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13th INAUGURAL LECTURE

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Gombe State University

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Esteemed Academic and Administrative Staff
Cherished Friends and Guests
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My Dear Family Members
Members of the Press
Distinguished Ladies and Gentlemen.

1.0 Preamble

It is with joy and deep sense of humility that I stand before you this afternoon to deliver the 13th Inaugural lecture of this great University. Today's event is of special significance as this is the first Inaugural Lecture from the Department of Geography and the 4th Inaugural Lecture from the Faculty of Science. Also, this Inaugural Lecture is the 2nd to be delivered under the leadership of the Acting Vice Chancellor, Professor Sani Ahmed Yauta. Ordinarily, an inaugural lecture is an occasion when a scholar who is promoted to the rank of professor, publicly accepts his appointment by making public presentation in his field of study. Consequently, such a lecture is meant to mark the inauguration of a new professor to the chair of the subject he or she professes.

Mr. Vice Chancellor Sir, the topical task we are here to address today is **The Intractable Environmental Challenge (Gully Erosion) in the Jewel State: Perspectives of a Geomorphologist** and I intend to do this from the perspective of the Chair of Fluvial Geomorphology. As a specialty, this is an area within which one has traversed for the past two decades. As an outstanding branch of Physical Geography, Geomorphology is seen as the field that describes and analyzes the geometry and spatial variability of landforms as well as their origin and evolution in the course of time. Fluvial geomorphology on the other hand is the study of the interactions between river channel forms and processes at a range of space and time scales. I am therefore immensely grateful to the Almighty God for the grace to stand before this audience today to deliver this lecture. This exercise gives me the opportunity to share with you some of my 20 years of experience in the academia.

1.1 Emergence of Department of Geography in Gombe State University (GSU) and the Journey so Far

Mr. Vice-Chancellor Sir. Geography is a scientific discipline that concerns itself with the study of complex interactions between man and his environment. Geographical studies are distinct from any other disciplines as it emphasizes on spatial aspects at a particular time period or over a time period. Geography analyses the physical, socio-cultural, economic, political landscape and the relationships between places over the period of time. It thus seeks to examine the relationship between the earth and its people through the study of place, space and environment- asking questions of where, what and also why and how?

According to Bednarz, (2011), Harris, (2012) National Research Council, (1997) cited in Mashi (2024) Geography is integral to science for several compelling reasons. Firstly, it equips individuals with the skills necessary to navigate the world, making it as fundamental to daily life as basic arithmetic. By understanding geographical concepts, students gain insights into global processes and phenomena, which contributes to a well-rounded education. Secondly, geography acts as a gateway to other disciplines. It stimulates inquiry into a variety of subjects, including technology, geology, environmental and medical sciences, anthropology, and economics, fostering a multidisciplinary approach to learning. Geographical knowledge is also very crucial for tackling contemporary issues such as environmental challenges and international relations.

The foundation of Geography was laid down by the Greek Philosophers such as Hipparchus, Eratosthenes and Plato, and Roman philosophers such as Strabo and Ptolemy. Several other scholars including Arab geographers such as Al-Kawarazimmi, Ibn-Batuta and Ibn-Khaldun, and Chinese geographers such as Pei Xiu, Fan Chendga, Shen Kuo and Xu Xiake have all contributed to its development. Geography was largely descriptive in nature throughout the Ancient period up to the medieval period. The emergence of modern Geography can be traced to the likes of Alexander Von Humboldt and Carl Ritter and several other scholars that followed them. Geography, however, did not become a university-level discipline despite its long history of existence until much later in the 19th century due to several factors concerning its relevance, nature and methodology. In fact, it was only in the early 1870s that geography first became a university discipline in Switzerland and Germany. Thereafter, other European countries, followed towards the end of the decade. In Britain and the United States, however, the establishment of Geography as an academic discipline met with stronger resistance (Holt-Jensen, 1990; Encarta Encyclopedia, 2007). In Britain, the first departments of geography were not established until the beginning of the 20th century, precisely Oxford in 1900; and Cambridge in 1908. Similarly, in the United States, although individuals were appointed to teach geography from the late 1870s, the first department was not established until 1903 in Chicago (Ofomata 2008).

Mr. Vice-Chancellor Sir, there is a concept called dualism in Geography which could be traced back to Bernhard Varenius (1622-1650). Dualism simply means the dichotomy or break up of Geography into two broad divisions namely Human Geography and Physical Geography. Physical Geography deals with the study of man's physical environment and it includes Geomorphology, Climatology, Oceanography, Biogeography, Astronomy, Meteorology, Pedology, Hydrology, Biogeography, and Geomorphology to which I belong. Human geography concerns itself with the study of man and his socio-economic activities. This branch of geography consists of several sub-divisions such as Population Geography, Demography, Political Geography, Economic Geography, Industrial Geography, Medical Geography, Agricultural Geography, Rural Geography, Urban Geography, cultural geography, transport geography, regional geography and tourism geography. The 21st century Geography have further witnessed additional two branches the interdisciplinary includes geo-physics, geochemistry, (environmental geography) and applied geography (quantification, cartography, GIS and Remote Sensing), that requires unbundling.

Geography plays a vital role in understanding and addressing complex global and local issues. Its exploration of spatial inter-dependencies provides valuable insights into economic flows, migration, environmental dynamics, and societal challenges. By integrating various scales and perspectives, geographic research enhances our understanding of complex systems and informs policy and practice. Continued interdisciplinary collaboration and innovation in tools and methodologies will further improve our ability to tackle pressing global challenges and enhance scientific understanding.

Today's environmental and societal challenges demand collective, interdisciplinary solutions that exceed the capacity of any single discipline (Mashi, 2024). Geography, with its complex and evolving nature, is well-positioned to contribute to solving global issues through its inherent flexibility. Jenkins (2007) highlighted geography's crucial role in linking various scientific fields, arguing that without it, the work of chemists, biologists, and physicists would lack cohesion.

The introduction of geography in the school curriculum in the present day Nigeria could be traced back to the period of World War II when geography became a part of Nigerian school system (Khalil, Sabiu & Muhammed, 2015). Although, the actual foundation for geography as a subject in the educational institutions of the country was laid in the year 1948, when University of Ibadan in which geography was one of the foundation discipline was established. After then, the subject has been undergoing some changes in its focus and methodology (Effeh, (ed.) 2007: 295). According to Ajayi (2001), Geography has passed through three distinct stages since its introduction into Nigerian school's curriculum and it is now entering the fourth stage in its development. These periods are:

a) The colonial period -1948-1960,

b) The indigenization era - 1960-1970,

c) The consolidation - 1971 to 1990s

d) The State Government and Private consolidation period

The colonial period 1948-1960, during this period, geography was first taught by the colonial masters with only one indigenous geography lecturer (Akin L., Mabogunje) who was employed in 1958.The main aim of geography syllabus at that time was to produce graduate geography teachers for post-primary institutions and administrators for the civil service (Alao 1978).

b. The indigenization period 1960-1970, the indigenization of geography education witnesses several changes in the Nigerian education. This include the establishment four new universities (University of Nigeria Nsukka, Obafemi Awolowo University Ife, University of Lagos, and Ahmadu Bello University Zaria) and geography department alongside. This has helped in the improvement of geography curriculum following the introduction of quantitative geography (Sada, 1982).

c. The consolidation period (1971 to 2015), the need for geography education in Nigeria was high because of the government's need to reconstruct and rehabilitate areas affected by the then civil war which lasted from 1966 to 1970. Hence, there was high need for well-trained geographers to provide the required man-power for spatial planning throughout the nation. This had led to establishment of additional seven universities (Ilorin, Jos, Calabar, Port Harcourt, Sokoto and Maiduguri) in 1976. All of them had geography as one of their foundation disciplines and the curriculum reflects modern scientific scope and orientation and degree of professionalism (Michael, 2000) and the fourth stage which I termed

d. The states' Government / Private consolidation period (1991 – date), was the involvement of states' governments and private organizations in the establishment of universities to complement the Federal universities in Nigeria due to increasingly number of applicants seeking admission into available Federal universities and demand for work force. Gombe state university falls under this period.

Mr. Vice-Chancellor Sir, the Department of Geography at Gombe state university is as old as the University itself. It was one of the foundation departments established in 2005, and began its academic activities in the 2005/2006 session with Dr Elisha Karu the pioneer Head of Chemistry Department as coordinator since at that time there was no qualified staff to head the department (only three lecturers: 1 Assistant Lecturer and 2 Graduate Assistant) from 2005 – 2007. As the most senior in the department then, the first task I encountered was curriculum development for the department. I had to seek assistance from sisters departments (ABU Zaria, BUK, MAU Yola, University of Jos and Maiduguri).

Later in 2007 professor J K Nyangaji became the first head of the department followed by Professor U. M Maryah from university of Maiduguri in 2008, Professor A.C Eziashi (University of Jos) took over from professor UM Maryah in 2009, all of them were employed on sabbatical. Dr M. Gumnior a German citizen took over from Professor A.C Eziashi in 2010 as head of department. Dr Yakubu Dan (May his soul rest in peace) took over from Dr M Gumnior in 2012- 2017. Dr Lazarus Abore Mbaya took over from Dr Yakubu Dan from 2017 – 2023 and Dr Yusuf U Ahmad took over the headship from Professor Lazarus Abore Mbaya in February, 2023 to date. Like the first and second generation universities in Nigeria where teaching staff were dominated by expatriate, Geography department at Gombe state university was no exception since from 2007 -2012, all the Heads of the department and senior lecturers were either on sabbatical, expatriate or visiting staff. These academic giants, worked very hard in building and putting the department on a very high academic pedestal. They brought into the department the culture of hard work, discipline, and collegiality and have distinguished themselves locally, internationally and made the department proud. Presently, the department have grown tremendously both in quantity and quality haven rose from three in 2005 to twenty-eight academic staff today, with over 70% of them completed their PhD. Because of improved quality of academic staff and equipped laboratories (GIS/RS, Cartography, Earth Science and Meteorological station) the department in 2019 mounted four post graduate programmes namely: PhD Geography, M.Sc Geography, Master of Environmental Management and Postgraduate Diploma in

Environmental Management. The department has produced over 500 undergraduates and 76 postgraduates over the last 20 years. The pioneer Ph.D. graduate produced by Department is Dr Danladi Aliyu whom I supervised. There are still several M. Sc. and Ph.D students in the department that are undergoing academic surgery, and it is my wish that they will come out alive.

The department hosted the 1st North-East zonal conference of Association of Nigeria Geographers (ANGs) with the theme Climate Change, Land Degradation and Security: A Geographical Perspective (Monday 25th – Thursday 28th September, 2023), where over 105 participants presented papers during the conference. The Department through international collaboration form the Youth Mapper where students are being trained in Web mapping and other mapping techniques that have improve their skills in GIS and consequently empowering them.

Mr Vice Chancellor sir, the students of Geography Department are not left out in extracurricular activities more especially football, as they won the vice chancellor's cup consecutively three times in addition to several others.

2.0 Concept of Environment, Environmental Challenge and Soil Erosion

The term ***"Environment***" refers to the physical surroundings of man, of which he is part, and on which he depends for his activities, like physiological functioning, production, and consumption. His physical environment stretches from air, water and land to natural resources like metals, energy carriers, soil, and plants, animals and ecosystems. According to the Encyclopedia Britannica (1994) Environment is the complex of physical, chemical and biotic factors that act upon an organism or an ecological community and ultimately determine its form and survival.

Environment can be seen as all physical, non-physical, external, living and non-living situations surrounding living organism that determine its existence, growth, development and survival at a particular time. So in reference to man, the environment has two broad components viz. physical or natural environment and social environment of human race which is a by-product of economic, social, and political interactions (Wikipedia, 2017). The environment thus provides the life support system for human existence and survival by supplying his needs for air, water, food, place of abode, raw materials, sink for the wastes he generates and indeed, his basic requirements for civilization and technological development. It also encompasses constantly interacting sets of physical elements and non-physical, living and non-living such as social, cultural, religious, political, economic systems, which determine the characteristic features, growth and sustainability of both the component elements of the environment and the environment itself (Muoghalu, 2004). Hence, sustainability in this context relates to the ability of the ecological, economic and socio-cultural systems in a manner that does not limit the possibility of meeting the present and future needs of the various components and aspects of the environment

Environmental challenges on the other hand, refers to the existence of crises in the environment in such a way that it can cause damage to man or his environment. In essence, they are occurrences that are dangerous or potentially harmful to man and his environment (Wright and Boorse, 2011; Mahatma, 2009; Enger; and Mary, 1995). Mary (1995) described an environmental challenge as any crisis event that surpasses the ability of an individual, community, or society to control or survive its consequences. Petters (1995) defined an environmental challenge as any form of harm, danger, peril or any risk of loss in the environment. He described it further as any situation in nature or in the environment which is destructive or probably detrimental to man or any other component of the environment. It results from the deterioration of environmental quality. Environmental challenge also refers to the existence of crises in the environment in such a way that it can cause damage or harm to man and his environment (air, water, soil, plant, animals, and all other living and non-living element of the planet of earth). Environmental challenge is the state in which the order and law of the ecosystem are collapse as the ecological function it originally had is destroyed due to the influence of human activities. Ayuba (2015) stated that environmental problem arise from conflict between nature and human actions through environmental insult (what we do to the environment); environmental response (how the environment reacts or responds to what we do) and environmental cost (the price we pay for our actions or inactions).

Environmental challenges may be broadly grouped into major and minor types depending upon their potential to cause damage to human life and property (Joseph, 2009:1). Also, environmental challenges are classified under the broad titles of natural and artificial, based mainly on their mode of occurrence. Natural events occur suddenly and swiftly and consequently cause severe damage to the society and surrounding (Santra, 2011:560). Artificial challenges are influenced or induced by man. They have some elements of human error, negligence and or intent. The earth as an ecosystem, has a threshold or terminal borderline within which it can effectively absorb or withstand the impacts or effects resulting from circumstances within and without it, if dangerous deterioration and overstrain is to be avoided (Uche, 1995:9).

Environmental challenges in Nigeria are not restricted to any particular sector of the country. Like the harmattan, wildfire, it acts across all regions of the country-rural and urban (Okosodo and Omonzejie, 2004:33). The different ecological zones of Nigeria are associated with peculiar human and economic practices and their attendant ecological and environmental problems (Okosodo and Omonzejie, 2004:34).

The most common environmental challenges in the country are desertification, landslides, flood, and soil erosion. These problems are distributed across the country based mainly on the prevailing geological, vegetal, hydrological or climatic condition. For instance desert encroachment is a major problem in the Sahel vegetation region of Nigeria. Jewel state on the other hand for the purpose of this lecture refers to a lovely and vibrant place that symbolizes preciousness, beauty and rarity. However, the Jewel state is facing numerous environmental challenges such as soil erosion, desertification, drought, climate change, and floods that is threatening its beauty and preciousness.

Mr Vice chancellor sir, for the purpose of this lecture I will dwell on *Soil erosion (gully erosion) an intractable environmental challenge* affecting our dear Jewel state. Taking steps to preserve the quality and quantity of our soil resources should require no justification. Our future ability to feed ourselves and live in an unpolluted environment in the Anthropocene depends on our ability to reduce the rates at which our soils are currently eroding. The current and expected unprecedented environmental changes at a global scale make this task even more urgent.

2.1 Concept of Soil Erosion

Food and Agriculture Organization of the United Nations (FAO 2017) define, soil erosion as "the accelerated removal of topsoil from the land surface through water, wind, ice or gravity and tillage". Water erosion on agricultural land occurs mainly when overland flow entrains soil particles detached by drop impact or runoff, often leading to clearly defined channels such as rills or gullies. Wind erosion occurs when dry, loose, bare soil is subjected to strong winds. Wind erosion is common in semiarid areas where strong winds can easily mobilize soil particles, especially during dry spells. This dynamic physical aeolian process includes the detachment of particles from the soil, transport for varying distances depending on site, particle and wind characteristics, and subsequent deposition in a new location, causing onsite and offsite effects. Tillage erosion is the direct down-slope movement of soil by tillage implements where particles only redistribute within a field. Although soil erosion occurs naturally under all climatic conditions, the FAO argues that it is "significantly increased and accelerated" due to "unsustainable" human activities. Soil erosion begins with detachment, which is caused by break down of aggregates by raindrop impact, sheering or drag force of water and wind. Detached particles are transported by flowing water (over-land flow) and wind, and deposited when the velocity of water or wind decreases by the effect of slope or ground cover. Saha, S.K (2004) described soil erosion as a three stage process: (1) soil detachment, (2) transport, and (3) deposition of eroded particles. Different energy source agents determine different types of erosion. There are four principal sources of energy: physical, such as wind and water, gravity, chemical reactions and anthropogenic, such as tillage. Three processes of dispersion, compaction and crusting, accelerate the natural rate of soil erosion. These processes decrease structural stability, reduce soil strength, exacerbate erodibility and accentuate susceptibility to transport by overland flow, interflow, wind or gravity.

As far as erosion under action of water is concerned, detachment and the transport of soil particles from the land by water, including runoff are two main phases (Schwab *et al.*, 1993). Detachment is the dislodging of soil particles from the soil mass primarily by rain splash and from running water. Transport of soil particles can be described as the movement of detached soil particles from the original location by rain drop splash and runoff.

Broadly, soil erosion can be classified in to two categories:

1. Geological Erosion – natural erosion
2. Accelerated Erosion – caused by mankind

Geological erosion is the type of erosion by which there is state of equilibrium of normal land eroded with its reclamation, or the rate of soil formation balances that of soil removed. Geological erosion occurs independently from human activities. It has been a main process of landscape development. While accelerated erosion is the increased rate of erosion that often arises when man alters the natural ecological system by various landuse practices. Man induced erosion occurs because of the disturbance of the soil caused by human activities. Hence fall into the subject of environmental resource management (Ibitoye *et al 2008*). Soil erosion is a disastrous form of environmental degradation. It is disastrous not only in the havoc it is capable of wreaking but also in the fact that it can go on unnoticed until it is too late for its effects to be reversed.

2.1.1 Processes and Forms of Soil Erosion

Soil Erosion involves the detachment and transportation of the broken rocks and materials from upstream to downstream or highlands to lowlands and delivery to the river system. Erosion results from energy transmitted from rainfall and wind. In most areas, raindrop splash and sheet erosion are the dominant forms of erosion (Wei et al., 2017). Although detachment and deposition processes of soil erosion occur simultaneously in an environment, the processes of detachment dominate on hill environment whereas processes of deposition dominate on valley. Fig 1 shows the schematic diagram of erosion processes from detachment to deposition. Firstly, the raindrop on hitting the soil surface detaches soil particles as splash erosion, and then accumulates as a thin layer on the surface runoff sufficient enough to initiate overland flow as sheet erosion. Then, rill erosion is developed as the flow progresses and the transport capacity of the runoff increases, the runoff starts scouring and cutting the soil leaving visible channels as it travels down the slope (Poesen et al., 2003 and Sukho 2014). Similarly, as it progresses the channels walls and heads gradually increase in sizes up to a time the walls and heads will start collapsing due to gravity to form much larger gully erosion sites. Consequently, the runoff and sediments are often discharged into fluivial systems like lakes, rivers, streams where it continues its off-site importance (Sukho 2014). Sukho (2014) give detailed types of fluvial soil erosion as follows:

i. **Splash erosion:** This represents the first stage of the erosion process. It occurs when rainwater hits the soil surface, resulting in the displacement of soil particles

   The following are some basic principles to be considered in splash erosion:

- Soil splashing is resulting from the impact of water drops directly on soil particles.
- If a raindrop strikes a land covered with a thick blanket of vegetation, the drop breaks into a spray of clean water- it then slowly finds its way into soil pores. But if it strikes bare soil, considerable splashing occurs
- The falling drops break down soil aggregates and detach soil particles and the fine materials from the soil are removed, less fertile sands and gravels remain behind.
- The principal effect of splash erosion is to detach soil and transportation of the detached soil takes place then after.
- The number and size of drops and the velocity of drops determine the impact of raindrops per unit area. Large drops may increase the sediment carrying capacity and the velocity of raindrops, on the other hand, is affected by its size, height of fall, wind velocity and air resistance.
- It has been observed that a single raindrop may splash wet soil as much as 60cm high and 150cm from the spot where the raindrop hits.
- Continuous bombardment in a rainstorm by millions of raindrops causes damage by beating the bare soil into a flowing mud.

ii. **Sheet erosion:** This form of erosion leads to the removal of soil in thin layers by rain or by flows of water on the surface of the soil. It is the most damaging form of soil erosion by water and results in the loss of topsoil, which contains the most nutrients. Sheet erosion mostly affects sloping land that has been farmed, which has resulted in little vegetation to protect it.

