 2025

Published online: June, 2025

### KEYWORDS

High Plains, Lowland Plains, Riverine  
Depressions, Anthropogenic, Floodplain

### INTRODUCTION

The physical landscape characteristics and related aspects of the study area were examined and presented in this chapter. The presentation begins with the Geomorphology of the area by describing the Landforms evolved in response to a combination of natural and anthropogenic processes observed in the area. It is of utmost important in this type of research to undertake such task because understanding of geomorphology and its processes is essential to the understanding of physical geography. Moreover, it is a well-known fact that the landscape was built up through tectonic uplift and volcanism after which denudation sets in by erosion and mass wasting, that produces sediment that is transported and deposited

elsewhere within the landscape or off the coast. Landscapes are also lowered by subsidence, either due to tectonics or physical changes in underlying sedimentary deposits. These processes are each influenced differently by climate, ecology, and human activity.

With this therefore, the study here extends the sphere to account on such geomorphologic processes particularly common in the environment of the study area. These are mainly erosion of different scale and dimension. Although the early stages of soil erosion, such as rill and inter-rill, are common and can be easily controlled using recommended soil conservation techniques, the formation of gullies has become more severe, posing a threat to settlements and the already limited arable land.

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## METHODOLOGY

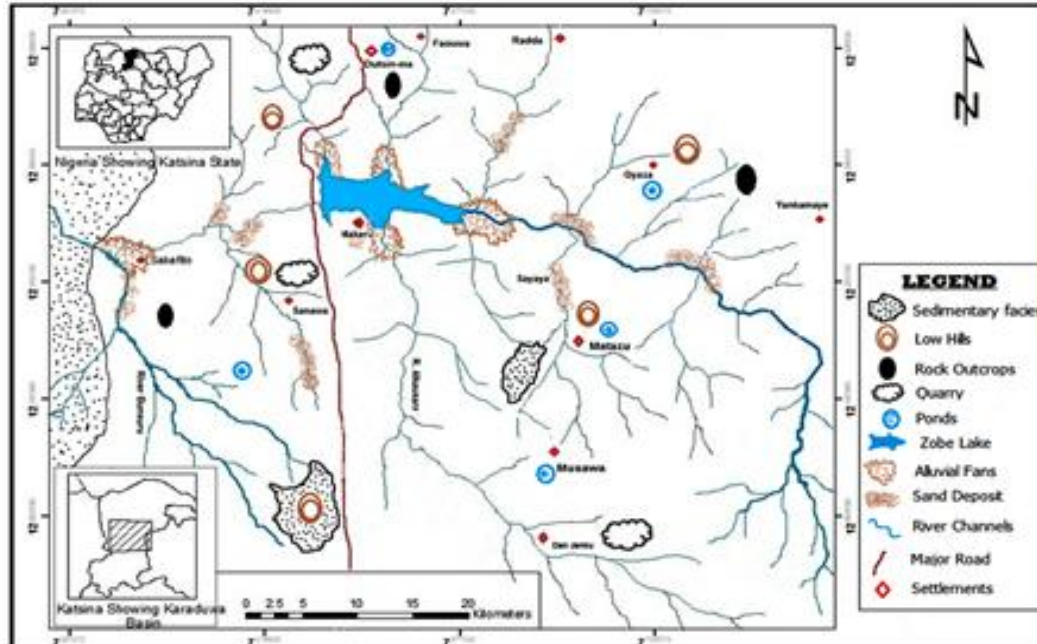
The method used in this study involved direct measurement during reconnaissance survey and use of spot imagery viewer and maps to identify points in the area. Previous record and historic information were also used in this study. Consultations were made from both government and non-governmental organization and data obtained. Put together all information used in this study was obtained from primary source.