The following signs are indicators of sheet erosion:

- Roots are exposed
- Stones are exposed

- Soils become more of gravel
- Deposits of eroded soils at bottom slopes
- Sub soil becomes mixed with topsoil
- Crop yields fall gradually

iii. **Rill erosion:** Rills are shallow drainage lines less than 30 centimetres deep. Therefore, rill erosion occurs when surface water flows within these lines, consequently eroding the soil.

iv. **Stream Bank Erosion:** Stream erosion is the scouring of soil material from the stream bed and cutting of the stream banks by the force of running water. Stream bank erosion is often increased by the removal of vegetation, overgrazing, or tillage near the banks. Scouring is influenced by the velocity and direction of the flow, depth and width of the stream, soil texture and alignment of the stream. Rivers and streams often meander and change their course by cutting one bank and depositing sand and silt loads on the other. The damage manifolds during flush floods.

v. **Gully erosion:** Gully erosion is the erosion process whereby water concentrates in narrow channels and over short periods removes the soil. Gully erosion produces channels larger than rills. As the volume of concentrated water increases and attains more velocity on slopes, it enlarges the rills into gullies. Gully can also originate from any depression such as cattle trails, footpaths, cart tracks and indicates neglect of land over long period of time. Gullies are deep channels that are larger than rills (more than 30cm and cannot be removed by farming. Numerous definitions of gullies have been proposed in the past. A more succinct definition but an equally useful one is given by Graf (1983) who describes a gully as a V- or U-shaped trench in unconsolidated materials with a minor channel in the bottom, but not necessarily to major stream channel. Gully erosion is defined as the process whereby runoff water concentrates in narrow flow paths, displacing soil or soft rock particles, resulting in incised channels larger and deeper than rills and usually carries water only during and immediately after heavy rainstorms (Poesen *et al*., 2003). Such incised channels are called gullies and bear many local names such as dongas, sluits, vocarocas, ramps and lavakas (Huggett, 2007). Gullies are morphologically defined by steep sidewalls and stepped channel slope with actively eroding head scarp which make them different from stream channels (Al-Soufi, 2004). The words deep depressions, channels or ravines have also been used to describe gullies.

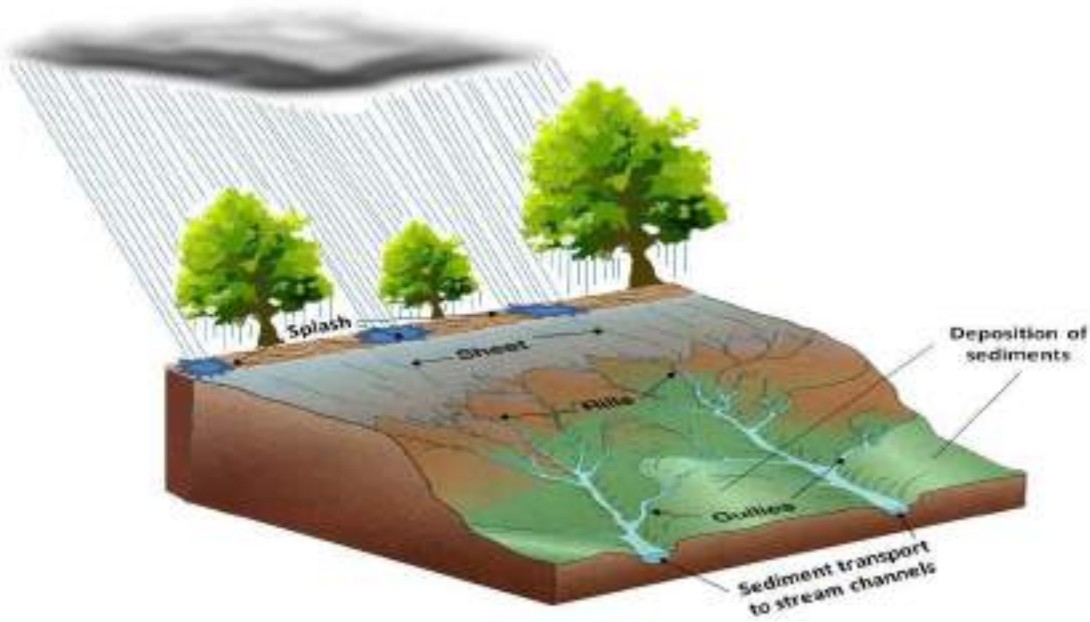


Fig. 1: The soil erosion processes. Source: Sukho (2014)

Gullies are man -induced, and are caused by the concentration of surface flows such that the amount of soil detachment and transport leads to the formation of channels that cannot be completely smoothened by normal cultivation methods. Gullies are more severe in the developing world especially when the communities affected generate a significant amount of its Gross Domestic Product (GDP) from agriculture related activities (Ibitoye *et al* 2008). Several distinguishing characteristics of gullies are noted by Whitlow, R (1989):

(1) Gullies are developed where water is concentrated and this may be a direct or indirect result of man's activities;

(2) Gullies typically form in unconsolidated deposits and deeply weathered materials;

(3) Gullies are characterized by intermittent flows that rarely, if ever, reach bankfull levels; and

(4) Gullies are generally recent features in the landscape and may exhibit phases of rapid growth. With respect to last attribute Schumm (1985) observes that gullies are associated with short-term changes in the landscape.

Gullies may be continuous or discontinuous; the latter occurs where the bed of the gully is at a lower angle slope than the overall land slope. Discontinuous gullies erode at the upslope head, but sediment themselves at the end of the discontinuity. Gullies are obvious features in a landscape, causing the undermining of buildings, roads and trees. Several conditions are conducive to gully development. They tend to form where land slopes are long and land use has resulted in loss of vegetation and exposure of the soil surface over a large area so that the land now produces more runoff. They are particularly prevalent in deep loamy to clayey materials, in unstable clays, on pediments immediately down slope of bare rock surfaces and on very steep slopes subject to seepage of water and to landslides (Mosoud *et al.,* 2008)

2.1.2 Nature and Development of Gully Erosion

Gullies may be of an ephemeral or permanent in nature. An ephemeral gully is often defined for agricultural land, implying small incised channels larger than rills, which can be refilled by normal tillage equipment, only to reform again in the same location even from a single rainfall event (Wilson *et al*., 2008). Permanent or classical gullies are large and deep incised channels that cannot be easily destroyed by ordinary farm tillage equipment (Poesen *et al*., 2003). Related to ephemeral gullies and permanent gullies is rills, which are intermittent erosion channels smaller than ephemeral gullies that are less likely to form in the same position once obliterated.

Gully erosion may be initiated in three ways:

(i). by overland flow taking advantage of minor irregularities on the surface to collect in increasingly distinct, but shallow channels called rill, usually where vegetation cover are lacking or where slope gradient is steep

(ii). by surface run off taking advantage of man-made features such as footpaths, cattle tracks, roads and associated drainage ditches, cultivation and

(iii). by the rejuvenation of the pre-existing drainage network in an area

2.1.3 Stages of Gully Development

A gully develops in two distinct stages: waterfall erosion and channel erosion along the gully bed. Waterfall erosion can be sub divided into three stages: The following stages of surface gully development are generally recognized:

Stage 1: Formation stage - In this stage the rill erosion scour of the top soil in the direction of general slope as the runoff water concentrates. This stage normally proceeds slowly where the top soil is fairly resistance to erosion.

Stage 2: Development stage – In this stage there occurs upstream movement of the gully head and enlargement of the gully in width and depth. The gully cuts to the C-horizon, and the parent material is also removed rapidly as water flows.

Stage 3: Gully advancement- when water fall from the gully head it starts carving a hollow at the bottom, the steep gully-head wall collapses. This process is repeated again and again, so that the gully head progresses backwards to the upper end of the watershed. As the gully head advances backwards and crosses lateral drainage ways caused by waterfall erosion, new gully branches develop. Branching of the gully may continue until a gully network or multiple-gully systems cover the entire watershed.

Stage 4: Healing stage – In this stage, vegetation starts growing in the gully.

Stage 5: Stabilization stage - In this stage, gully reaches a stable gradient, gully walls attain a stable slope and sufficient vegetation cover develops over the gully surface to anchor the soil and permit development of new topsoil.

2.1.4 Classification of Gully Erosion

Gullies are classified under several systems based on their different characteristics; such includes shape, size, plan form and position in landscape.

(i). **Gully classes based on size**

One of the gully classification system is based on size - depth and drainage area. It is a steep-sided channels, often with steeply sloping and actively eroding head scarp landscape usually ranging from 30cm to 30m deep, caused by the intermittent flow of water, usually during and immediately following heavy rains (Poessen *et al*., 2003). Table 1 describes small, medium and large gullies and is commonly used in manuals on erosion.

Table 1: Gully Classes Based on Size and Drainage Area

Gully Class	Gully Description	Gully Specification	Drainage Area (Ha)
G1	Small	Less than 1metres deep. Bed width not greater than 18m. Side slope varies	< 2
G2	Medium	Depth between 1- 5m, bed width greater than 18m and side slopes between 8 and 15%	2 – 20
G3	Large	>5m, side slope very steep and active branching gullies.	>20

Source: Adapted after Oparaku, (1999)

(ii). Gully classes based on shape

This system classifies gullies according to the shape of their cross sections.

(a) U-Shaped gullies are formed where both the topsoil and subsoil have the same resistance against erosion. Because the subsoil is eroded as easily as the topsoil nearly vertical walls are developed on each side of the gully.

(b) V-Shaped gullies develop where the subsoil has more resistance than topsoil against erosion, and;

(c) Trapezoidal gullies can be formed where the gully bottom is made of more resistant material than the topsoil and subsoil, leading to greater erosion rate along the banks (Desta and Adugna, 2012, Fig 2).

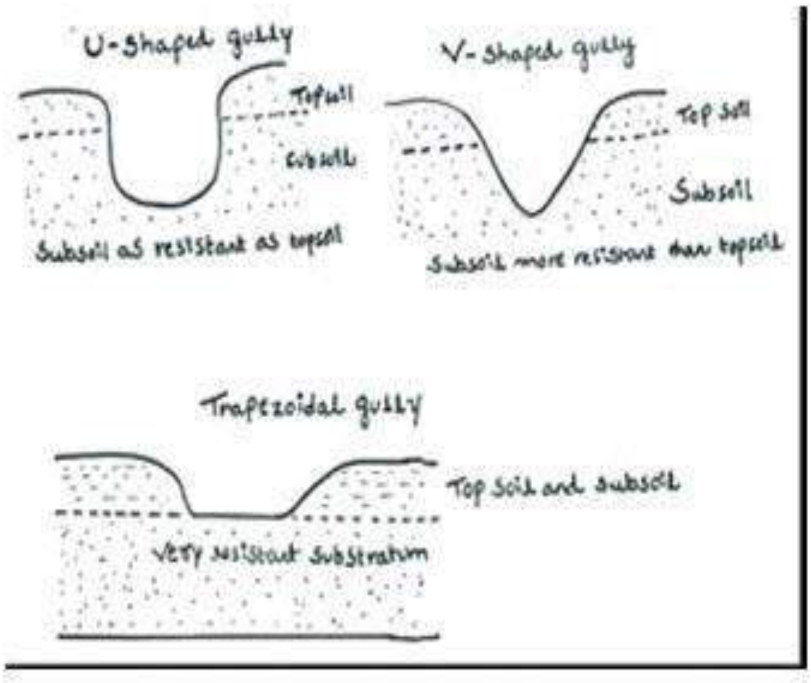


Figure 2: Illustration of the cross section of gullies (a) V-shaped,

(b) U-shaped and (c)

Trapezoidal shaped (adapted from Poesen *et al*., 2002)

iii. Gully classes based on their Plan form

Gullies are also classified and defined by their plan form. Ireland *et al*. (1939) recognized six categories of gullies based on plan form such as linear, bulbous, dendritic, trellis, parallel and compound (Fig. 3). Dendritic gullies have many branching tributaries with headward cutting that accentuates the dendritic character. Trellis gullies are characterized by tributary branches entering the main channel at approximately 90° angles. Parallel gullies are composed of two or more parallel tributaries which empty into the main gully (Ireland *et al*., 1939). Linear gullies are long and narrow, with a narrow head and few tributaries along the sides. They commonly occur along natural or man-made drainage lines. Bulbous gullies are broad and spectacular at the upper end but may be linear in the downstream part. They are often incised upland and have a semi-circular head with small tributaries or rills entering from the sides. Compound gullies are a combination of two or more of the above drainage patterns (Ireland *et al*., 1939). Generally, the classification of gullies in this manner follows drainage patterns, since gullies occur along natural drainage lines (Ehiorobo and Audu, 2012).

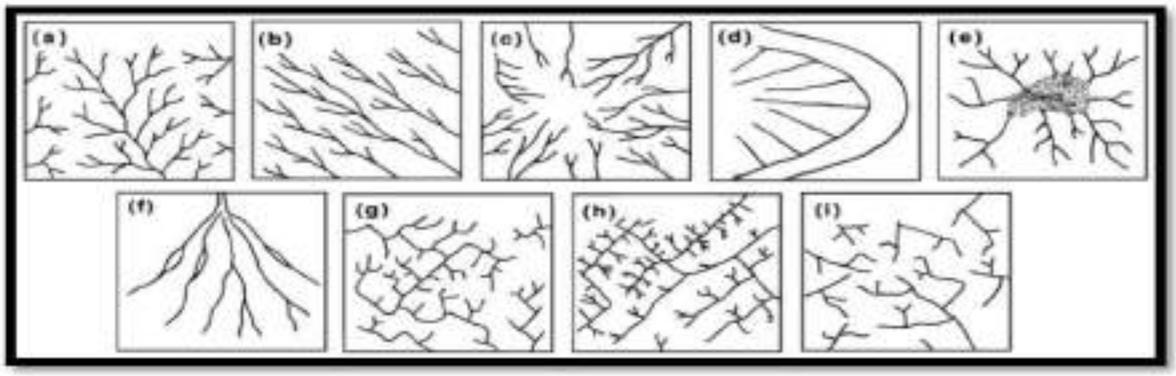


Figure 3: Typical sketches of various drainage patterns (a) dendritic, (b) parallel, (c) radial, (d) centrifugal, (e) centripetal, (f) distributary, (g) angular, (h) trellis, (i) annular **(Source:** Twidale, 2004 in Ehiorobo and Audu, 2012)

(iv) Classification Based on the Position in the Landscape

Gullies have been classified based on their position in the landscape such as valley floor, valley side and valley head (Poesen *et al*., 2003; Morgan, 2005) and each can be continuous or discontinuous (Poesen *et al*., 2002). Valley floor gullies take the form of ephemeral gullies, developed in topographic swales in a landscape where runoff concentrates (Al-Soufi, 2004; Morgan, 2005). They occur where the surrounding hillslopes are convexo-concave, and land is used for arable farming where soils are freshly tilled and loose. Valley side gullies occur approximately at right angles to the main valley line where local concentrations of surface runoff cut the hillside, subsurface pipe collapse or local mass movements create a linear depression in the landscape. Once valley side gullies are formed, they grow upslope by headward retreat and downslope by the incision of a channel floor (Morgan, 2005). The origin and development of valley head gullies and valley side gullies is the same and both reflect the expansion of a drainage network (Higgins *et al*., 1990; Poesen *et al*., 2003).

v. Gully classes based on continuation and Discontinuation

(a) Continuous gullies consist of many branch gullies. A continuous gully has a main gully channel and many mature or immature branch gullies. A gully network (gully system) is made up of many continuous gullies. A multiple-gully system may be composed of several gully networks. Valley floor, valley side or valley head gullies are continuous when they are part of a drainage network

(b) Discontinuous gullies may develop on hillsides after landslides. They are also called independent gullies. At the beginning of its development, a discontinuous gully does not have a distinct junction with the main gully or stream channel (Poesen *et al*., 2003). Flowing water in a discontinuous gully spreads over a nearly flat area. After some time, it reaches the main gully channel or stream. Independent gullies may be scattered between the branches of a continuous gully, or they may occupy a whole area without there being any continuous gullies. Discontinuous gullies decrease in depth rapidly downstream, thus their bottom gradient is much gentler than the original valley floor. They begin with the head cut associated with the knick point along the flow path (Desta and Adugna, 2012).

2.1.5 Mechanisms of Gully Erosion

Gully erosion is a complex phenomenon, often controlled by a combination of processes, making it difficult to describe its mechanism for development (Oygarden, 2003).

The main processes involved during gully initiation include overland flow, expansion due to deepening and slumping of side walls of the rills (Watson, 1990), subsurface flow or piping (Shit *et al.*, 2013) and gully head retreat at the Knick point (Poesen *et al.*, 2003). These mechanisms are discussed below.

a. Overland flow

Gully erosion is primarily caused by overland flow processes (Shit *et al.*, 2013). There are two recognized mechanisms of overland flow generation, namely Hortonian and saturation (Huggett, 2007).