### The Geomorphological Settings of the Area

On a macro-scale the landscape of the study area is part of the vast upland that extends across northern Nigeria, reaching from eastern Sokoto to Bauchi and Abuja. This upland reflects a stage in the geomorphic history of the area (Tugrul et.al. 1999). Morphologically the Karadua Basin under study falls under three physiographic regions, the first is the uplands or high plains, the second is the lowland plains and the third is the Riverine depressions (see Figure 1). Within these three main morphological units are found other small units that describe the geomorphology of the

area at a small-scale. These divisions of units are presented in Figure 1 below in order to have a generalized view of the geomorphological settings of the area.

Geomorphological mapping starts with identifying the basic units that make up the landscape. Understanding the nature and characteristics of these units is essential for the success of any geomorphological research. Ashmore, (2015) has broadly defined a geomorphic unit as "an individual, genetically homogeneous landform produced by a definite constructional or in the other way destruction geomorphic process." Furthermore, even though most landforms can be viewed as "genetically homogeneous" in relation to current processes, the characteristics of most landforms are partly shaped by past processes of a different nature. Wiley (2021) has highlighted that "each part of the land surface is the end product of an evolution governed by parent geological material, geomorphological processes, past and present climate, and time."



**Figure 1:** Geomorphological Map of Karadua River Basin (Study Area)

**Source:** - Spot 4 Imagery, 2023; National Geological Survey of Nigeria, 2023.

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### High Plains

From what could be seen in the map (Figure 1), the high plain or the upland areas occupied the eastern part, north-eastern and south-eastern regions of the study area. The area is vast but has a very gentle slope ranging from  $1^\circ$  to  $6^\circ$  towards the south west of the study area. These areas represent largely the upper course of the streams that form the drainage system in the catchment. Thus, the source of most of the drained water that collects in Zobe Lake.

### Lowland plains

These are the next lower step of the upland plains occupying the whole central and western region of the study area. The main difference between the two landscapes is mainly due to differences in elevation but the other geomorphologic units are almost the same. This region extends far west to the next lower level area of the sediment formation. The area of the sediment formation has not been given distinct description on the geological map of this study. It is only shown to mark the boundary of the area under consideration in this study.

### Floodplains

Floodplains are regions next to water channels that become submerged during seasonal flooding. They are primarily formed by point-bar deposition and, to a lesser extent, by sediment settling during overbank flows. The deposits on floodplains are usually poorly sorted, featuring thin layers of silt, sand, and sometimes gravel. Over time, as repeated floods lead to overbank deposition, the floodplain surface rises progressively, with the sediment transitioning from coarser materials at the base to finer particles toward the top (Antonelli and Villa, 2004).

Nanson (1986) and others proposed that the formation of floodplains is influenced by factors such as energy levels (mainly determined by channel slope) and the availability of sediment for movement. As a result, high-gradient streams typically have limited capacity for lateral accretion, like point-bar formation, and instead, floodplain development primarily occurs through vertical accretion.

In this study area, floodplains extend along the sides of stream channels, varying in scale and size. The floodplains of the major rivers are particularly wide, reaching up to 4 km in some locations, while in other areas, they narrow to several meters, as illustrated in the morphological map (Figure 2.1). It is clear to see that the wide flood plains occupied predominantly the base level of the upland plains by the sides of the larger rivers of the Karadua, Kagara and Alkausara. These are the upper course of the Karadua at the east, north and south of the mapped area. At the tip end of almost all the river, where they enter the Zobe Lake, is a region of Recent Alluvial deposits. These deposits are of fine materials and form an Alluvial fan-like shape. This recent deposit is also found at the downstream of Karadua River at the confluence where it joins River Bunsuru.

These accumulated depositional materials have created regions with very low relief intensity, especially common in the lower sections of the drainage systems. While current erosion is largely governed by climatic factors, there is growing evidence that human activities have likely accelerated the process in recent years. Especially noteworthy are the herding activities of the nomadic Fulani whose cattle are driven over areas which are already prone to sheet and rill erosion. Increase in the rural population and the number of cattle could lead to accelerated erosion in delicate areas.

The sediments forming the recent alluvium can be relatively shallow in some areas, but those near the Zobe to the east, extending down to the Uplands plains and the tip end of the Alkausara stream, are significantly deeper. The composition of this formation is primarily a mixture of gravels (less than 16%), sands (over 65%), and silts (around 25%). It is believed that groundwater fluctuations, along with soil formation processes, have modified these sediments, making the recent alluvium inseparable from the older alluvial plains beneath it.

## Hills

A hill is a landform that rises above the surrounding ground, resembling a small elevation on the Earth's surface. Natural hills are continuously formed through various geological processes, one of which is faulting. This occurs as the rocks beneath the Earth's surface constantly move and change the landscape (Thomas & Thorp, 1995). Hills can also form through surface erosion, which occurs when rock, soil, and sediment are carried away and accumulate in a new location. Erosion can both erode hills, as wind and water wear away material, and contribute to their growth by depositing material from other areas. In this way, hills are defined as elevated landforms with distinct summits, though in regions with scarp/dip topography, the term may refer to a flat area without a prominent peak. Hills are typically lower in elevation than mountains, although those formed through faulting can eventually evolve into mountains (Thomas & Thorp, 1995).

Within the upland Plains of this study area there are a number of hills. These are very low hills that rise in isolation and often occur at various distances away from one another. They as well appeared in the lowland plains but are distinguished by their sizes. At the eastern part they are a bit higher and broader. These features are either in form of earth material or with a mixture of rock fragments. The hills found in the north and eastern parts are characterized by rocky terrain.

They are steeper than those at the other parts. Though they are all small hills, but some rise up to 35 meters above the ground level and occupies an area as large as 2500 – 35,000 m<sup>2</sup>. An example is the Dutsin Kwaru located directly eastern the large Quarry few kilometres south-western the Zobe Dam. This is shown in Figure 2. Residual hills composed of weathered materials and capped by laterites occur, but they are restricted to the northern part of Karadua basin at the extreme end of the study area.



**Figure 2:** A small Dutsin-Kwaru Hill at Dutsin-ma (Source: Researcher – West of S/Gari 3km South of Zobe Dam 13/04/2023)

In general, the relief units presented here constitute a part of what Bennett and Simon (2004), and many other writers after him, have described as the high plains of Hausa land which is usually referred to as gently undulating plains of central northern Nigeria.

## Rocky Outcrops

An associated features found in this terrain are the prominent rounded rocky out crops and rocky terrain. These occurrences are dominated by the gigantic Inselberge at the center of Dutsin-ma town, from which it derives its name '*the Rock of Ma*'. Rocky outcrops form striking features in the landscape of most of the study area. They occupy almost all land use type areas, from settled area to farmlands etc. Dutsin-ma (Ma-Rock) is a large rocky conical peak (oval-like), a resistant granitic outcrop with steep sided slopes of almost 90° at the base. There are also minor occurrences of granitic rocks with a number of isolated outcrops all across the catchment. Examples are shown in Figure 3 and 4.



**Figure 3:** Showing the Gigantic Inselberge in Dutsin-ma town

**Source:** Researcher – Dutsin-ma Town Centre North of Zobe Dam 18/09/2023.





**Figure 4:** Showing an Isolated Rock outcrop in the Study Area

**Source:** Researcher – West of S/Gari 3km South of Zobe Dam 13/04/2023.

### Terrace

A terrace is a flat landform that borders a downcut or uplifted area, featuring sloping sides. Terraces are classified as either depositional (fill) or erosional (cut) based on their formation. Depositional terraces result from the accumulation and later entrenchment of alluvial materials, essentially abandoned floodplains that show vertical and lateral sediment deposition over time. Erosional terraces form through the removal of bedrock or alluvial deposits from a former valley floor. Many terraces found today date back to the Pleistocene or Holocene eras and reflect changes in river systems due to climate shifts and geomorphic processes between glacial and interglacial periods (Clayton, 1994). Various terrace types exist, named according to their formation and local conditions, including river terraces, which are common in this study area (Goes, 2001).