Hortonian overland flow occurs when rainfall exceeds the infiltration rate and is more common on bare rock surfaces and deserts (Huggett, 2007), while, Saturation overland flow occurs during rainfall events on a saturated surface. Hortonian overland flow extends to the catchment divide, saturation overland flow is usually confined to slope concavities and hollows (Bull and Kirkby, 1997). According to Le Roux and van der Waal, (2006), erosion by saturation overland flow occurs when a persistent rain results in a saturated surface in such a way that water can no longer pass through the soil. Saturation overland flow occurs during rainfall events on a saturated surface.

b. Rill expansion

Gullies may also be established due to the deepening and slumping of a rill side walls through the shearing effect of concentrated overland flow (Pathak *et al.*, 2006). Stocking and Murnaghan (2000) define rills as shallow linear channels usually aligned perpendicular to the slope and occur in a series of parallel erosion lines. Rills initiate when runoff water is channeled into natural depressions or along lineation's caused by roads, culverts and tracks left by tillage equipment. A particular rill amongst a series of parallel rills may erode faster than others due to the localized variations in soil erodibility or slope roughness. As the principal rill develops, water flow is diverted laterally into it and in the process the neighboring rills are overtopped and destroyed. A progressive increase in runoff associated with a wet spell or poor land use practises may deepen and widen the dominant rill to the extent that it is classified as a gully.

c. Gully head retreat and deepening

Gully erosion, particularly a bank gully is initiated by Knick points or small surface natural depressions, or depressions caused by livestock tracks, furrows and ruts left by farm machineries (Svoray and Markovitch, 2009). The concentration of runoff or overland flow at the knick points or at the intersection with rivers or streams may cause waterfalls and plunge pools leading to undercutting and slumping, exposing a gully head. Subsequent to the formation of a gully head, the expansion or spread occurs rapidly through headward retreat and channel wall failures (Poesen *et al*., 2003). Gully head retreat involves through-flow from the scarp and surface flow concentrated over the head of a scarp which scours a plunge pool at the base of the head. As the gully deepens, undercutting of the scarp leads to collapse (Watson, 1990). The gully expands and deepens until soil is completely removed from the ground or until bedrock is reached (Le Roux and van der Waal, 2006; Nwilo *et al*., 2012). The failure of channel walls involves slumping due to flow saturation and undercutting of the base of the banks caused by scouring action of the water flow, leading to collapse.

c. Subsurface erosion or piping

Gullies are also caused by subsurface flow or piping. Subsurface erosion is the process whereby soils are removed below the surface. Subsurface flow takes place under localized saturation flow conditions mainly in silt-clay materials containing cracks, fissures and discontinuities which promote the through-flow (Huggett, 2007). The gully formation process occurs when water reaches and super saturates the relatively slowly permeable subsoil, and moves soil particles laterally as seepage, thereby developing subsurface channels. The movement of water through subsurface flow may be slow until the water breaks through the soil surface further downslope (Desta and Adugna, 2012).

The process is then advanced by steep hydraulic gradients in a soil of high infiltration capacity, but low intrinsic permeability, so that water does not move readily into subsurface matrix. Subsequently, water passes rapidly into the soil until reaching an impermeable layer where it moves along as subsurface erosion. Rapid flow results in headward erosion within soil and enlarges a pipe. When the ground surface subsides, pipe networks are exposed as gullies (Le Roux and van der Waal, 2006; Desta and Adugna, 2012). The progressive development of piped areas may lead to the development of non-piped badlands where surface or near surface erosion processes dominate.

3.0 Status and Trends of Soil Erosion

3.1 Global Status and Trends of Soil Erosion

.World land resources are declining day by day due to soil erosion, so much that it has become the main focus of researchers and engineers (Gessess, Bewket and Brauning, 2015). At present, soil erosion rates are higher than formation rates. This means its loss and degradation is unrecoverable in a human lifespan, as it can take up to 1,000 years to produce just 2 to 3 centimetres of soil. According to the FAO, (2017) 33 percent of the Earth's soils are already degraded, with approximately 80% of agricultural lands are facing higher rates of soil loss, and transported sediments severely affect the natural and built environment, and over 90 percent becoming degraded by 2050. It is estimated that soil erosion is affecting the wellbeing of billions of people. According to Chuenchum et al., (2020) about 2.5 to 4 billion tons of soil is annually eroded worldwide. Land use change induced by anthropogenic activities, especially the intensification of farming systems, deforestation, and overgrazing has been shown to significantly accelerate ~ 60% of the present soil erosion by altering hydrological and geomorphological processes (Garcia-Ruiz et al., 2015; Valentin et al., 2005; Yang et al., 2003). It was also estimated that the land use change would contribute to a ~5% increase in potential soil erosion by the 2090s (Yang et al., 2003).

In a 2018 assessment report for the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), more than 100 experts argued that land degradation posed a "serious danger to human well-being". Their findings revealed that at least 3.2 billion people were at risk of being negatively affected by land degradation, such as malnutrition and forced migration. This is due to 43 percent of the world's population living in regions affected by land degradation. IPBES also estimated that 4 billion people will be living in drylands by 2050, with land degradation and climate change having forced 50-700 million people to migrate.

Continental and country-specific perspectives on soil erosion by water is a common phenomenon under all climatic conditions encompassing all observed continents. Country-specific results and changes of the estimated annual average soil erosion values between 2001 and 2012 shown that South America has the highest prediction of average soil erosion rate (3.53 Mg ha−1 yr−1) in 2001, followed by Africa (3.51 Mg ha−1 yr−1) and Asia (3.47 Mg ha−1 yr−1). North America, Europe and Oceania show considerably lower predicted values, totaling 2.23, 0.92 and 0.9 Mg ha−1 yr−1, respectively (Chuenchum et al., 2020). Similarly, growing population triggers ever increasing demand for food and crop land which leads to exploitation and waste of natural resources like forest, soil and water resources. According to FAO (2015) over 40% of soil in Africa is degraded and this is particularly worrisome because the livelihood of 83% of Sub-Sahara African people depend on land resources. Moreover, by 2050, food production in Africa needs to increase by 100% to keep up with ever increasing population demands FAO (2015). All of these make soil erosion key environmental, social, and economic issues for many African countries, especially Nigeria the most populated African country.

Classified based according to the International Monetary Fund and United Nations classification, the least developed economies experienced the highest prediction of soil erosion rate in 2001 (4.81 Mg ha−1 yr−1), equal to

4.8 Pg yr^{-1} and 13.6% of the global soil erosion. The less developed economies have the second highest predicted rate of soil erosion (4.74 Mg ha^{-1} yr^{-1}) equal to 59.2% of the global soil erosion, followed by the advanced economies (1.61 Mg ha^{-1} yr^{-1}) and the transition economies (1.02 Mg ha^{-1} yr^{-1} Chuenchum et al., 2020).

Pimentel et al. (1995) asserted that accumulation of various anthropogenic activities and man induced erosion have led to abandonment and shifting of valuable lands to unproductive lands. However, among all types of soil erosion, approximately 55% of global soil loss is caused by fluvial erosion (Yang et al., 2003,). Food production on global crop has been reduced by 16% due to the menace of soil erosion and land degradation (Pimentel, 1993). This is particularly worrisome as the global current rate of soil erosion on agricultural land has been found to be leading to massive loss in land productivity per year (Pimentel, 2006) as US$8 billion is lost annually from global gross domestic product an estimated cost of soil erosion by water (EU's joint research Centre 2019).

Because of its negative impacts on environment and human society worldwide, gully erosion research has attracted increasing attention as a ubiquitous and severe issue (Vanmaercke et al., 2021). It has led to the development of some known irreversible badlands in China (Fu, Wang, Liu, Liu, Liang and Miao, 2017), Nigeria (Lazarus, (2013); Igwe, P U; Ajadike, J C; Ogbu, S O. (2023), Abdulfatai, Okunlola, Akande, Momoh and Ibrahim, 2014).

3.2 Nigeria Status and Trend of Soil Erosion

Environmental challenges such as soil erosion is generally considered the most serious threats to humanity and their impact will remain the main issues for the 21st century (Lar R 2001). According to Lazarus (2012), Food and Agriculture Organization (FAO, 2017), Ofamata (2007) and Adamu, Oku, Ishaya and Chude (2019 (Fig.4a and b) soil degradation by erosion is common in Nigeria and its severity was noted to account for 37.5% (342, 917 km^2) as low, 4.3% (39,440 $km^{2)}$ as moderate, 26.3% (240, 495 km^2) as high and 27.0% of 255, 167 km^2 as very high. Ofamata (2007) identify three major categories of susceptibility based on the underlying geology of the areas, and subdivided into seven classes.

(a) Areas of high susceptibility include the unconsolidated sediments of:

(i) Quaternary alluvium ,e.g. areas of low relief

(ii) Coastal plain sands

(iii) Weakly consolidated sediments of the tertiary to cretaceous lignite formation.

(b) Areas of moderate susceptibility include those:

(iv) Crystalline rocks of the pre-Cambrian to Paleozoic Basement Complex, and

(v) Moderately consolidated cretaceous sediments of the Niger and Benue valleys and the Cross-River plains.

(c) Areas of Low susceptibility are:

(vi) those of weakly consolidated Tertiary sediments of Sokoto Basin and Kerri-Kerri formation,

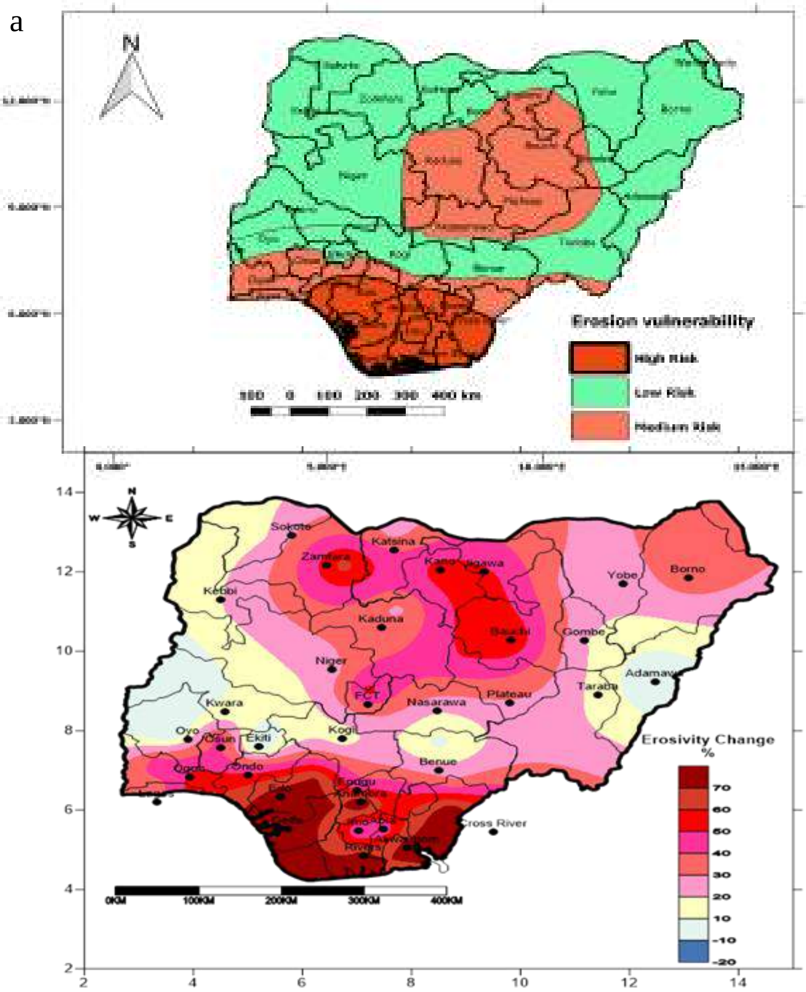
(vii) Unconsolidated Tertiary to Recent sediment for the Chad Basin.

Accelerated soil erosion manifested in form of sheet, rill and gullies has devastated a significant part of the entire country. The estimated number of gullies in the country was at 3,000 (Eshiwani, George S. 1989) in 1989 and rose to over 5,700 gullies erosion sites nationwide in 1997(Agagu, 2009). This figure has certainly increased as numerous new gullies have emerged and many of old gullies have grown rapidly to disaster levels. In terms of area extent over 6000km^2 of the land are affected by erosion and about 3400km^2 were gullies (NEWMAP, 2017). Even as far back as 1978, of the 75,488km^2 of South-eastern Nigeria, accelerated erosion affected 53,028km^2 or 71.25% of which 15,450km2 or 20.46% was afflicted by intense degree of sheet erosion while active gullies covered 121km^2 or 1.6% of the area (Ofomata,2007). In terms of the area affected and the threat to agriculture, sheet erosion is considered to be the most serious type in Nigeria. Fig. 4 a- d, further reveals that every part of Nigeria is affected by one form of soil erosion or the other and that erosion in desert frontline states (Borno, Yobe, Kaduna, Kano, Kebbi, Jigawa, Gombe, Sokoto and Zamfara) is a result of the combined effect of wind and water action, while the other parts of the country are affected mainly due to the action of running water. However, NEST (1991), observed that gully erosion is the most observable, best documented, and most frightful type in Nigeria even though, it occupies the smallest proportion of eroded land in the country (Titilola *et al*.., 2008).

The World Bank Country report on Nigeria in 2009, listed gully erosion as one of the top five major hazards threatening the Nigerian environment. The occurrence of gullies have caused severe loss of soils, particularly for agricultural productivity in many parts of Nigeria (Ananda,I and Herath, G. 2003) and resulted in economic, human and social losses in many cities (Mbaya, 2012, Egboka, C.E 2004).

Salako (2008) also reported that rainfall contributes to 70% of the erosion (gullies) in Nigeria and around the world while, NEWMAP (2019) reported 70% of gullies are caused by faulty termination of drains by construction companies. It is an ecological, environmental, economic, and humanitarian disaster resulting in land degradation.

In general, the climate and geology of Nigeria makes detachment, redistribution, and deposition a significant part of perturbation and natural landscape-forming process. But these processes of soil erosion have been significantly impacted by long-standing anthropogenic activities in the past which involved replacing ancient shifting method of cultivation with a more intensive and unsustainable cropping systems (Lal, 1993).

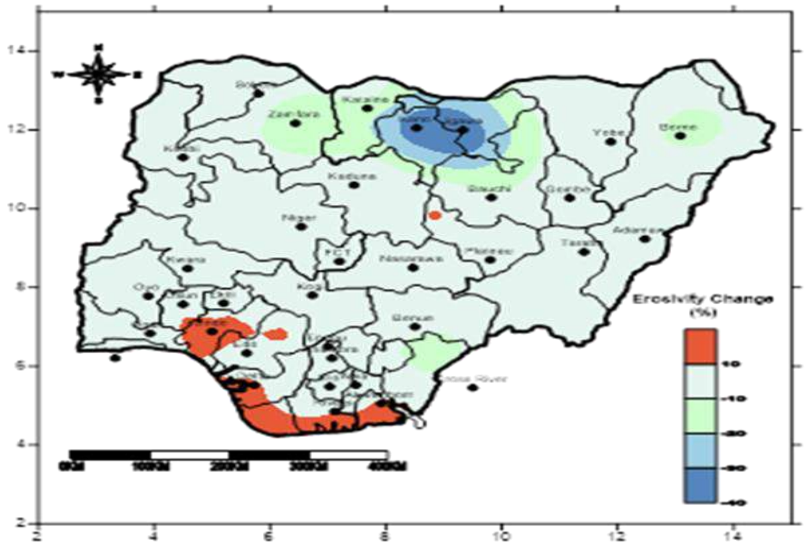


A

B

(A) -Vulnerability of Nigeria to Water (Fluvial) Erosion as at October 2019 (Water
(B) - Projected Water Erosion occurrence by 2050 using Dynamical

Downscaling Assessment of Climate in Nigeria



C

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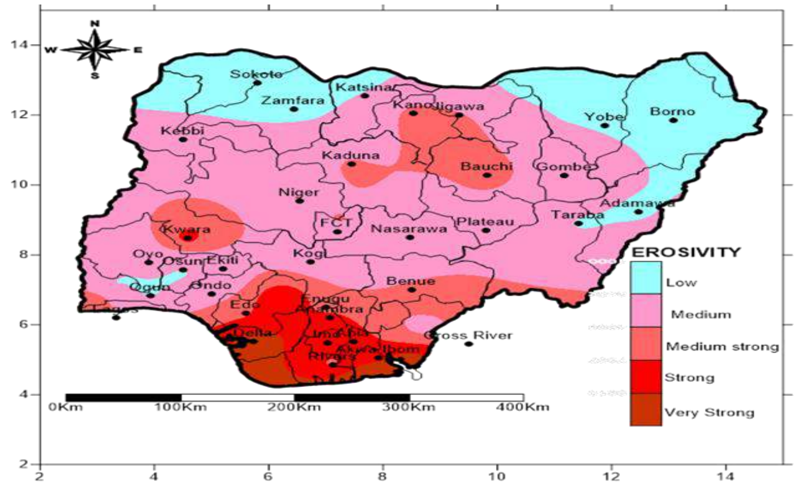

D

(C) - Aggressiveness of rainfall to cause Erosion in 1987
(D) - Aggressiveness of rainfall in Nigeria to cause erosion using 47 years data from 47 stations

Fig. 4 a - d. Vulnerability of Nigeria to Water (Fluvial) Erosion as at October 2019 (Water Erosion Hotspots in Nigeria and How Serious)
Source: Adamu, Oku, Ishaya and Chude (2019)

Adamu, Oku, Ishaya (2019) and Abdulrahan B and Yusuf D. S (2023) predicted occurrences and severity of water erosion for 2050 (Water Erosion Future Outlook (2050 Fig 4b) in Nigeria, revealed that 15% and 10%

generally higher in the Southern and Northern parts of Nigeria, respectively. Specifically they predicted 85% higher in Edo, Delta, Bayelsa, Rivers, Cross River and Akwa Ibom States; 65% higher in Abia, Ebonyi, Ondo, Ogun, Anambra, Enugu, Osun and Lagos States. While, 55% and 60% over the Federal Capital Territory, Gombe, Borno State, respectively (Fig.4b) On erosive power of rainfall to cause erosion it was high throughout the country from 1971 – 1980 using Modified Fournier Index rating (Arnoldus, 1980). Fig.4c shown that 10% increase in erosive power of rainfall was observed. Comparatively, very high erosivity was observed over Ondo, Edo, Delta, Bayelsa, Rivers, Cross River and Akwa Ibom States (90%), while 70 – 10 % were observed in Kano, Borno, Kadund, Gombe Niger, among others in Nigeria. Fig. 4d show the Aggressiveness of rainfall in Nigeria to cause erosion using 47 years data from 47 stations. It revealed that lowest erosivity was observed in Nguru in Yobe, Kastina town, Gusau in Zamfara State, while the highest was observed in Calabar, Cross River State and Eket in Akwa Ibom State. Of the 36 States and FCT, low erosivity observed in 17% of the States, moderate in 43%., moderately Strong in 18%., strong in 13% and very strong in 9% (Adamu, Oku, Ishaya and Chude, 2019)

Also using peltier model of the distribution of erosion risk in the world, Ologe (1988) revealed the distribution of erosion risk in Nigeria on the following patterns:

(i) Stations having a mean annual rainfall greater than 1778mm lie within the World zone of minimum fluvial erosion;
(ii) Stations having a mean and annual rainfall less than about 762mm and those with a rainfall between 1524mm and 1778mm fall within the zone of moderate fluvial erosion.
(iii) Stations with rainfall between about 762mm and about 1524mm lie within the zone of maximum fluvial erosion.

This includes the whole of the Nigerian savanna except the Sahel. Gombe lies within this station.