River terraces are the remnants of former floodplains, fans, or delta plains that have been elevated above the current river and floodplain due to channel incision. Multiple episodes of incision and deposition can lead to a series of terraces at varying heights, creating complex valley structures. A river terrace is the flat surface left after a river cuts into its previous valley floor. These terraces represent abandoned river channels and floodplains and serve as records of historical changes in river flow and sediment supply. Terraces may extend continuously along a valley or be fragmented due to tributary incision or

other geomorphic processes (Howard et al., 1968).

Terrace formation occurs when different factors cause rivers to cut deeper into their valleys, leaving their former floors elevated above the active channel. This incision can happen gradually or suddenly, driven by increased flow energy, a lower base level, or reduced sediment load, which enhances the river's erosive power. Changes in climate or base-level adjustments that steepen the channel gradient can increase discharge and Stream Energy. In the study area, river terraces occupy the space between major and minor tributaries of the Karadua drainage system, varying in size according to local gully and stream behavior. This feature is represented in the geomorphological map of this study area as the portions intersecting the channels networks (Figure 1 above).

### Gullies

A gully typically refers to a small, narrow, but relatively deep stream channel that is difficult to cross or climb, and for which terms like valley or gorge seem overly grand. It generally suggests a young erosion feature with steep sides and a steep headwall, formed in loose soil or regolith, usually by intermittent water flow from rainstorms or meltwater (Patton & Schumm, 1975). Gullies vary widely in their formation, growth processes, and environmental factors such as substrate, vegetation, and climate, leading to significant differences in their appearance and regional characteristics. Some gullies expand at their head and may be continuous or discontinuous depending on local conditions. They can grow downward from mid-hill slopes, hilltops, or valley floors (Patton & Schumm, 1975).

During headward erosion, gully heads may split, creating a dendritic pattern, and occasionally, two branches reconnect, forming a circular valley around a central hillock. A gully is larger than a rill, a smaller, shallow watercourse that can typically be crossed by a vehicle or removed by plowing. Gullies generally range from 5 to 10 meters in length, 1 to 1.5 meters wide, and similar in depth, but they can also reach hundreds of meters in length, tens of meters wide at ground

level, and up to 20 or 30 meters deep (Harvey, 1992).

Human activities, especially land misuse, are a major cause of gully formation. Deforestation, logging, burning, overgrazing, or cultivating hillsides without terracing, especially when plowed downhill, often make land vulnerable to erosion. Other human-related causes include runoff along downhill paths or tracks, re-grading of hillsides, and concentrated runoff from roads or construction sites. Soil compaction, which shifts the balance from water infiltration to runoff, or mass movement after a hillside is undercut or overloaded, can also trigger gullies. However, natural factors such as severe or prolonged storms, or changes in climate that increase annual rainfall or storm intensity, can also cause gullies. When left unchecked, gullies will eventually cease expanding, though this may only happen once they've eroded their entire upslope watershed or run out of erodible material (Harvey, 1992).

In this study area gullies are the most common landscape features found almost everywhere. Because of the nature of the climate and human activities of the area, gullies develop at different scale in farmlands, settled areas and along major and minor roads. A geometrical study of these gullies is conducted below in the 'pattern of erosion' and their distributions.

### Streams

A stream can be said to be a natural body of running water flowing on the surface of the earth. A stream flows steadily usually from natural causes finding its way to the downstream by the influence of the water current. It can also refer to surface water finding its way over land from a higher altitude to a lower altitude, all due to gravity (Church, 1992). When rain falls on the land, it either infiltrates the soil or becomes runoff, which moves downhill toward rivers and lakes, eventually reaching the sea. Most landscapes have some degree of slope, allowing water to flow downhill. Initially, this water forms small creeks, which then combine as they descend, merging into larger streams and rivers. (Church, 1992).

Streams are common features on the surface area of this study area. They designed the

entire drainage network that forms the entire Karadua drainage basin. Their distribution in the basin covers from the smallest sixth order streams of the Karadua to the largest trunk of the first order.