4.0 Gully Erosion in the Jewel State

4.1 Spatial Distribution of Gully Erosion in Jewel State

Ishiyaku Abdulkadir and J. Satish Kumar (2020) revealed that degraded land area in Gombe state occupied 12,952.3 sq.km representing about 72.2% of the state's land area. The magnitude of Land degradation spatially, indicating that it's getting higher and at alarming rate. This degraded areas are caused by soil erosion, desertification, deforestation and changes in landuse due to urbanization among others. All forms of soil erosion in Gombe state are prevalent however, gully erosion is the most obvious because of their remarkable effect on the landscape. According to Gombe State Development Plan 2021 – 2030 (2021) and Gombe State of Ministry of Environment (2021), there are about two hundred (200) active gullies in Gombe State affecting almost all the 11 LGA in the State. According to Jibo, A. A., Laka, S. I. and Ezra, A. (2023), Aliyu Danladi, (2024), Lazarus, (2012, 2017), Yila, et al., (2017), Mahdi Faiza Doho et al., (2024), and Samuel Osusha Loya1, Buba Wali (2023), the gully erosion sites are located in Akko LGA (47), Gombe (67) Yamaltu Deba (8), Balanga (7), Billiri (12), Kaltungo (15), Funakaye (9), Dukku (7), and Kwami (11) cutting across different landuse such as residential, educational, commercial, as well as agriculture in the state. Overall, the above scenario has made environmental sustainability a major problem facing the state

4.2 Distribution of Gully Erosion in Gombe Metropolis

Mr vice chancellor sir, this inaugural lecture dwelled more on gully erosion in Gombe metropolis the capital of Gombe state, Nigeria. Previous studies conducted in Gombe township erosion control and the ministry of environment (2003) on the yearly physical assessment of gully situation after each rainy season shows that the total length of gullies within the metropolis is about 121.5km, out of this only 5.6km in length have fully been controlled while 7.62km have been partially controlled leaving about 107.3km still uncontrolled, (SEEDS 2006). Comparing the result of the manually digitized gully and ground truth measurements in 2016, Mbaya, L.A (2017) found that most of the previous uncontrolled or partially checked gullies have increased in length to a total of 131.02 km as against the 121.50 km in 2003. This represent an increase of 9.72 km (7.42 %) over the 13 years period or about 75 metres annual increase in gully length, despite various control measures taken by previous and current government (Table 2 and Fig. 5).

On spatial distribution of gully/ streams orders, the first order, second, third, fourth and fifth orders are the tributary that contributes to the main gully channel (sixth order). Aliyu D. (2024) reported that there were 615 first order gullies representing 62%, second order has 173 gullies or 18%, third order gullies has 89 or 12%, the fourth order has a total of 51gullies (5%), the fifth order consist of 30 gullies or 2% and the sixth order number which is the main gully has 11 in number representing 1.0% respectively. The sixth, fifth and fourth orders are the main stream channel (gullies) which tends to dominate the north-western part with their head incision towards the north eastern parts of the metropolis. This is due to the effect of the topography of over 400m above sea level dominating the western parts of the study area. The first and second order Gullies /stream constituted the most spatially distributed and the most hazardous environmental problem threatening lives, infrastructural development and generally hindering the physical expansion of the town.

Table 2: Distribution of some Gully Erosion Sites in Gombe Metropolis

S/N	NAME OF GULLIES	LENGTH	LOCATION
1	Gully Erosion site from Wuro Bajoga to Barunde Bridge with fingers.	27434m	Akko L.G.A
2	Gully Erosion site from F.C.E (Tech) staff sch. To railway line.	5580m	Gombe, Gombe L.G.A
3	Gully Erosion site from Checheniya to local govt. workshop Gombe	2500m	Gombe, Gombe L.G.A
4	Gully Erosion site from Railway line to Mallam inna boreholes.	3566m	Gombe, Gombe L.G.A
5	Gully Erosion site from Barunde Bridge to Bogo Stream.	2830m	Gombe, Gombe L.G.A
6	Gully Erosion site at Dawaki Qrts. Gombe.	1150m	Gombe, Gombe L.G.A
7	Gully erosion site from mummy market to Kwanan Alheri.	3567m	Gombe, Gombe L.G.A
8	Gully erosion site at markazu science secondary.	3370m	Gombe, Gombe L.G.A
9	Shamaki/Tudunwada- -comprehensive to Railway line (phase2).	5563m	Gombe, Gombe L.G.A
10	Gully Erosion site from Orji housing estate to Shongo housing estate to CBN drain.	2275m	Gombe, Gombe State.
11	Riyad qrts. Gully erosion site	2311m	Riyad, Akko L.G.A,
12	Gully erosion site, second gate Gombe State University, Jauro Kuna Gombe.	800m	Gombe, Gombe State.
13	Gully erosion site from railway line Arawa B to WuroKesa.	2238m	Arawa B, Akko L.G.A
14	Gully erosion site from old Yola road to Buhari model primary school (phase 1).	4650m	Gombe, Gombe L.G.A
15	Gully erosion site from Buhari model primary school to Bagadaza (phase 2).	3944m	Gombe, Gombe L.G.A
16	Gully Erosion site from Railway Line to Unguwa Uku.	5621m	Gombe L.G.A.
17	Gully Erosion site from Bishop's House to Buhari Estate.	1550m	Gombe, Gombe L.G.A
18	London mai Dorawa to G.S.U	2,625	Gombe, Gombe L.G.A
19	Behind Joy Academy -Buba Shongo	1502	Gombe, Gombe L.G.A

20	Makwalla Darazawa Junction- Sani Labaran House	1005	Gombe, Gombe L.G.A
21	Mammy Market- Abubakar Umar Memorial Pri. Sch. Army Barrack	945	Gombe, Gombe L.G.A
22	FRSC Office New GRA- Tula Road, behind former quarters	3,246	Gombe, Gombe L.G.A
23	Herwagana Modibbo-Railway	2,920	Gombe, Gombe L.G.A
24	Kasuwan Shanu-Tudunwada Pri. Sch.	1,870	Gombe, Gombe L.G.A
25	Pantami-Barunde-Madaki-Doma phase II	2,250	Gombe, Gombe L.G.A
26	Nassarawo Phase A and B	957	Gombe, Gombe L.G.A
27	Wuro Bundu-Tumfure	560	Gombe, Gombe L.G.A
28	Pantami-Barunde-Madaki-Doma phase I	1090	Gombe, Gombe L.G.A
29	Herwagana Primary School	750	Gombe, Gombe L.G.A
30	G.S.U-Mallam Inna-Kagarawal	9700	Gombe, Gombe L.G.A
	Total	**131 002M**	

Source: Lazarus 2017

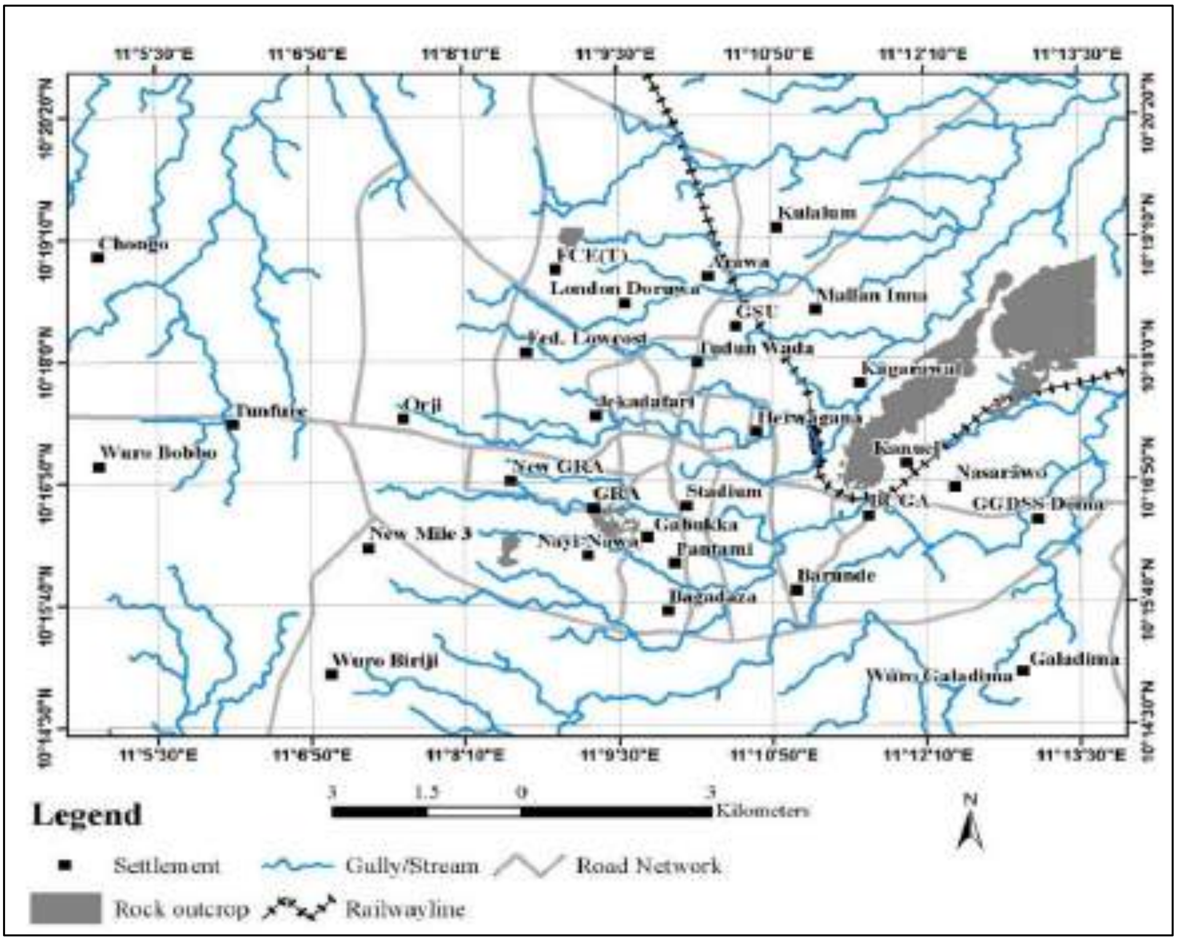

Fig. 5: Gully Distribution/ Density of Gombe and Its Environs. Source: GSU GIS laboratory Analysis, 2024

On gully erosion susceptibility in the state capital, Fig 6 revealed that 0 – 5km radius from emir's palace falls within very high susceptibility. These include Tundu wada, mallam Inna, Kagarawal, Ungwa uku, Pantami, Bagadaza, Barunde, Galadima, London Maidorowa, Arawa, Nasarawo, Gabuka, Nayi Nawa Hayin Missau and Tukulma., 6 – 10km radius are classified as high susceptibility (Bogo, Doma Tumfure and Manawashi), 11 – 15km radius are considered medium, while more than 15km radius falls within low to very low susceptibility respectively. This reveals that gullies are concentrated in the very high susceptibility class and it decreases as it gets to the low susceptibility class, Gupta et al. (2008) stated in his work that the distribution of density decreases from the high susceptibility class to low class. Thus, the severity of gully erosion in Gombe and its environs decrease as one traveled out of the town.

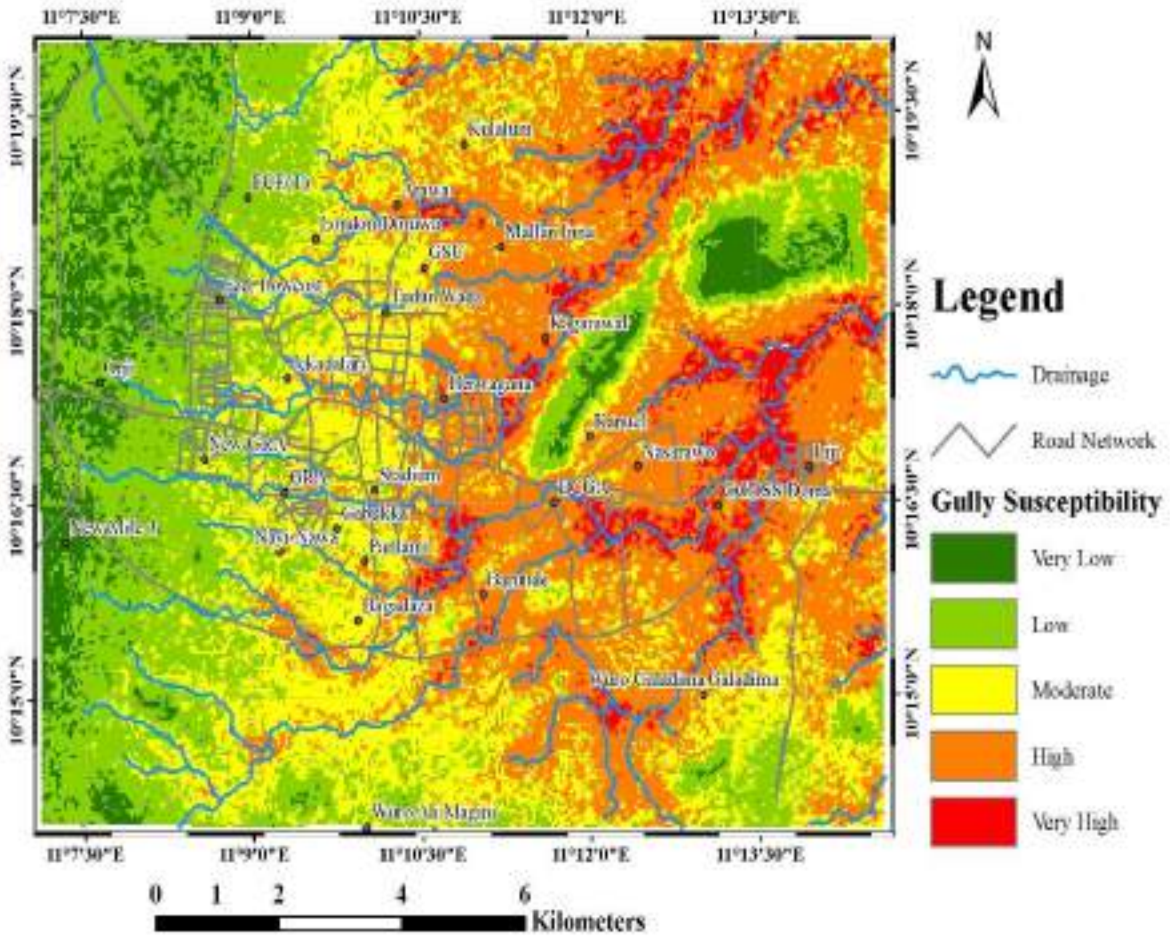

Fig. 6: Gully erosion susceptibility map of Gombe and its Environs
Source: GSU GIS Laboratory Analysis, 2024

4.3 Morphometric Properties of Active Gully Erosion Sites

Gully morphometric properties (depth, width, area extent, slope angle, cross section and length) varies in with locations and nature of soils / geology. The mean depth of gully profiles ranges from 9.0m to 10.5m for the major active gullies such as that of Nayi Nawa – Kabuka – Pantami – Barunde/Madaki, Ungwa Uku, FCE – Mallam Inna and host others. On the other hand the first, second, third, fourth and fifth orders gullies ranges between 1 – 8 metres depth.

The analysis of top and bed widths of gully profiles ranges between 22m to 52.5m with mean bed width of 26,2m for the major gullies, while the 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th} order gullies falls between 1 – 20 m respectively. The increase in bed and top widths of the sampled gullies could be attributed to the porous nature of the soil, increase in runoff due to increase in catchment area and inadequate drainages.

Slope angle for major gully sites were between 1^{0} – $5^{0}$with mean value of 3^{0}. The relatively no variations in slope angle among the sampled sites was attributed to the low topography of the study area. Similar work by Iorkua,S.A (2006), Rahab, N.O (2009) and Ibitoye, M; Eludoye, A (2010) who found severe gully on slope inclined at 3^{0}, as this depend on factors of vegetal cover, nature of soil property and rainfall intensity.

Cross sectional area is the catchment surfaces that drain runoff into gullies. The cross sectional area of the gully profiles in 1999 was 188.6 m^2 and increased to 257.7m^2 in 2009, representing 36.6%. Gully profiles with more catchment areas will have more runoff and consequently, increased in depths, bed and top widths. This could be the reason why Nayi Nawa – Kabuka – Pantami – Barunde/Madaki, Ungwa Uku, FCE – Mallam Inna has highest mean values in depth, bed and top widths and volume of soil loss than their segments.

Hayin Misau Gullies

Gabuka – Nayi Nawa gullies.

10^0 36’ 22’’N 11^0 36’ 125’’E

4.4 Factors Influencing Gully Erosion in the Jewel in the Savanna

Mr Vice chancellor sir, I’m may be tempted to ask is Gully erosion in Gombe a Natural or manmade disaster?

The process of soil erosion is control by natural and human factors as summarized by Sakho (2014) using the equation.

$$Erosion = f(C, T, V, S, H)$$

Where: C = climate, T = topography, V = vegetation, S = soil properties, H = human activities.

Gully erosion in Gombe state is a long-term historical process, which is influence by the above equation.

4.4.1 Climatic Factors

Climate is one of the most important factors of soil erosion. As rain falls, the energy of raindrops disintegrates the soil particles and the runoff produced serves as agent for transporting sediment from one location to another. Salako (2006) also reported that land degradation in many tropical regions occurs because of high rainfall erosivity and poor soil conservation practices during the rainy season. Lazarus A. Mbaya, (2011 and 2013) and Mbaya L.A (2012) in his study of 15 hydrologic years in Gombe, particularly with regards to annual rainfall revealed that of the 15years period under study, only 4 years (1996, 2001, 2004 and 2010) has total annual rainfall less than the mean annual (800mm), while the 11 years received more than the mean annual total, representing 73.3%. This amount is high in an urban environment with increasing sealing surfaces. Ologe (1987), found out those stations with mean annual rainfall of 762mm to 1524mm lies within the maximum fluvial erosion.

The studies also showed that monthly rainfall increase from the onset (June) and reached its peak in August/ September, implies that, it was during the months of July, August and September that gully growth and destructions took place. This is as a result of exceeding threshold of rainfall and soils saturation. The soils left for the long dry season are exposed to high temperature disperse and disintegrate easily on contact with rainfall – runoff impact., coupled with increased sealing surfaces.

With regards to averag daily rainfall pattern for the 15 hydrologic years has 17.82mm per rainfall. While, rainfall duration of ≤ 30min for the Jewel in the Savanna showed a mean of 34.2mm. Similar work carried by Nyanganji (1997), Salako (2007) and Capra *et al.*, (*2009*) found out that most of erosive rainfall events occurred during the first 15 and 30 minutes of rainfall. The maximum rainfall intensity of ≥ I-hr ranges between 39.6mm to 123.7mm, with mean maximum of 75mm/hr. These intense storms with mean minimum of 25mm per hour on exposed surfaces such as Gombe metropolis accelerate gullies, hence, each rainfall events in a year is erosive and therefore gully erosion will propagate and more destruction will increased.

4.4.2 Geological/Soil Factors

The mode of erosion and its condition of formation is usually controlled by the nature of the underlying geology (Ezechi and Okagbue, 1989). The geology plays direct and indirect influence on the gully formation. The lithological properties of the exposed geological formation affect the occurrence of gullies (Golestaniet al. 2014). The geology thematic map (Fig 7) represents the distribution of the gully erosion within the study area for the underlying lithology. The lithology thematic map was digitized from a geologic map produced by Nigeria Geological Survey Agency (NGSA) and was classified into four, according to the lithologic unit of the area; they include Kerri-Kerri Formation, Gombe Sandstone, Yolde Formation, and Pindiga Formation. The indirect effect is on the soil formation and the nature of soil which contribute significantly to erosion processes. High erosion risk is associated with units of loose and unconsolidated geological formations while least susceptible areas are within the consolidated lithology (Ofomata, 2007). It is documented that gully erosion is more predominant in the sedimentary terrain and perhaps in the basement/sedimentary contact areas (Abdulfatai *et al*., 2018). For instance, in an area where the local geological composition is poorly consolidated, the activity of denudation over it is usually significant. This situation is well represented over the poorly cemented sandstones of the Gombe town. High erosion risk matched with the weak, unconsolidated and highly weathered geological lithology as in the case of the lithological condition of the outcrops in Gombe (Mbaya L. A 2012).