The stream network also includes broad valleys known as storm channels. Within these shallow storm channels are deeply cut incised channels, which can be up to 2 to 3 meters wide. **Figure 5** below and **Figure 6** show the wide channels and the incised channels respectively.



**Figure 5:** Wide storm Channel at upstream Karadua

**Source:** Researcher – East of Zobe Dam 02/04/2023.



**Figure 6:** The incised channels cut within the wide storm channels

**Source:** Researcher – 2km West - Below Zobe Dam 20/09/2012.

### Manmade Lakes and depressions

Within the major units described as Plains in this area also found lakes, quarries and burrow pits of various sizes and complexity as shown in Figure 7. The largest of these lakes is

the Zobe Lake occupying the central area of the catchment. In the northern part of the area is the Dutsinma Dam Lake. This dam is small in area to just about 6.5% of the Zobe in comparison and has created a small basin of its own in the same northern part of the region. These are the only Lakes associated with streams specifically meant to feed them.

There are also prominent features known as quarry in this area. Quarry is a type of open-pit mine from which rock or minerals are extracted. In this study area Quarries are generally used for extracting construction materials, such as dimension stone and granite. Many quarries naturally fill with water after abandonment and become lakes. Others are made or converted into landfills. Water-filled quarries can be very deep with water, often 15 meters or more. The most common in the area is the one excavated for the construction of Zobe Dam located 3.5 kilometers south of the dammed reservoir.



Figure 7: Showing Borrow Pit at Kakeru Village.  
Source: Researcher – At Makera Village East of Zobe Dam 28/05/2023

Depending on their water supply and bottom clay material, the lakes and basins may be used as water storages, Aquatic life habitats, for animal drinking and for domestic use (example in Figure 8 below). The dry lake beds are dominated by organic rich fine sediments which form cracking clay soils and calcareous in nature (see Figure 9). The cracked material varies in composition according to the nature of the lake sediments. For

example the shallow Lake at the higher plains of the east near Musawa town is mainly fine sand, whereas others, for example those at the downstream areas are fine clayed.



Figure 8: Showing a lake with water storage near Makera Village

Source: Researcher – Along S/Gari-Makera Rd. S/E of Zobe Dam 04/11/2023.



Figure 9: Dry bed's cracking clay Material in a lake near Musawa Town

Source: Researcher – Along Musawa/Mataza Rd. South of Zobe Dam 02/04/2023.

### Geomorphological Processes

The major geomorphic processes include those of Aeolian and fluvial erosion and deposition. These processes are continuous phenomena which have been in operation in the past and also in present time. It is believed that the wind drift cover and other Aeolian features were produced during an arid phase characterized by arid processes while deep chemical weathering and tremendous rill and gully erosion are believed to have occurred during a humid phase to produce the pre-weathered laterite-capped hills and



exposure of rock out crop such as the gigantic Inselberge in Dutsin-ma (Antonelli and Valle,2004).

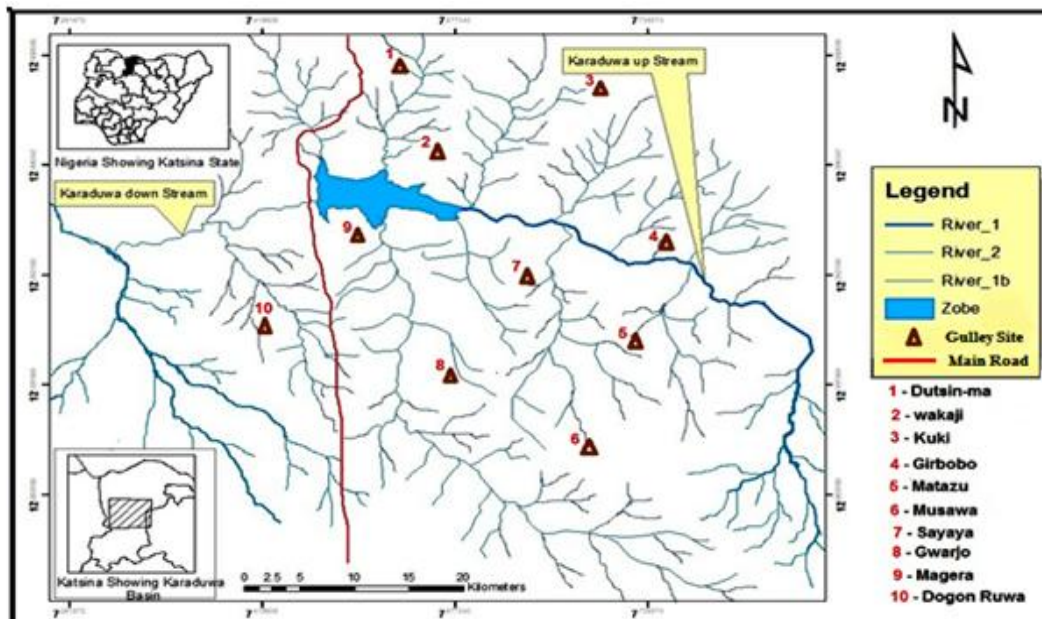
The laterite on top of the hills is said to have been formed on an already developed plain during the mid to late Tertiary period (Micheal, 2007). The formation of the laterite must have been followed by a period of fluvial processes which probably started with stream incision and lateral planation controlled by the resistant laterite cap. (Micheal, 2007). A period of valley infill probably followed that of incision and this was probably caused by another change in climate to a less humid phase or by some changes in the hydrology of the basin. The dry phase which occasioned the Aeolian activities mentioned earlier is believed to follow that of valley infilling. This will explain the presence of wind drift cover on both weathered regolith and ancient alluvium on the upland and terrace plains.

#### The Types of Erosion in the Study Area

The main fluvial processes include sheet, rill and gully erosions. They are prominent along stream banks, slopes of ridges and on

depression. Sheet wash on slopes joins together into rills which develop into gullies. Once established, the gullies elongate by head-ward erosion into the surrounding at least developing a tributary catchment to the mainstream. Rills and gullies that develop along the channels play a significant role in the expansion of certain depressions and the extension of the stream channel network.

During the field survey for this study, several gully sites were identified and examined across the study area. The spatial distribution of these gullies is presented in Figure 10 below. The basic geometric variables of the gullies were measured following the appropriate technique described in the methodology part of this work. The cross-sectional information of the various gullies were computed by taking in to consideration their latitudinal and longitudinal locations, and topographical heights (elevation). Table 1 below presents the results of the measurements and computations. Example of such gullies studied is also shown below in Figure 11.



**Figure 10:** Locations of Gully Sites Measured in the Field (Source: Sport 4 Imagery, 2008)

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**Figure 11:** Showing an Active Gully near Dutsin-ma Town (**Source:** Researcher – Along Wakaji-D/ma Rd. N/E of Zobe Dam 20/09/2023)

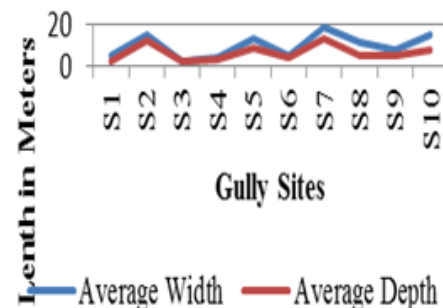
**Table 1:** Geometric Characteristics of Gullies in the Study Area