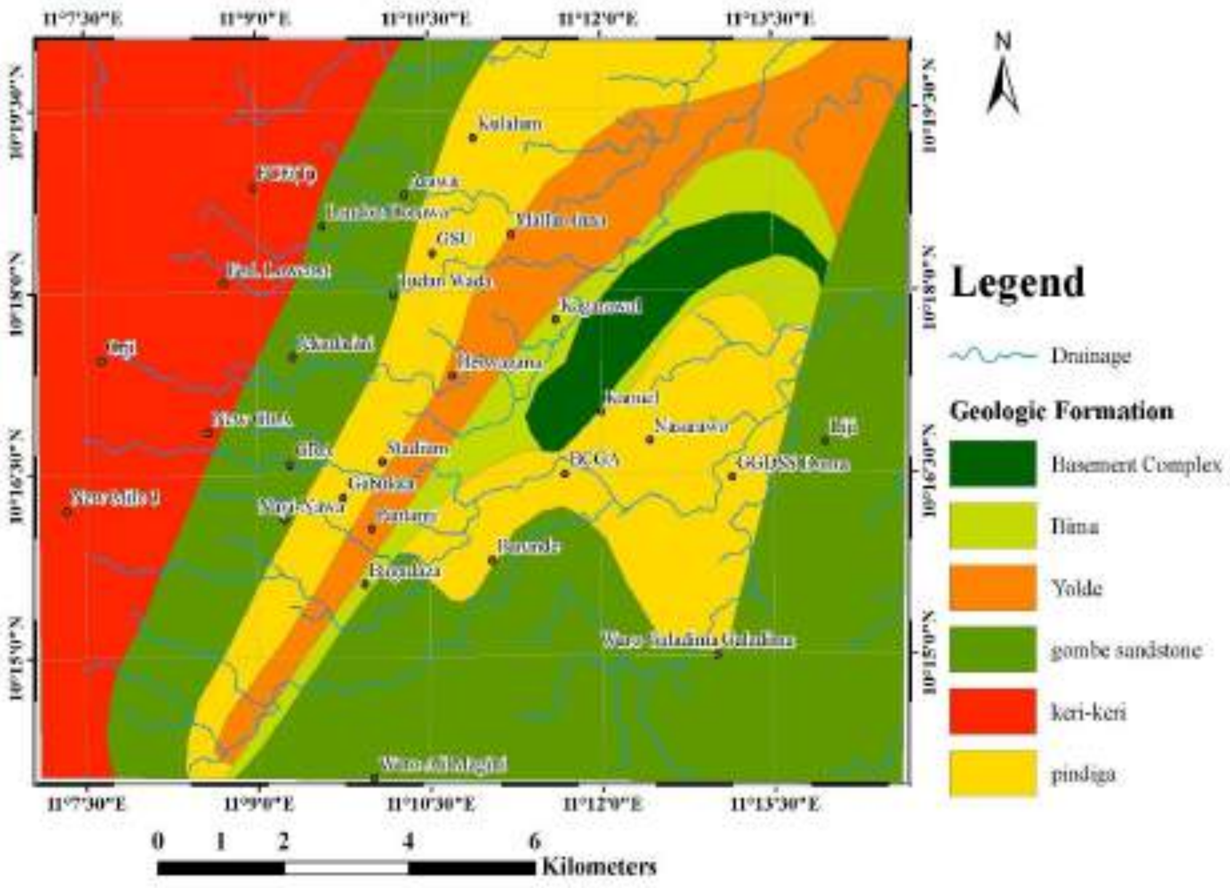

Fig. 7: The Geology of Gombe Town its Environs. Source: Ogbonnaya Igwe et al.., (2020)

Soil Shear Strength (Cohesion and Angle of Internal Friction)

According to Obiefuna *et al.,* (1999) shear strength is the maximum internal resistance of the soil to movement of its particles by sliding or slipping. The forces that resist shear are the granular friction and cohesion. The mean value of cohesion for gully sites in Gombe was 0.2 kg/cm^3 while, the mean angle of internal friction ranges between 24^0 - 26.5^0. The importance of this test is that the force due to runoff and the seepage flux are only resisted by the angle of internal friction when the value is > 40^0 (Obiefuna *et al.*, 1999).

4.4.3 Soil Physical Characteristics

Atterberg limits (liquid limit, plasticity limit and plasticity index)

The Atterberg limits (liquid limit, plasticity limit and plasticity index) of Gombe geology/soil shows the liquid limits (LL) were between 27% - 28.2 %. The plasticity limits (PL) for gully sites examined has mean of 20%, indicating medium to slightly high plasticity according to Anon, E (1979) rating. The soil samples are soft and could be crushed by fingers and hence erodible. The mean plasticity index (PI) for gully sites was 4.6%, hence explaining their contributions towards the weakness of soils and frequent slumping and sliding of the gully surfaces. Low LL and PL in these soils made the soil to be loose, non-coherent and to slide upon getting in contact with water or even to disintegrate under dry conditions (Mbaya L.A 2012). However, Rienks *et al*., (2000) have argued that the Atterberg limits do not provide means of identifying potentially dispersive soils, but did observed that the higher the values of PL, LL and PI, the higher is the resistance to disperse. This is also a function of the particle size distribution.

Soil Porosity and Permeability

Porosity is the ratio of the space taken up by pores in a soil to its total volume. The degree of porosity shows the ease to which water can percolate and disintegrate the structure of the soils. According to British standard (1990) and Canadian Soil Science Society rating, scale, porosity of sandy surface soils range from 35% to 50%, whereas finer textured soil ranges from 50%

to 60% and compact sub soils may have as little as 25%–30% total pore space. The mean porosity of soils along gully sites in Gombe ranges between 45%. Hence, soil porosity of Gombe town contains low volume of voids relative to the volume of solids. Soils of low porosity are more porous and less cohesive, this prone to erosive forces.

The permeability ratings according to O'Neal (1952) for Gombe was between $2.8x10^{-3}$ - $3.8x10^{-3}$indicated that all the layers were rapid. This shows the loose and porous nature of these soils, which explains the ease of collapse of the soils with water saturation.

Consequently, gully incision and side wall slumping will continue to increase, thereby increasing headward progression of gullies and destruction of more houses. This is the characteristic of soil porosity of the Sudan Savanna as found by Yakubu, S. (2004) and Rahab, N.O (2008) in Zaria. Similarly there is strong relationship between bulk density and porosity since the lower the bulk density, the higher the porosity, thereby creating ease for hydraulic transmission within the soils.

Bulk density

Bulk density is a property that determines the hydrological functions of the soil and determines the rate at which rainfall is absorbed. The infiltration of water into the soil is also affected by soil bulk density. Soils bulk density ranged from 1.4–2.3g/cm3 (Mbaya L.A 2012 and Flayin, Malum Japhet; Udochukwu, Martins Okechukwu, 2022). This indicates that the soils are slightly high and compacted compared to the average standards values of 1.33 g/cm3. Where the bulk density is high, infiltration reduces and increases overland flow that results into erosion.

Soil textures:

The formation of gullies in Nigeria is directly related to the underlying geology and severity of surface processes operating in the surface geology and soil cover. The erodibility process of soil is influenced by soil properties: structure, texture especially with respect to cohesiveness, organic matter, particle size distribution, structural stability, infiltration capacity, clay content and nature of the underlying substratum (Amangabara, 2012). Soil's physical properties are a major contributing factor to runoff, soil infiltration, gully occurrence, and soil resistance to erosion (Xia, D., et al. 2015).

Four soil texture types were identified in Gombe metropolis, they include sandy loam, stony, sandy clay, and sandy. There is a dominance of sand in all classes, which could be attributed to the high erodibility since sand has no cohesion. The mean soil particle size analysis along gully profiles showed 78.3 % sand, 9.0 % silt and 12.7 % clay. This means the soils are highly sandy in nature (Mbaya L.A 2012 and Flayin, Malum Japhet; Udochukwu, Martins Okechukwu, 2022). The soil is marked by deposits of iron oxide pebbles and is loose, very permeable and deficient in plant nutrients (Orazulike, 1992). Clayey soil occurs to the south and southeast of the town and around railway station. The soil is either derived from the Pindiga Formation or a clayey of Gombe Sandstone. The soils are rich in montmorillonite and possess an appreciable shrink- swell capacity and therefore are susceptible to all forms of erosion.

High proportion of sandy soils, leads to high water percolation and infiltration due to high proportion of clay content at the bottom layer. This leads to increase in the collapsing and slumping of gully walls. The sandstones and shales (Gombe Sandstone and Pindiga Formations dominated Gombe town geology and have been accelerating gully erosion through rock fracture and weathering.

Moisture Content

Moisture content mean values for Gombe gullies ranges from 9.8 g/cm^3 - 11.9 g/cm^3. This could have attributed to the long dry season despite the impact of urban waste water that flow into these gully sites and the nature the soil/geology of Gombe. This will have implication on the survival of *paniculatu / Pitadeniastrum africanum* planted to check gully erosion.

Aggregate stability is a measure of the structural stability of soils. Factors that influence aggregate stability are important in evaluating the ease with which soils erode by water, the potential of soils to crust and/ seal, and its permeability. The mean aggregate stability of gully sites has 5.5 - 6.0. This implies that the soils are highly erodible and least cohesive despite the 38.5% proportion of clay contents.

4.4.4 Soil Chemical Characteristics.

Soil pH

Arabi *et al.*, (2010) and Mbaya L.A (2012), Martins Okechukwu and Udochukwu, (2022) and Flayin et al.., (2022) found that the mean soil pH value for gully sites was 6. 32. This indicates the soils are slightly acidic (between 6 and <7). Acidity in soils affect microbial activities on organic matter which might enhance the binding of soils to resists erosivity of rain runoff effect, otherwise high acidity dissociates soils which might be prone to erodibility

.**Metallic concentrations**

The mean concentrations of phosphorus (P) from the sites was 18 mg·kg–1. Concentration tends to increase down the slope of the gully sites and falls within medium standard ratings. Potassium (K) concentrations fluctuate between 2.3 - 3.27 mg·kg–1. These concentrations are higher by standard rating with range of (0.15 to >0.30) and values of >1.2 mg·kg–1. Exchangeable K is a part of the cation exchange capacity of soils and is adsorbed on the soil colloids. For Calcium (Ca), the mean values was 8.0 mg·kg–1. All the values are classified as being «high» ratings of soils. Ca strives on soil with pH range 6 to 10 and above referred to as an alkaline metal (Martins Okechukwu Udochukwu, 2022). Magnesium (Mg) mean values for the gully sites was 2.3 mg·kg–1. All the values are above the standard values. Both Ca and Mg are secondary nutrients givers in soils, hence they bind soil particles together (Martins Okechukwu Udochukwu, 2022). If calcium and magnesium are the predominant cations in a soil, exchange complex, tends to be easily permeable, thereby leaving the soils in granular structure and therefore susceptible to erosion. Sodium (Na) mean value from the gully sites was 0.53 mg·kg–1, this was far above the standard ratings. Na readily reacts with other substances in chemicals processes in soils. High sodium concentration contributes to the weakening of soil aggregates and their dispersion under rain drop impact. The results of soil Organic Matter (OM) showed that the mean value was 0.75. All the field values are below the values of <1.50, 1.5–2.50 and >2.50 representing low, medium and high rates respectively. Earlier studies in the area indicated that top soils which inhabit most plant nutrients and organic matter are removed by erosion leaving soils with low nutrient status, poor structure and low water holding capacity (Balzerek, H., Werner, F., Jürgen, F., Klaus-martin, H., Markus, R.2003). Organic matter content in soils should be in the range of 1.9–3.0 % to bind the soil and attain productivity (Ghadiri, H., Hussein, J., Dordipour, E., Rose, and C. 2004). The mean values of CEC for the gully sites range from 6.21. This means the CEC is slightly at medium level in the soils when compared to standard ratings. Cation Exchange Capacity (CEC) is the total capacity of a soil to hold exchangeable cations. It influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification and erosion. High CEC value (>25) is a good indicator that a soil has a high clay and/or organic matter content and can hold a lot of cations. A soil with a low CEC value (<5) is an indication that a soil is sandy with little or no organic matter that cannot hold many cations (Ernest, C. 2016).

4.4.5 Soil Erodibility

Soil erodibility is a measure of soil susceptibility to detachment and transport by water, which is in turn determined by different soil properties as well as the rainfall characteristics. Aggregates stability, organic matter, clay mineralogy, and other chemical and physical soil properties are important factors, which affect soil erodibility as well as rainfall. Soil aggregate stability and erodibility indices are two main crucial factors, which contribute to soil erosion and runoff (Hammad *et al*., 2006; Pimentel, 2000). It is a measure of a soil's susceptibility to particle detachment and transport by agents of erosion. Igwe (2003) remarked that a number of factors such as the physical and the chemical properties of the soil influence erodibility.

. Factors affecting the erodibility of a soil includes: particle size of soil, land slope, vegetation, and presence of salt and colloidal matter in the soil, moisture content of soil, soil compaction, human activities, and rainfall characteristics (Suresh, 2006). The soil factor, referred to as soil erodibility in the Universal Soil Loss Equation (USLE) is defined as the ease with which soil is detached by splash during rainfall or by surface flow or both (Renard *et al*., 1997). Soil erodibility is related to the integrated effect of rainfall, runoff, and infiltration on soil loss and is commonly called soil-erodibility factor (K). Soil texture, structure, organic matter, bulk density or compactness, as well as chemical or biological characteristics of the soil influence soil-erodibility (Babalola, 1978).

The Universal Soil Loss Equation is (Wischmeir and Smith, 1965):

A = RKLSCP Equation

Where A = Soil Loss; R = Rainfall erosivity; K = Soil erodibility;
L = Slope Length factor; S = Slope steepness factor; C = Crop management factor; P = Conservation factor.

Brodie and Rosewell (2007) found out that rainfall intensity is a contributing factor to the amount of suspended particles washed from urban areas during storms. Hence, they postulated that the square of rainfall kinetic provide a measure of the rainfall kinetic energy (KE) available for wash off process.

4.4.6 Topographical Factors (Drainage buffer, slope degree, Elevation, TWI, Slope Aspect, Curvature

a. Shape and size of watershed: The shape of the watershed has strong relationship with the time of concentration and peak runoff rate. If the time of concentration is high, pick runoff rate is low. The size and shape of a drainage area have an effect on the run-off rate and amount of surface water. The larger the watershed, the greater will be the amount of run-off. As a result large watersheds have greater chances of gully erosion than small watersheds. Experiments have shown that when the velocity of runoff is doubled, the amount material of a given size that can be scratched and carried is increased about 32 times: and the size of the particle that can be transported by pushing or rolling is increased about 64 times.

The movement of eroded sediments is usually facilitated by drainage, therefore it could be said that gullies are associated with drainage. The erosive actions in the drainage channels consequently reduce the shear strength of the slope material thereby increasing their chances of failure by sliding (Ozioko, O. H, Igwe, O. (2020). Analysis of result obtained from the drainage buffer shows that the 0-500m class has the highest followed by 500m-1km, and 1km-2km incidence of gully occurrences. Thus the probability of gully occurrence decreases as the distance from drainage increases.

b. Length and gradient of the slope: There is a direct relationship between steeper and longer slope terrain and the quantity of sediment eroded. The steeper the slope, the higher will be the velocity and erosive power of the run-off. This is one of the most important factors for gully erosion. Also, if the slop length is large, the possibility of gully formation is high.Steep slope produces high velocity runoff, thereby increasing the scouring and cutting potential of flowing water. Gombe town is generally within a low-lying area (Fig 8.), however, the western parts are generally higher in elevation (643 – 536m) than the eastern parts (372m), except some isolated hills like the Gombe and Lijji. (A GPS reading taken at Yola / Bauchi junction shows 626.3m a.s.l and at the roundabout (old market) 454.8m a.s.l, representing a height difference of 171.5m through a distance of about 3km. The same GPS reading was taken around PHCN power station along Dukku road which showed 603.5m representing a difference of 148.7m with that of old market (centre of the town) through a distance of about 3km and mean slope gradient of 5^0. This is considered high gradient for unprotected surface. The slope length indicates the gravity of low infiltration and high runoff conditions.

Digital elevation model of Gombe metropolis shows five classes of slope degree 0 -2 2-4, 4-9, 9-16, 16-43 (Fig. 9). Slope angle that inclined at 3° to 50° represents a slope gradient of about 63 % of the spatial variations; causing low infiltration and high runoff conditions which weakens soil structure thereby making it vulnerable to the intensity of gully erosion and in a site causes severe gullies (Flayin, Malum Japhet; Udochukwu, Martins Okechukwu, 2022). Surface flow accumulation is common in flat areas and consequently the formation of the gully (Ghorbani Nejad et al. 2017). The relationship between slope degree and gully occurrence reveals that slope degree class 0-2 have high incidence of gully erosion than other classes.

c. The topographic wetness index (TWI) which is a secondary topographic factor within the runoff model is usually employed to determine the extent to which topography control hydrological processes. TWI estimates the possibility of water accumulating in soil due to slope and upstream catchment area (Rahmati et al. 2016). Gomez-Gutie´rrez et al. (2015), noted that TWI has to be considered in evaluating gully erosion susceptibility. The TWI map was divided into four classes (Fig.12), they include: < 7, 7.0 - 8.5, 8.5 - 10.6,>10.6 Analysis TWI of Gombe metropolis shows high class of 8.5 - 10.6 indicating gully occurrence (Ogbonnaya Igwe et al.., (2020)

d. The slope aspect has major control over the vegetation type because it influences the duration of sunlight. The slope aspect affects transpiration and moisture content also, evaporation, and indirectly affects the erosion process (Jaafari et al. 2014).Nine classes corresponding to flat north, northeast, east, southeast, south, southwest, west and northwest are represented in the aspect map (Fig 9), the result from aspect shows that the following classes have a strong relation with gully occurrence: flat face, east, southeast, and north.

e. Profile curvature - Extensive analysis of profile curvature reveals useful geomorphological information (Davoodi Moghaddam et al. 2015).Three classes of the profile curvature (Fig.9 - 10) include, convex and concave. Conditioning factors. Analysis of the profile curvature reveals that the concave class has a major contribution to gully occurrence while, the flat class and convex class have very low occurrence of gully erosion respectively.

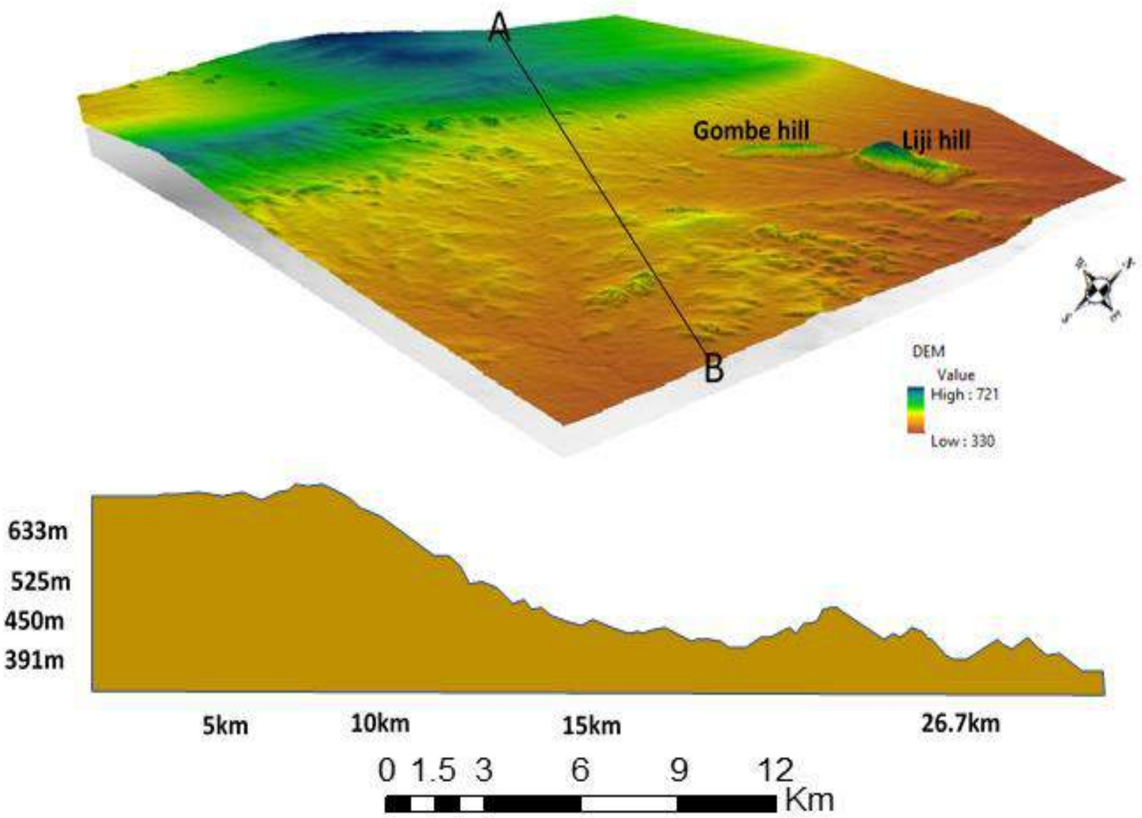

Fig.10: DEM and Topographical Profile of Gombe and its Environs.
Source: Mbaya L (2012); Ogbonnaya Igwe et al.., (2020)

4.4.7Anthropogenic (Human) Factors

The anthropogenic factor is mainly the disruption of the ecological system caused by poor land use and ever-increasing pressure put upon the available resources by the expanding population. More specifically over-exploitation, over-grazing, deforestation and poor irrigation practices, and these are influenced by factors such as changes in population, climate and socio-economic conditions. It is obviously a complex inter-relationship, which inherent extreme variability of climate as manifested in frequent drought; disruption in ecological balance caused by poor land use and ever increasing demand being made on the available resources by the expanding population and socio-economic systems of the improper land-use practices and poor land management (Lazarus et al.., 2012). Various human activities has contributes significantly to soil erosion problem in the Jewel in the Savanna. Soil/land has been subjected to intensive pressure from human uses which induce degradation, soil loss, and erosion; such human factors include overgrazing, excessive farm activities, tillage, clearing of bushes, extractive industries, road construction, bush burning, over-population, residential buildings and development of urban centers.

Ibitoye and Adegboyega (2012) also maintained that human activities such as construction works involving haphazard erection of buildings on steep terrains, ineffective or uncompleted drainage projects encouraged the concentration of runoff and gullies.

i. Population Growth

Some writers claim that soil erosion increases as a function of population density (Roose, 1996). Pieri (1989) stated that it is true in a given agrarian system, if the population passes a certain threshold, land starts to run short, and soil restoration mechanisms seize up. FAO (1998) reported that in the Sudano-Sahelian zone, when the population exceeds 20-40 inhabitants per sq km, the fallow period for shifting cultivation is shortened to the point of ineffectiveness, and one speaks of densely populated degraded area when the population reaches about 100 inhabitant per sq km.

The population of Gombe in 1919 to projected population in 2055 are as follows: 1919 was 300, 1950 (26, 000), 1960 (41000), 1970 (63000), 1980 (99000), 1990 (15300), 2000 (230000), 2010 (342,000), 2020 (509, 000), 2024 (596,000), 2035 will be (1,234, 000) and 2055 (1 923, 000) respectively, given an annual growth rate of 2 – 9%. (Tiffen, 2006; SLK, 2001, NPC, 2006, UN, 2020 Danladi 2024). The interplay of factors of population growth clearly produced the rising trend well above the national average of 3.0%. This has serious ecological consequences more especially increased development of man-made gullies / flood disaster and other environmental challenges in the metropolis and its environs.

ii. Urbanization and Landuse changes

In the early stages in the urbanization of an area, the land is cleared of vegetation to make room for human occupancy. As urbanization progresses and construction work goes on, the landscape becomes more compacted, reduces infiltration capacity of the land, thereby increasing runoff. In the advanced stage of urban growth, infrastructural development such as roads, housing, and industries, prevents infiltration and increases the amount of surface runoff; this runoff concentrates and consequently produces gullies. Generally, bare surfaces and low vegetated areas are gully erosion-prone. The spatial and temporal analysis of Gombe’s urban layout disclosed centrifugal growth, building densification and urban layout modification (Balzerek, *et al.*, 2003). This development resulted in the unification of the traditional settlement and the peri- urban areas in 1997 to formed a single urban body, which reached the size of 30km^2 in 2000 ((Balzerek, 2003). This expansion has led to an urban intrusion into the peri-urban environs far beyond the original town borders and is followed by significant change in landuse which has increased the sealed surface thereby reducing the infiltration rate of the rain water (Balzerek, *et al.,* 2003). Gombe urban centres have witnessed high density of buildings in the residential areas and the percentage of impervious surfaces is high including most of the Government Reservation Areas (G.R.A).

Bulus L. Gadiga, Mala Galtima (2017), L.A. Mbaya, G. O. Abu, Y.C. Makadi1 and D.M. Umar (2019) and Ogbonnaya Igwe, Onwuka Solomon, Ozioko Obinna (2020) and Lazarus (2024) in their analysis of Land Use and Land Cover changes (LULC) of Gombe metropolis over time reveals several key trends. The built-up area has experienced substantial growth, increasing from 5.31 km^2 in 1984 to 19.88 km^2 in 2024, with projections suggesting it will expand further to 45.62 km^2 by 2055. In contrast, cultivated land has decreased significantly, from 32.04 km^2 in 1984 to 19.31 km^2 in 2024, and is expected to decline further to 9.19 km^2 by both 2035 and 2055. Bare surfaces initially increased from 8.15 km^2 in 1984 to 19.74 km^2 in 2024 but are projected to decrease to 6.63 km^2 by 2055. Rock outcrops have remained relatively stable, with only minor fluctuations around 5.35 km^2. Thick vegetation has sharply declined from 18.89 km^2 in 1984 to 5.80 km^2 in 2024, with projections indicating it will further decrease to 3.29 km^2 1.73km^2 by 2035 and 2055 respectively. The total land area assessed remained constant at 70.08 km² throughout the study period and projections. These trends highlight a significant shift towards urbanization and a notable reduction in both cultivated land and vegetation (Fig 11 - 14).

Table 3: Landuse Land cover (LULC) change of Gombe Metropolis 1984 – Predicted 2055

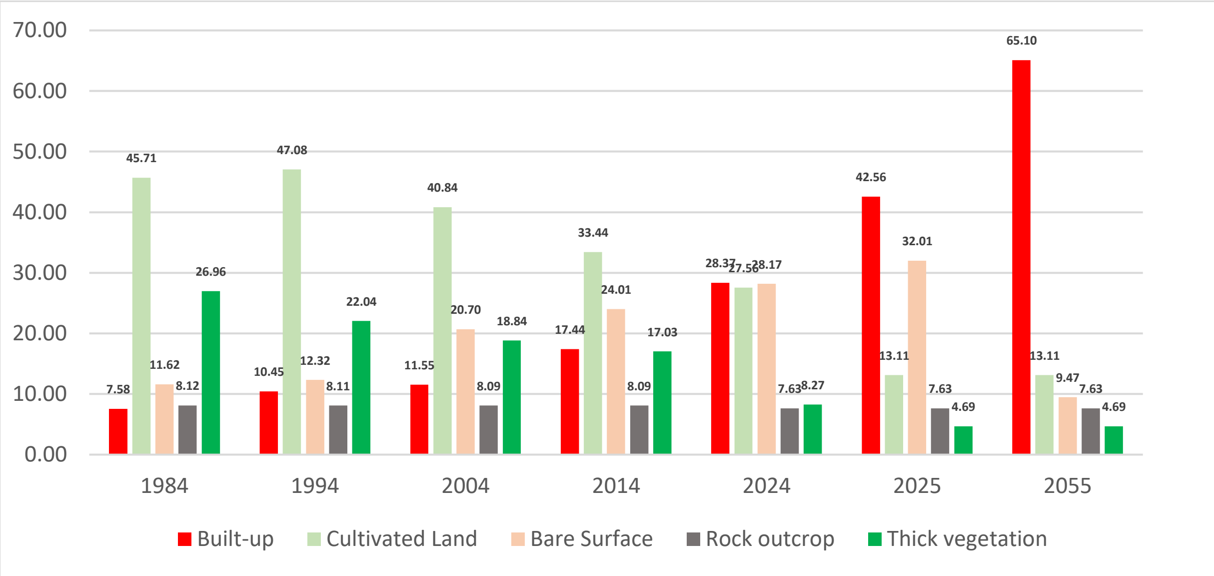

Fig. 11: Percentage Land use Land cover changes of Gombe and its Environs (1984 to 2055) Source: GIS laboratory Analysis, 2024

The primary factor influencing this development in Gombe is its relatively peaceful nature in Nigeria's North East region, which is frequently afflicted by civil unrest, most notably the Boko Haram crises in Borno, Yobe, and Adamawa states, as well as cattle rustling and banditry. Due to its proximity and the hospitable nature of its residents, this resulted in the metropolis serving as a safe landing place for displaced people.

Thus, urbanization increases the Hydrologically Significant Impermeable Areas (H.S.I.A) and so increases runoff and consequently gully erosion hazards. The net effects of urbanization on erosion include high proportion of the rainfall is translated into runoff, the runoff occurs more quickly, flood peak are generally high and the recurrence interval of flooding is increased, leading to destruction of urban land and infrastructure, and may render development more expensive. Replacing native soils and vegetation with engineered, impervious surfaces has been clearly linked to increases in the amount of runoff that is generated during rainfall events.

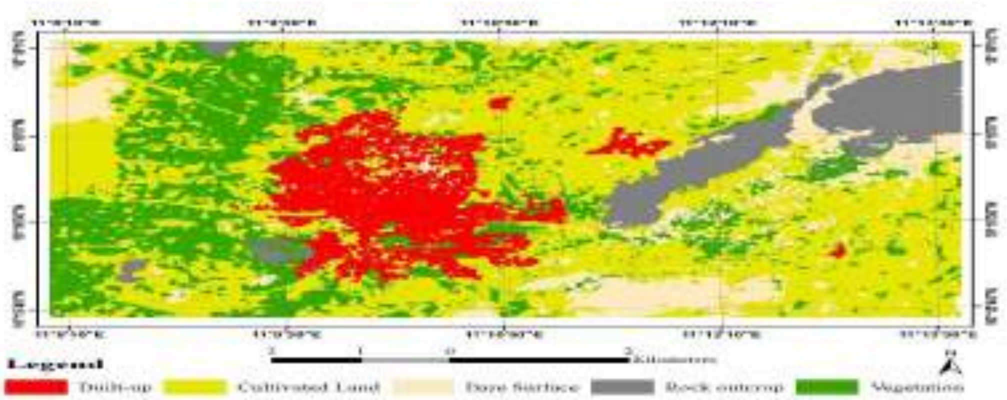

Fig. 11: Land use and Landcover change of Gombe and its Environs (1994)
Source: GIS laboratory Analysis, 2024

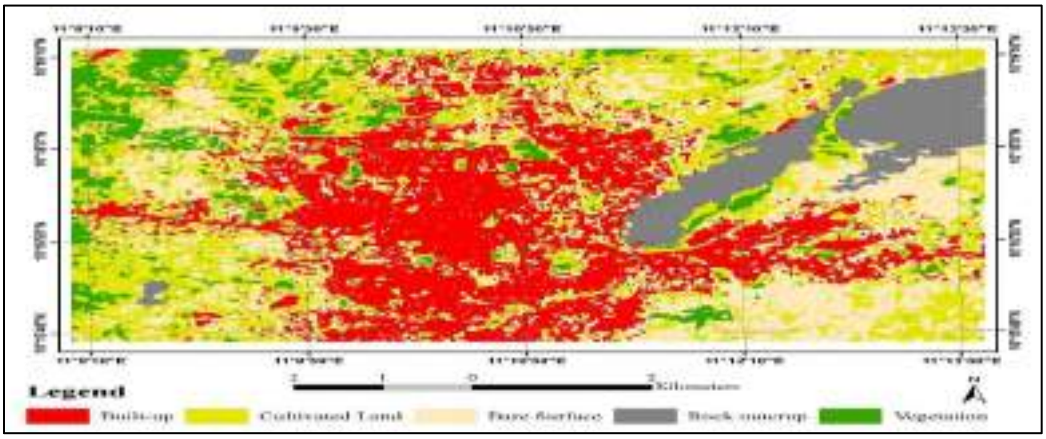

Fig. 12: Land use and Landcover change of Gombe and its Environs (2024) Source: GIS laboratory Analysis, 2024

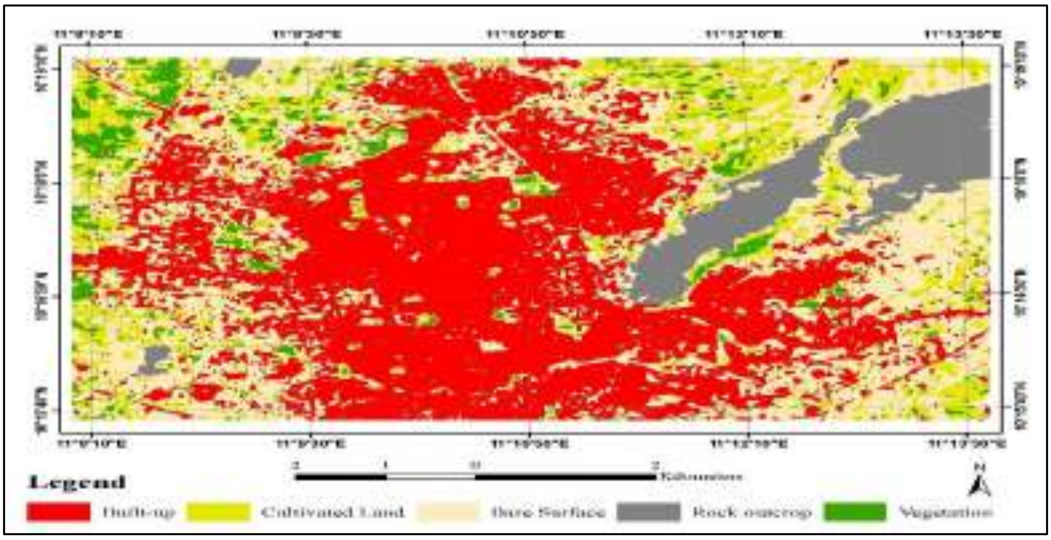

Fig. 13: Land use and Landcover change of Gombe and its Environs **(**2035) Source: GIS laboratory Analysis, 2024

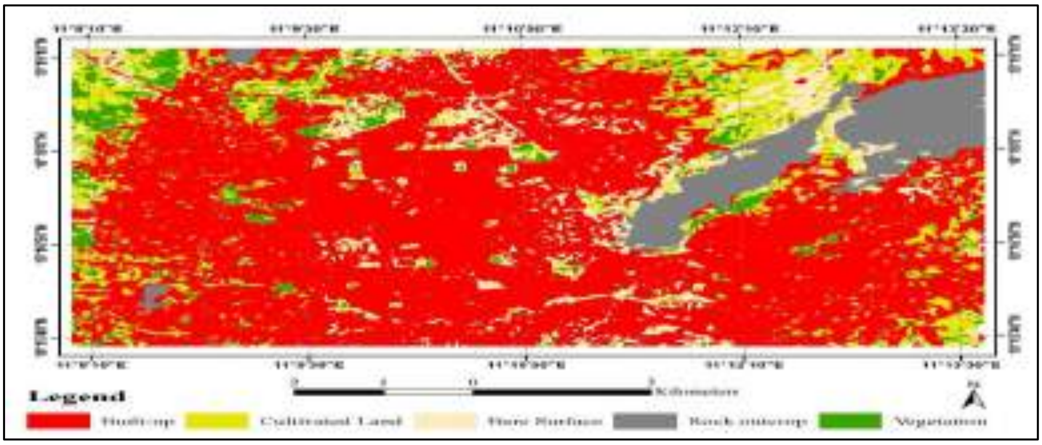

Fig. 14: Land use and Landcover change of Gombe and its Environs (2055) Source: GIS laboratory Analysis, 2024

iii. **Poverty**

Despite huge crude oil income, living standards in Nigeria are sliding below the poverty line. As public policy, population increase and environmental change widen the social gap, scarcity, scramble over resources and social conflict will make the target of eradicating extreme poverty unachievable

(Lazarus, et al.., 2012). To a large extent therefore, the people in this state depend heavily on the natural resources of their areas. Thus, the well-known interrelationship between Poverty and Environmental degradation obtains whereby poverty generates environmental degradation (soil erosion) which in turn accentuates poverty (Madu, 2007). Overall, this state is among states in Nigeria that is least developed in terms of the ability to meet basic needs. Per capita income is not only low, but the population growth rate is high, morbidity and mortality rates are high, medical services are lacking, the transportation system is chaotic and food security is not guaranteed. Therefore fuelwood exploitation, overgrazing and cultivation of marginal land are seen as possible responses to a harsh and inhospitable environment and poverty.

iv. Road Pavement

Roads and road construction result in soil erosion due to the impacts of rainfall affecting geomorphic and hydrologic processes. Research has shown that the creation of road cut and fill embankments with steep slopes and little vegetation cover, as well as the concentration of runoff from the road surface and intercepted subsurface flows influence the hydrologic and geomorphic processes. Road cut embankments, however, are the major sources of erosion than other parts of the road with slope gradient being the most important factor influencing soil erosion. Over 90 per cent of gully erosions in Nigeria are caused by poor termination of drains during road construction activities. (NEWMAP, 2017).

According to Ogbonnaya Igwe, Onwuka Solomon and Ozioko Obinna (2020) paved roads effectively concentrate surface runoff in Gombe. Road construction and expansion projects tend to encourage slope instability. Road buffer reveals that <1km and 1-2km have a strong correlation with gully occurrence. This suggests that the probability of gully occurrence decreases with distance from the road. Road construction through steep lands, without adequate provision for drainage systems, is a major cause of gully erosion. Inadequate drainage systems for roads (small number of culverts, insufficient capacity of road ditches, etc.) are a major cause of gulling.

v. **Climate Change**

Do you noticed that the pattern of rain distribution, particularly here in Northern Nigeria has changed this year? For the first time in many years, areas of high altitude experienced dry-spells of almost four weeks, at a time when it rains every day in the sahelian area of lower altitude. Apparently, from mid-july to mid-august, states such as Taraba, Adamawa and Benue receives less rain than Borno, Yobe, Katsina, Jigawa and the rest of states in the Sahel Savannah. This is exactly what climate change is talking about. The alterations and gradual shifts and changes in weather patterns affects nature and environments and subsequently destabilize the appearance of weather parameters.