S/N	Site	Location	Lat. Location	Long. Location	Elevation (m)	Mean Width (m)	Mean Depth (m)	Cross Section (m <sup>2</sup> )	Gully Shape
1	S1	Dutsin-ma	12°26'27"	7°30'21"	522	04.5	02.2	09.9	V- Shape
2	S2	Wakaji	12°25'12"	7°31'20"	504	14.6	6.0	87.6	U- Shape
3	S3	Kuki	12°24'36"	7°37'32"	528	01.8	02.6	04.7	V- Shape
4	S4	Girbobo	12°18'19"	7°43'46"	513	03.6	03.2	11.5	V- Shape
5	S5	Matazu	12°13'41"	7°40'41"	532	13.0	05.5	71.5	U- Shape
6	S6	Musawa	12°08'09"	7°39'15"	573	05.0	03.7	18.5	V- Shape
7	S7	Sayaya	12°16'01"	7°38'43"	535	08.8	02.8	24.6	U- Shape
8	S8	Gwarjo	12°08'13"	7°33'57"	546	11.0	04.5	49.5	V- Shape
9	S9	Makera	12°20'41"	7°29'47"	507	08.0	04.4	36.0	V- Shape
10	S10	Dogon Ruwa	12°19'26"	7°24'05"	486	13.2	05.2	68.6	U- Shape

Table 1 indicates that among the gullies measured, site S2 at Wakaji is the largest in terms of overall size, as well as mean depth and width. This gully has a striking U-shape, with sides resembling cliffs and reaching a depth of up to 6 meters. Its shape and dimensions are attributed to the local soil conditions in the area. The second largest is site S10, which, with a cross-sectional width of 68.6 meters. The smallest gully, in terms of cross-sectional area, is S3, measuring just 4.7 square meters. Figure 12 further illustrates these characteristics, showing clear interrelationships between the gullies and the correlation between average depth and width within each one.

The general results from the table suggest that gullies are distributed throughout the study area, regardless of their proximity to the

dam. This implies that local factors such as climate, geology, soil conditions, vegetation cover, and human activities—rather than the dam—are the key factors influencing the extent of erosion across the study area.



**Figure 12:** Mean width and depth of gully

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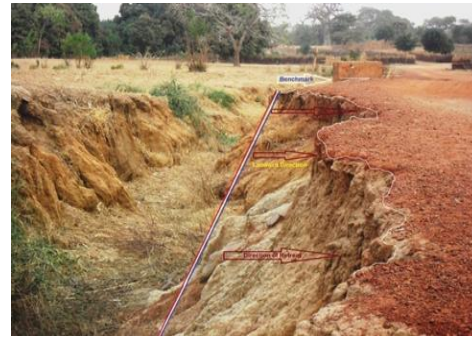
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### Rate of Retreat in Gully Erosion across the Study Area

Gully erosion in this study area is dynamic with a high magnitude of increase. The landward movement of gully sides along roads, farmland and settlements are noticeable and very alarming but yet doesn't seem to be receiving adequate and proper attention by the people concerned. This makes the situation relevant to research works in different fields including geomorphology. This is because of its usefulness to consider measuring the rate at which the devastating phenomena increases and how it relate or affect other components of the ecosystem. It has been a very difficult task to undertake this exercise in this study area because of a number of reasons which include lack of relevant materials to apply the modern methodology.

Lack of historical aerial photos and satellite imageries are the specific short comings to be precise. Nevertheless, attempt was made to conduct the measurements using the direct physical measurement alternatively. This is adopted from the work of Dyke *et al* (2005) in his ecological studies under the project of Sanctuary Integrated Monitoring Network. This method involves physically measuring the rate of bank retreat along primary and secondary channels within the depressions. Using fixed benchmarks, annual surveys are conducted to determine how much of the soft sediment bank has eroded each year and how far the bank edges have been retreated.

The measurements in this work were achieved by using specific gully sites as samples. That is gullies with marked demarcations which are constructed or made at certain known period, and currently the edge have now retreated landward leaving just a sign of the former bank. Figure 13 shows one of the sample gullies measured and also used to demonstrate the field technique for the method used. This was achieved because of the nearby culvert and embankment constructed along the channel which is used as the Benchmark.