Temperature and rainfall are good indicators of climate change. Lazarus A. Mbaya (2016) found that climate change have accelerated soil erosion directly through increases in surface air temperature and decreases / increase in rainfall regimes, and indirectly through changes in vegetation and surface cover. During the protracted, severe and prolonged droughts as witnessed since the 1950s, the fragile sudano- sahelian environment associated with sparse vegetation leaved large areas unprotected from splash and wind subjected to soil crusting, consequently runoff tends to increase and concentrate, thus promoting gully erosion and accelerated desertification than ever before. A drier climate in the semi-arid zone like Gombe state is thus expected to foster rill and gully development.

vi. Watershed Degradation/ Deforestation

The above ground parts of vegetation protect the soil from the energy of raindrops, runoff, and wind while the roots stabilize and improve the mechanical strength of the soil, resulting in reduced soil erosion.

The constant deforestation of the savanna woodland due to population explosion and increased agricultural activities in the region expose the bare soils to the vagaries of weather thus escalating the soil erosion problems. The implication is that the soils are frequently subject to different degrees of erosion including accelerated erosion. Deforestation is one of the most important factors in soil erosion process in the Jewel in the Savanna. The changes of agro forest landuse within the catchment area of the Gombe gullies shown the Kerri Kerri escarpment has a thick vegetation cover expanded downhill towards Gombe in addition to the dense natural dry savanna vegetation, covering the slope surface of the catchment area western part of the town. However, since late 1996, the natural vegetation has continuously witnessed transformation. First, the savanna woodland (forest reserve) has been cleared for agricultural use and fuelwood collection. Later, in 1997, these agricultural fields became speculated plots, and were converted into build up areas due to urban expansion (when Gombe town became the state capital).

The devastation of the forest reserve (6km^2) and the surrounding savanna shrubs and the transformation of former farmland with bush fallow into urban built-up environment decreased the infiltration rate and caused an accelerated surface runoff through gullies (Mbaya, 2012). For instance the area covered by vegetation decreased from 62% in 1976 to 27% in 1996 then decreased again to 11% in 2016. The farmland increased from 25% in 1976 to 43% in 1996 and decreased to17% in 2016.This was as a result of the conversion of farmlands to infrastructures. By contrast, the settlements increased from 2% in 1976 to 15% in 1996 and subsequently to 51% in 2016. (Bulus L. Gadiga, Mala Galtima (2017) and L.A. Mbaya, et al.., (2019)

vii. Overgrazing.

FAO (1983) reports that some 23 percent of the world's land is used for grazing livestock, and soil erosion caused by overgrazing is one of the most important environmental problems in the developing world. On an average, rangeland in developing countries is a third more crowded with livestock than rangeland in the developed world. Overgrazing by cattle reduces plant cover, eliminating the most desirable forage species first. The Sudano-Sahehalian zone of Nigeria is said to support much of the country's livestock economy, hosting about 90 % of the cattle population, about two-thirds of the goats and sheep and almost all donkeys, camels and horses (Ayuba, 2005). In this zone, which carries most of the livestock population, nomadic herdsmen graze their livestock throughout the area and are constantly in search of suitable pastures. Additional pressure is also put on pasture resources by livestock from neighbouring countries, notably Cameroon, Chad and Niger respectively. The frontline states as well as the buffer zone are located along two of the pastoral corridors of Nigeria. The corridors are: Sokoto/Kebbi/Zamfara /Katsina, Niger and Kwara state axis, and terminating in Oyo State.

the north-east corridor emanating from Niger/Chad / Cameroun Republics and running through Adamawa, Borno, Yobe, Gombe, Bauchi, Taraba, ,Jigawa, Kano and Plateau, and terminating in the Benue/Niger river basins. Both corridors form parts of arid eco-zone and run through Sudan Savannah, terminating at the Guinea zone of the middle-belt and some southern states. These corridors carry millions of heads of cattle annually with an average livestock population density of 23 per hectare, well above the carrying capacity. (Lazarus, et al.., 2012).

Overgrazing through the trampling on forage land by large numbers of cattle accelerates the death of plant and vegetation cover causes the grasses and plant residual matter to decline and further contributes to land degradation, especially increased soil erosion and lower soil fertility.

viii. **Poor Agricultural practice**

The rapidly growing population and urbanization are major reasons for the land use intensification for ever increasing food demand required to feed the population. For instance, Gombe state population is growing at 3.5% per annum while food production required to match this growth is only increasing by 1.5% for the past five years (CBN and NPC report 2017). In addition, 70% of the people are farmers (United Nations, 2012). The major driver of these changes is the continuous increase in population from 2.3 million in 1991 to 3.5 million in 2006 and to 5.2 million in 2023 (Nigeria Population Commission 2006, Aliyu D, 2024). This has put more pressure on marginal lands and consequently led to soil erosion

ix. **Land use management**

Gombe state covers an estimated land area of about 17,258.6 km^2 and has a human population of over 5,000,000million people (300 people/km^2). The use of land varies from one geographical location to the other which is dependent on the socio-economic need of the people. However, most of the current land use practices in state contradicts land use policies as stipulated in the Land Use Act 1978. This is because in the rural areas, the traditional method of land ownership by birth and communal clan are still in practice as the local people depend on the land resources for their livelihood. In addition, the government do not monitor local land uses as stipulated in the Act except if there is vital natural resources discovery in the area. Moreover, the Act made good provision for demarcation of the Nation's land into cities and local regions as well as fees payable for developing it and vest power to allocate lands in the hand of State Governors. However, the structure of the Act dwells more on land tenure system than land use policy (Akamigbo, 1999). Therefore, many communal and family lands which were being used and or rarely utilised were divided among individuals and families which has led to unplanned land use and fragmentation by the landowners in their bid to avoid takeover by the government. Consequently, the excesses of the Land Use Act have led to series of land degradation and soil erosion because of poor conservation and sustainable provisions. In addition, the Act dwells more on land acquisition rather than land conservation and sustainability.

x. Poor waste management Practices and Sand mining

Poor waste management practices such as dumping of refuse into drains and waterways prevent the proper flow of water characterized most of drainages in Gombe metropolis. This practice results in flooding leading to increase gully erosion and its attendant consequences.

Unsustainable land use practices also such as improper sand mining strips away the top soil and tilling process associated with crop cultivation loosens the top soil, creating paths for runoff (NEWMAP, 2012). Observation showed that sand mining is one of the fastest growing businesses in Nigeria, especially in Gombe town, where the demand for sand is very high for construction purposes.

5.0 Environmental and Socio-economic Effects of Gully Erosion

In the absence of concrete remedial and mitigate measures, it is estimated that the total cost of environmental degradation in Nigeria would amount to about US$8.10 billion per annum out of which, land degradation alone (including desertification and soil erosion) in the Sudano – Sahelian zone (SSZ) accounts for about 73% (FGN, 2002**).** Soil erosion causes off-site problems as well as on-site soil degradation (Lal, 1988). On-site effects are particularly important on agricultural land. Typical off-site problems are the reduction of the transport capacity of rivers and drainage ditches, an enhancement of the risk of flooding, the blocking irrigation channels and the shortening of the life of reservoirs. The existences of gullies in an area do have a multitude of influences on development endeavors.

According to findings from Heiko Balzerek et al.., (2003) Mbaya L.A (2012), Lazarus, (2016), Aliyu and Ray U (2014), Muhammad S. A et al.., (2022), Flayin et al.., (2022) Samuel Osusha Loya1 and Buba Wali (2023), Mahdi Faiza Doho et al.., (2024) the effects of soil erosion in a gully-affected areas are summarized as follows:

i. Loss of productive land (gullies often occur in the most productive area of a watershed)

Soil erosion and soil productivity are intricately related and that they cannot be separated easily. Usually erosion results in a net decrease of the long-term inherent productivity of the soil. It also affects long term productivity by reducing tilth and the soil's water holding capacity. In particular, long-term productivity is decreased by the removal of plant nutrients and organic matter from the top soil. It removes the fine silt and clay particles that hold plant available water and provide nutrients to plants**.** It also decreases the infiltration capacity of the soil, which leads to increases in surface runoff.

ii. Destruction of Houses: Soil erosion more especially gully erosion has causes destruction of houses more especially in Gombe metropolis. Studies by Mbaya, (2012), Aliyu and Ray U (2014), reported that over 1000 houses were destroyed between 1996 -2023, with over 5382 people displaced. This implies an average loss of 37 houses and 200 persons displaced per annum. Furthermore, over 2000 houses with population of over 15000 persons has crack and falling into gullies in the gully prone areas located ≤ 30m to the gully corridor. Dissection and fragmentation of plots causing access and management difficulties

iii. Damage to infrastructures such as roads, bridges, culverts, buildings, altering transportation corridors and irrigation or water supply schemes. Gully erosion has also destroyed many roads and culverts/ bridges in the Gombe state. Over 45km length of 23 different street roads both tarred and untarred and 22 culverts / bridges were destroyed thereby, increasing the cost of intra transport of the affected areas. For instance the shortest and the only major road and bridge that link Barunde and the main market were destroyed hence the people constructed a ply over in 2014. Reduced amenity and property values including destruction of farm facilities such as fences or roads

iv. Loss of Live: Gully erosion has caused loss of lives since 1996. Report showed that about 15 persons and 40 domestic animals died in 2014. This figure maybe more with current level of gully erosion threat on residents. This people were reported to have died as result of collapse houses.

v. Local lowering of the water table (gullies suck water from springs, dug-wells and hand pumps, because by lying below they have an effect of negative pressure).Gullies are often blamed for enhanced drainage and accelerated acidification processes (e.g., Eitel et al., 2002; Daba, 2003). For instance, in the arid region of the Negev highlands of southern Israel, gully incision erodes alluvial sediments and loess deposited along the valleys. In the Ethiopian highlands and southern Niger the development of gullies has led to an enlarged drainage resulting in soil moisture decrease and a corresponding crop yield reduction on plots located near the gully walls (Nyssen et al., 2004c). Similarly, in Gombe town which enjoyed an easy access to groundwater in the past now suffers because of gully erosion. Assessment of hand dug wells in Dawaki, Madaki, Yelonguruza, Bagadaza, Mallam Inna, Ungwa Uku and Barunde quaters has shown that wells with an average depth of 9 to 30 metres which contain water throughout the year have dried up. This has forced many communities to seek contaminated water from the gully bed. However, Arabi *et al.*, (2009) reported that gully erosion does not affect lowering of ground water, but do agree that, the entrenchment of stream beds, silting up of springs by soil creeps have greatly reduced the usefulness of several sources of water supply

vi. Silting up of storage dams, ponds, waterways and irrigation canals, and even fertile agricultural fields and Gully erosion dramatically affects sediment budgets and flux rates, and influences stream dynamics. Fingerprinting the origin of sediments within catchments to determine the relative contributions of potential sediment sources has become essential to identify sources of potential pollution and to develop management strategies to combat soil erosion. Globally, about 80% of the sediment in the reservoir has come from gully and channel erosion (Wasson et al., 2002). The sedimentation of river Gongola particularly the Dadin Kowa dam which is the main water supply to urban Gombe and its environs due to gully erosion menace arising from Gombe metropolis through river Magariya, have added financial burden on the government in treating water for urban consumption and generation of electricity, reduced fish population, amount of water for irrigation and navigation on the Gongola River more especially during dry season.
vii. Financial Implication: The Gombe state government in collaboration with Federal government (Ecological Fund) has spent billions of naira on gully erosion control measures more especially since 1996. For instance, the GSU – Mallam Inna- Kagarawal gullies cost over 3 billion naira, while the FCE – London mai Dorowa – Arawa- Mallam Inna gullies cost over 12 billion naira (Aliyu Danladi, 2024). This excluded other numerous engineering control measures in the 11 local government areas of the state that runs into billions of naira, in additional to cost implication of individual and communities effort of gully erosion control measures. Such huge amount of money so far spent would have channeled to other sectors of the economy to improve

the livelihood of the people, had it been the concept of *prevention is better than Cure* was adopted.

6.0 Gully Control Measures

The nearly yearly occurrence of gully erosion disaster in Gombe necessitated the need for continuous mitigation measures to curtailing the dangers threatening the environment, farmlands, public facilities and safety of residential houses. Mbaya L.A (2017) revealed there are 131.02 km lengths of gully erosion in Gombe town as at 2015. Out of the 131.02 km length of gully erosion, only 41.32 km length has been controlled under engineering method representing 35.92%, leaving over 90km length uncontrolled. Thus requires short and long term control measures on the part of the vulnerable communities, government at all levels and other stakeholders.

Generally, in gully erosion control, the following three methods must be applied in order of priority:

(a) Improvement of gully catchments to reduce and regulate the run-off volume and peak rates;

(b) Diversion of runoff water upstream of the gully area;

(c) Stabilization of gullies by structural measures and accompanying re-vegetation.

6.1. Prevention of gully formation

The principle of *prevention is better than Cure* is highly relevant for gullies. Preventing the formation of a gully is much easier than controlling it once it has formed. If incipient gullies are not stabilized, they become longer, larger and deeper. Under certain climatic and geological conditions, vertical gully banks can easily become as high as 20-30 meters or more.

Prevention is also more economical than cure because structural measures are considerably more expensive than preventive measures. Even if the resource is available, the technique of its rehabilitation is more difficult and complex. Therefore, in gully control, emphasis should be given to the following practices:

(a) Proper land-management practices:

- Adoption of conservation effective, improved soil, water and crop management practices in a ridge to valley approach for all catchment contributing to the gully.
- Protection of the soil by good canopy during rains,
- Prevention of forest fires and illegal wood cutting in plantations and natural forests,
- Applying control grazing, and re-vegetation of open grazing lands,
- Maintenance of soil fertility through proper inputs, crop rotation and control of land degradation,
- The immediate stabilization of moderate sheet and rill erosion, and incipient gullies in rangeland, bare surfaces and cultivated areas.

(b) Retention and infiltration of surface water:

In addition to proper land-management practices, specific slope-treatment measures, such as retention and infiltration ditches, terraces should be carried out above the gully area, and in the eroded area between the branch gullies, to reduce the rate and amount of surface run-off. These also decrease the cost of structural gully-control measures.

(c) Diversion of surface water above the gully

In many cases, the simplest, cheapest and safest gully control method is to divert runoff before it enters into the gully. Diversions constructed above the gully area can direct run-off away from gully heads, and discharge it either into natural waterways or earth dam. Cutoff drains and waterways are drainage management structures which are commonly used to divert runoff before reaching gullies, cultivated lands and residences. They are effective measures for soil and water conservation in general and gully rehabilitation in particular.

6.2. Gully control measures

Stabilization of gullies involves the use of appropriate structural and vegetative measures in the head, floor and sides of the gully. Once gullies have begun to form, however, they must be treated as soon as possible, to minimize further damage and restore stability. There are a multitude of physical and biological techniques which can be applied for effective gully treatment. The combination of the two measures (biophysical approach) is the best solution for effective gully control and for productive use of the gully area. The construction of gully physical structures will be followed by the establishment of biological measures. The natural regeneration which is coming after the gullies are protected and enclosed should also be considered in the overall rehabilitation scheme.

To obtain satisfactory results from physical and biological measures, it is vital to understand the nature of the whole gully system/network and properly diagnosing of the different parts in the gully section: the gully bed, gully sidewall and gully offset. Overall, stabilized watershed slopes are the best assurance for the continued functioning of gully control structures. Therefore, attention must always be given to keeping the gully catchment well vegetated.

a. Physical Control Measures

In gully control, temporary physical structural measures such as engineering, gully reshaping, brushwood, sandbag, loose stone, gabion and arc-weir check-dams are used to dissipate the energy of runoff and to keep the stability of the gully. Check-dams are constructed across the gully bed to stop channel/bed erosion. By reducing the original gradient of the gully channel, check-dams diminish the velocity of water flow of runoff and the erosive power of runoff. Run-off during peak flow is conveyed safely by check-dams.

The gully head is often the most difficult to deal with, especially if it is more than about 2 m high because of the erosive power of falling water. Control structures for large gullies require an engineering design and are expensive. If the stabilization of gully head appears too costly or difficult, there are two approaches: One is to divert runoff away from the gully head so that it ceases to erode. The other is to place a check-dam close enough to the gully head so that it will trap sediment, raise the floor level and submerged the head. The use of stepped gabions, stone *rip-rap*, brushwood carpet, sandbag and planting grass sod are alternative measures which can be sued for gully head treatment. For stability of structures and quick healing the gully head should be reshaped and planted with grass sod.

i. Gully reshaping and filling

Gully wall reshaping is cutting off steep slopes of active gully flanks in to gentle slope (Minimum at 45% slope), up to two-third of the total depth of the gully and constructing small trenches along contours for re-vegetating slanted part of the gully walls and beds. If the gully is wide and has meandering nature with huge accumulation of runoff flowing down, cut off soils and soil materials can be washed away by runoff water and requires constructing of retaining walls, to protect displaced (not yet stabilized) soils and soil materials and newly created sidewalls of the reshaped gully.

Gullies with very little water flow can be stabilized by filling and shaping, that is, if the surface water is diverted, and livestock are kept out. Steep gully heads and gully banks should be shaped to a gentler slope (about a one-to-one slope). Filling of gullies is applicable only for small discontinuous gullies, in their early stages of development. The filled gully area can be planted even be used for cultivation. Rills and incipient branch gullies may be filled in by spade, shovel or plow (on cultivated lands).

Generally, in the filling and shaping process the following need to be considered:

- The soil should be well compacted
- Brushwood check-dams
- The filling operation should be done before the rains
- To protect it from erosion, close growing crops should be planted or seeded immediately
- The entire work of shaping and filling should be done in one operation

Brushwood check-dams made of posts and brushes are placed across the gully. The main objective of brushwood check-dams is to hold fine material carried by flowing water in the gully. Small gully heads, no deeper than one meter, can also be stabilized by brushwood check dams. Brushwood check-dams are temporary structures and should not be used to treat ongoing problems such as concentrated run-off from roads or cultivated fields. They can be employed in connection with land use changes such as reforestation or improved range management until vegetative and slope treatment measures become effective. In areas where the soil in the gully is deep enough, brushwood check-dams can be used if proper construction is assured. The gradient of the gully channel may vary from 5 to 12 percent, but the gully catchment area should not be as such huge which produces high amount of runoff volume.

ii. Loose stone check-dam

Loose stone check-dam is a structure made of relatively small rocks and placed across the gully or small stream, which reduces the velocity of runoff and prevents the deepening and widening of the gully. Sediments accumulated behind a check-dam could be planted with crops or trees/shrubs, grasses and thus provide additional income to the farmer. It is commonly used to check gullies on highly eroded grazing and cultivated lands and hillsides.

iii. Gabion check-dam

Gabions are rectangular boxes of varying sizes and are mostly made of galvanized steel wire woven into mesh. The boxes are tied together with wire and then filled with either stone or soil material and placed as building blocks. Small stones can be used as the wire mesh will prevent them being washed away. If large stones are used, they must be placed carefully with small stones filling the spaces between them otherwise water may jet through the gabion and undermine the ground beneath. Gabions are filled in situ and as they are very heavy they will not be washed away provided they have been correctly installed. The main advantages of gabions are that they are tough and long lasting provided that the wire has been well galvanized.

iv. Arc-weir check-dam

Arc-weir is a structure made up of stones connected with mortar of cement and sand. The main objective of this dam is to hold fine and coarse material carried by flowing water in the gully or torrent. It is a very rigged structure highly susceptible to damage as a result of piping. When properly constructed, it is highly resistant to greater water pressure. The structure is very susceptible to damage as a result of runoff coming with boulders. From technical and economic point of view it is not necessary to build masonry check-dams to control channel erosion in every gully.

vi. Engineering measures

The engineering measures of controlling gully erosion includes the installation of control structures such as drop spillways, chutes, formless flumes, pipe less spillways, etc. whereas large gullies maybe controlled by reduction of the surface inflow, by shaping and intensive natural or artificial revegetation, or by the installation of control structures such as drop spillways, chutes, formless flumes, pipe spillways, waterways construction can be used to stabilize small gullies. These are permanent structure designed to protect the gullies from further expansion and at the same time help in storage of water. Three types of structures commonly used are (1) chute spillway, (2) drop spillway, and (3) drop-inlet or pipe spillway. Chute spillways are used at the head to convey the water safely to the gully head. The drop spillways are used along the gully bed to act as control points so that the gully bed is not eroded below the crest level of the structure. The drop inlet spillways are used at appropriate locations in the gully for storage of water.

vii. Contouring is the practice of performing field operations, such as plowing, planting, cultivating, and harvesting, approximately on the contour. This practice helps to reduce surface runoff by impounding water in small depressions, and decreases the development of rills.