**Figure 13:** Sampled Gully Retreating from a Benchmark

**Source:** Researcher – Along Wakaji-D/ma Rd. N/E of Zobe Dam 20/09/2023

Table 2 presents an approximate estimated rate of erosion of some gullies across the study area in centimetres per year (cm/yr). To account for local variability in retreat rates, a mean erosion rate is determined for each segment. And the names used in the table are relative locations of the gully sites being the closest nearby settlements. Despite the fact that most gully sides cut and retreat in a high rate, there are locations where erosion rate is relatively low. This is why the average results presented in the table are not significantly very high. There are locations identified as erosion hot spots with a rate of retreat up to 72cm/yr along Wakaji gully site.

**Table 2:** Rate of Retreat/erosion along Gully sides

S/N	Location	Yearly Retreat/Erosion Mean (cm/yr)	Rate of Standard Deviation
1	Wakaji	36	14
2	Dutsin-ma	11	08
3	Makera	18	10
4	Kurechi	16	06

From what is presented in the Table 2, generally erosion occurs along most of the segments considered here differ greatly over short distances ranging from 0.5 to 2 m within the 100 m strip. The highest rate of retreat was found along Wakaji with an average rate of 36 cm/yr and

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a standard deviation of 14. The lowest value was found in Dutsinma with only 11 cm/yr and a standard deviation of 08. Figures 14, 15, 16 and 17 give a sketch of the rate of retreat in the four different gully sites at 100 meters segments each. These figures present a picture of the curvatures produced by erosion in each segment in the course of their retreat. The presence of gullies suggests that terrestrial erosion is significant in this location. It is again observed that vegetation cover plays significant role in regulating rate of erosion.

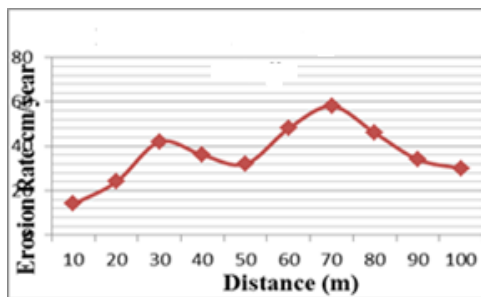


Figure 14: Erosion Rate at Wakaji

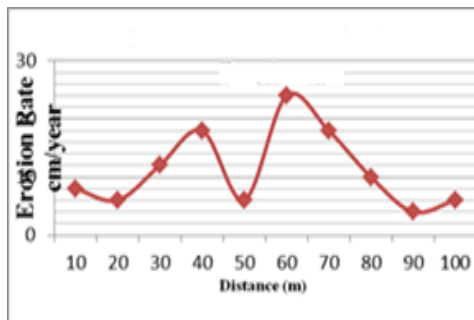


Figure 15: Erosion Rate at Dutsinma

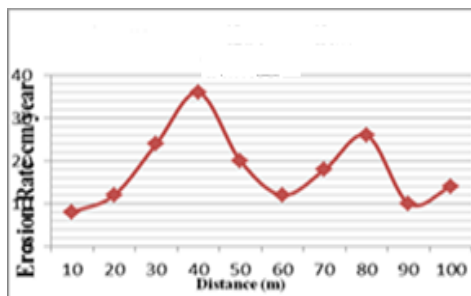


Figure 16: Erosion Rate at Makera

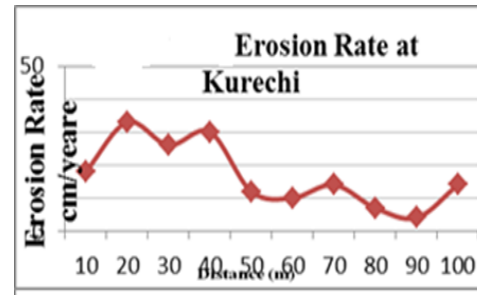


Figure 17: Erosion Rate at Kurechi

## CONCLUSION

Consequently, the activation of erosion and the process of infill are reaction to climate and/or hydrological changes in the basin which results the present marshes, ponds, mudflats, abandoned channels and meanders on the plains. In some places the plains are dissected by rills and gullies which are described differently as drainage channels, flood spill channels or flood siphoning tracks, (Ostaficzuk 1985; Bawden 1972).

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