Contouring on steep slopes (rolling lands) or under conditions of high rainfall intensity and soil erodibility will increase gullying because row breaks may release the stored water. Many studies revealed that contour cultivation together with good sod waterways reduced watershed runoff by 75 to 80 percent at the beginning of the season.

viii. Strip cropping is the practice of growing alternate strips of different crops in the same field. The strips are placed on the contour in order to control water erosion. The three types of strip cropping are contour, field, and buffer strip cropping. In contour strip cropping, layout and tillage are held closely to the contour and the crops follow a definite rotational sequence. In field strip cropping, strips of uniform width are placed across the general slope. In buffer strip cropping, strips of a grass or legume crop are placed between contour strips of crops in the regular rotations. Buffers may be even or irregular in width or placed on critical slope areas of the field. This is done to ensure protection from erosion or allow for areas of deposition (Schwab et al., 1983). In any given case, the type of strip cropping used is a function of the cropping system, topography of the area as well as the types of erosion hazards observed in the area.

b. Use of vegetation in gully control (Biological Measures)

Use of vegetation in gully control offers an inexpensive and permanent protection. The vegetation is affordable, easy to plant and environmentally friendly. Vegetative methods (cultural method) of gully control comprises grasses, shrubs and trees cover that helps to stabilize the gully and hinder further expansion. Suresh (2006) noted that vegetation acts in a variety of ways by intercepting raindrops through encouraging greater infiltration of water and through increasing surface soil organic matter and thereby reducing soil erodibility and protect the gully floor and banks from scouring. Grasses on the gully floor slows down the velocity of the runoff and causes deposition of silt. Vegetation can be established in a gully by natural recovery or use of planting materials.

The establishment of vegetation either naturally or artificially has to contend with a hostile environment. Thus, choosing an appropriate land use can drastically curtail soil erosion. Plants such as *vetiver, Bahama* grass, *Ipomoe Carnea, paniculatu / Pitadeniastrum africanum* are most suitable in gully stabilization and should be established both on the bed and the sides either by seeding or by sodding. It is always recommended that enough width be provided so that the flow velocities do not cause damage to the plant surfaces. Conservationists and farmers should properly assess the soil and moisture conditions in the gully head, gully floor/bed, gully sidewall and gully offset/gully buffer zone.

(a) Gully head

- It is the upper part of the gully (in topo-sequence) where the gully starts
- It is the location through which most of the run off enters to the gully
- This part in most of the cases is very much active for gully formation and expansion
- The most commonly accepted measures for this spot are physical structures, such as paving with loss stone, diverting water using cutoff drains and reshaping.
- Nevertheless integrated treatment with biological measures will also help in stabilizing the gully head.

- Some creeping plant species can be used for reinforcing the structures constructed

(b) Gully offset

- It is a part of gully area which is located away from the gully embankment and extended to the next land use type
- It is a part which has to be considered in the gully treatment scheme to avoid further expansion of the gully
- In most of the cases these areas are characterized by medium soil depth, moderately wet in the rainy season and dry in the dry season, and with moderate slope
- Micro basin construction, trench and sub soiling are recommended for better performances of crops planted in the area
- Thus the plant species recommended for the treatment of this area are those with moderate tolerance to dryness and wetness such as *Ipomoe Carnea, paniculatu / Pitadeniastrum africanum*

(c) Gully sidewall

- It is a part of the gully between the gullies offset and gully bed
- It is characterized by high slope gradient, shallow soil depth, susceptible to erosion and mass movement, very dry in most of the time due to less water holding capacity.
- Reshaping and hence constructing moisture harvesting structures are the recommended measures to treat gully sidewalls
- As far as farmers/land users are convinced to undertake reshaping, the gully offsets can be converted into potential areas for multiple purposes
- Biological measures can play a pivotal role in rehabilitating this section of the gully

- The species to be selected should have invading characteristics, with light foliage and steam biomass and high tolerance to drought e.g *Ipomoe Carnea*, *paniculatu / Pitadeniastrum africanum*

(d) Gully bed/floor

- It is a part of the gully on top of which the run off flows
- It is occupied with the flow of runoff throughout the rainy season
- This gully parts can be treated in the dry season with physical measures like arc weir, loose stone, and gabion, brushwood and sandbag check-dams.
- These areas are regarded as very wet in most of the year, with deep alluvial soil
- Thus the biological material recommended for this part of the gully should be tolerant to water logging, with high root biomass and, resistant to soil sedimentation and high flow of water, planting of water-loving or moist tolerant trees, shrubs and grasses such as

Pennisetum clandestinum, Pennisetum riparium, Pennisetum purpureum, adequately spaced, breaks the flow and velocity of water run-off, traps the sediment, and protects the gully bed from erosion.

Vegetation method of Gully Erosion control

6.0 Conclusion

The Jewel in the Savanna (Gombe) is facing serious problem of gully erosion causing untold hardships and misery on the lives of the people. Complex interdependent mechanisms between rainfall patterns, soil erodibility, landuse, topography has reduced infiltration, which caused a higher surface runoff. This has increased deep cutting, take up valuable land, raised the cost of building and the sinking of the ground water table. This chain of cause and effect hits most of the low income groups of the community, where the population density is highest and where the worst damages of gully erosion are found. The situation is further worsened by rise in value of urban land due to population increase. These force people to erect buildings on floodplains, consequently increase in both the magnitude and frequency of gully erosion in response to high storm water runoff and channel concentration. The risk of a hazard and the damage caused by gully erosion has to be covered by the individual, since none of the property is insured by commercial assurance companies. The people affected unfortunately often react with fatalistic equanimity and consider it a stroke of fate, a judgments, which is enforced by the cultural background, low income and possibly their lack of education. One has to conclude that the imbalance of nature and urban community is threatens the urban ecological system. The irreversible damages have to be approach without delay by appropriate countermeasures. We therefore, need to begin to think outside the box, close ranks and stop politicking with the environment. We need to unite, collaborate and partner, to sustain nature and civilization, and get ourselves rid of hunger, abject poverty and environmental degradation.

7.0 Recommendation

Many active gully erosion sites in Gombe have grown into monster valleys, threatening farmlands, residential buildings and access roads. Resources required for combating the menace has gone beyond what the State or even the Federal Government can readily afford. Though the Federal Government of Nigeria has established an Ecological Fund to finance ecological projects, including erosion control and prevention efforts, the Fund has not been able to meet the requirement of soil (gully) erosion challenges on ground. According to (Lawal.2018: Nnodim, 2018) whereas requests by various communities, groups and politicians for control of soil erosion and flooding exceed N1.1trillion annually, Ecological Fund Office receives between N12bn quarterly for the 36 states of the country.

In order to save the environment from further degradation of the rich and exhaustive resources, it becomes inherent to address the challenges so as to be able to achieve environmental sustainability.

Raven, Berg and Hassenshall (2010) submitted that the elements that contribute to addressing environmental problems include scientific assessment, risk analysis, public education and involvement, political action and long term evaluation. Disaster control process is concerned with recognizing, evaluating and eliminating/mitigating hazards that occur because of human errors and physical deficiencies in the environment (Jain and Rao, 2011:298). Natural events cannot be prevented from occurring but their impacts can be reduced if effective measures are taken in order to depress their severity, frequency and impacts. Based on several research carried out by Lazarus, (2012, 2013, 2016, 2017, 2019) and others on gully erosion seen as an intractable environmental problem in Gombe state the following recommendations are made:

1. Reforestation of the catchment areas and eroded lands can be effective at reclaiming and controlling gully corridors in the affected areas. Planting deep rooted perennial pastures, trees, or an appropriate mixture of both, such as *Pitadeniastrum africanum,* can help maintain healthy and vigorous levels of vegetation. Plant cover (vegetation) reduces the energy of raindrops and running water by imparting roughness to the flow of water thereby reducing its velocity, hence it will lessen the havoc. Also, planting of the trees with buttress roots should be encouraged to reduce the force of running water.
2. Enlightenment campaign and educating the populace on the actual causes of gully erosion as well as effective methods of controlling/preventing gully erosion. Gully erosion can be prevented when communities engage in more public awareness initiatives and put in place structures that can govern and implement best land practices. Effective land management practices coupled with pragmatic public awareness measures within the community is crucial to mitigate further onset of gully erosion in Gombe town. Communities should take part in initiatives that adopt and engage in small-scale, low technology input and best land management practices. For example, residents who pave their lands may not be aware that their actions could exacerbate gully erosion in the community because rainwater flowing out of their land to the surrounding regions causes surface run-offs and could initiate erosion.
3. Harvesting of rain water on the foot prints of homes and other building structures as a way of resource utilization. Diversion of water away from

erosion prone gullies, thus dispersing the erosive power of the water over well vegetated areas. Diversion banks are a simple way of achieving this. More so, natural drains, footpaths and culverts should be properly managed through maintenance to minimize the erosive power of runoff.

4. There should be a legislation prohibiting individuals from constructing buildings within certain offset distances of 30 metres from gully edges. It is essential that Gombe town master plans, especially in areas with a natural predisposition to erosion, include laws on land division, use and occupation and building codes with preventive measures against urban erosion be formulated and enforced.
5. Governments, wealthy individuals and NGOs should assist Universities and other research institutions with funds for research in related environmental problems. Research findings and suggested solutions should be implemented by the local, state, and Federal Government.
6. Government at all levels should take it as a matter of importance and urgency to respond to gully issues at its developmental stage. Since the causes of gully erosion include both natural and anthropogenic sources, and bearing it in mind that we have little or no control over the natural causes of gully erosion, stakeholders (local, state, and federal ministries of environment, agriculture, etc.) should discourage all practices that are capable of initiating gully erosion.
7. Control urban development through the process of zoning the land area for future development. Buildings already erected on floodplains under this option can be pulled down and stream channels enlarged and deepened. Paved parking lots and compounds can also be replaced with porous surface

8. Construction of drainages should be adequate and implemented according to drainage sub-basins; the implementation should be performed from downstream to upstream. The drainage systems should be periodically inspected, carrying out repairs in the destroyed areas and clearing obstructions and sediment from the storm sewers; empty lots should be kept under plant cover; circulation areas and other public spaces should be kept clean, solving the problem of urban solid wastes in to the drainages.
9. Surfaces and wastewaters must be gathered and collected through the gully or diverted from the catchment headwaters into earth dam for discharge, where their energy can be dissipated and used during dry season for small irrigation and domestic purposes.
10. Encourage all communities in the gully prone areas to form committees for erosion control, prevention and monitoring of gully erosion, their roles includes:
    a. Compiling the inventory of active and dormant gullies within the community and reporting to the Local Government on a yearly basis.
    b. Carrying out basic preventive measures such as clearing of drains, closing potholes created by run-off by side of roads streets or bush paths.
    c. Ensuring no part of community land is given out for excavation without involvement of Local or State for inspection (a sort of erosion impact assessment) and approval. For examples land owners negotiate or sell some piece of land to construction companies who excavate and carry sand for constructions purposes. Such pits left behind became the head of active gully erosion.

d. Monitoring the active, controlled and dormant gullies and reporting changes formally to Local Government authorities.

e. Prevention of bush burning and illegal tree cutting in plantations and forests, reserves.

f. Involvement of Local and State authorities on gully erosion impact assessment before selecting and clearing large area of bushes for community infrastructural use or for large scale farming

g. Planting trees, shrubs and perennial grasses in gully erosion corridors and watersheds areas.

h. Cooperating with the Local, State, Federal and international agencies in the control and prevention of erosion.

11. Establish an effective/functional erosion control unit or department at the three tiers of government (*Federal, State, and Local*) with well - defined and coordinate duties/roles. Empower the unit through legislation and allocate a certain percentage of the federal ecological fund to the unit on a continuous (*not adhoc*) basis. The Government should consider as a State and local government policy, setting aside 2-3 % of the state and local governments annual budget to ecological problems in addition to the National Ecological Fund. Other roles includes:

    a. Producing and updating local government gully erosion map on yearly basis (World Bank through NEWMAP and ACReSAL).

    b. Liaising with the State Government and communities within the Local Government for capacity building on gully erosion control and prevention.

    c. Supporting communities on basic gully erosion prevention measures.

d. Sourcing ecological fund to control erosion for or on behalf of communities.

e. Monitoring erosion control and prevention sites within the Local Government and formally reporting to the State, Federal and international agencies as the need arises.

f. Support the communities on gully erosion impact assessment as it concerns large scale clearing of bushes, excavation of land and community based opening of new access roads.

g. Undertake baseline data acquisition on all gullies with accurate information on topography of the various watersheds and surface hydrological characteristics; gully dimensions (length, breath, and depth); geo technical properties of the soils, and human activities, these data must be

h. Updated on a continuous basis and develop a gully erosion control/prevention Master Plan. This is extremely useful and necessary to assess how much water is actually flowing to the gully and the contributing sources.

i. Generate and follow master plans in development of cities.

j. Enacting relevant laws for control and prevention of gully erosion within the State.

k. Ensuring that qualified and tested construction companies undertake construction that meet best practice and maintenance of state roads and take responsibility for dealing with any gully which develops from road construction.

l. The state must developed a digital base map which is an essential tool in the ultimate and effective resolution of soil erosion issues.

Ministries, institutions and agencies responsible for the provision of rainfall data daily, monthly and yearly should make efforts to do so, update them and make them accessible to the public as this is not the situation in most countries of the world. With availability of data, researchers should be encouraged by government and donor agencies to conduct studies to develop regression equation (models) for computing rainfall erosivity and soil losses for different localities across the globe.

m. Ministries, institutions and agencies responsible for the provision of rainfall data daily, monthly and yearly should make efforts to do so, update them and make them accessible to the public as this is not the situation in most States.

n. With availability of data, researchers should be encouraged by government and donor agencies to conduct studies to develop regression equation (models) for computing rainfall erosivity and soil losses for different localities across the State.

The role of Federal Government - based gully erosion control and prevention measures

i Providing relevant legislation for control and prevention of gully erosion.

ii Providing adequate funding for Ecological Fund.

iii Corroborating with international agencies for funding and executing projects for control and prevention of gully erosion; such as what is being done with the World Bank through NEWMAP and ACReSAL.

iv Corroborating with and giving timely necessary information about on-going gully erosion prevention and control efforts to States, Local Governments and host communities.

v Use machinery of government to sustain fight against corruption and ensuring that project contractors work with the approved specification, schedule and budget.

vi Ensuring that qualified and tested construction companies undertake construction and maintenance of federal roads and take responsibility for dealing with any gully which develops from road construction.

The role of Higher Education Institutions –based Environmental Management Departments.

i. Teaching students the skills of integration, synthesis and systems – thinking and how to cope with environmental challenges they may find themselves

ii. Provide the model of sustainable practices for society

iii. Performing real world based research activities and dissemination

iv. Promote and enhancing inter disciplinary research approaches to erosion control and prevention measures.

v. Outreach to create enduring partnerships between academic institutions and communities in order to build capacity to solve a suitable solution of the problem in society

The role of Legislators (councilors, state and national assemblies)

i Initiation and Consideration of bills;

ii Oversight of the Executive;

iii Constituency Representation;

iv Investigating government policy initiatives; and,

v Reviewing and approving government budget and expenditure.

In order to strengthen representation as a core legislative function, lawmakers are expected to pursue an active strategy of improving service to constituents.

This can be done in many ways, including:

a. Sponsoring bills on the floor of the House;
b. Setting up of a Constituency Office to facilitate public access;
c. Regular physical visits to constituencies;
d. Meetings with interest groups in order to stay engaged with various issues of concern;
e. Presenting petitions in the National Assembly on behalf of constituents to ensure that their grievances are addressed;
f. Seeking public consultations and input on a bill;
g. Soliciting the opinions of constituents on certain legislative and policy issues;
h. Keeping in touch with community leaders;
i. Creating awareness and disseminating relevant information to constituents;
j. Actively participating in the budget process and ensuring that there is room for constituents to also participate through monitoring of local projects; and,
k. Actively engaging the media and civil society groups.

The role of Non-Governmental Organization

The NGO's constitute a worldwide net-work interacting with Governments and Internal intergovernmental organization in shaping international environmental policies:

i. Creating awareness among the public on current environmental issues and solutions.
ii. Facilitating the participation of various categories of stakeholders in the discussion on environmental issues.
iii. Protecting the natural resources and entrusting the equitable use of resources.
iv. Being involved in the protection of human rights to have a clean environment.
v. Analysis and monitory of environmental quality.

vi Organizing seminars, lectures and group discussion for promotion of environmental awareness.

vii Helping the implementation of community projects on environmental problems

12. Considering the poor soil quality attributes, soil conservation and management practices must place premium on improving the soil organic matter content with its potential to improving soil structural stability, and thus reduce soil erosion and gullying in the Jewel State. This is because the high bulk density and low porosity values were also accentuated by the fact that the sand particles tend to lie in close contact because of lack of bridging materials like organic matter; the soil being characterized by low organic matter content.
13. Both the affected people and landholders should be adequately empowered through grants by governments, donor agencies and non-governmental organizations (NGOs) prevent formation of gullies because they know when rills begin to occur in their localities and as such can stop their expansion into gullies by using some adaptive measures based on their indigenous knowledge.
14. Training the affected people and landholders on some adaptive measures to soil erosion is a major component in the management of gully erosion. These stakeholders should be trained to enhance those adaptive measures such as tree planting, crop rotation, use of compost as manure and ploughing across the slope, rather than along it which obtains in some communities today, for the management of rills wherever it occurs to prevent them from developing into gullies.

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CITATION ON PROFESSOR LAZARUS ABORE MBAYA

Lazarus Abore Mbaya was born to the family of Mr Abore Mbaya in 1964 at Nggwa village Hawul LGA of Borno State. He attended Sakwa primary school from 1971 – 1977; the then Teachers' College Gashua from 1977 – 1982; Federal College of Education Kontagora, Niger State 1983 – 1986 for his NCE; Federal University of Technology (now MAU) Yola for his B.Tech Geography 1992 – 1995; University of Maiduguri between 2002 – 2004 for his M.Sc Geography (Resource and Development) and proceeded for his Ph.D in Geography at the University of Maiduguri from 2008 – 2012. He was the first Ph.D graduate from the Department of Geography, University of Maiduguri since its establishment in 1976.

After his completion of NCE in 1986, he was employed as a teacher (Master II) with the Ministry of Education, Borno State. He was posted to Government Secondary School Benishiek in 1987 as Geography teacher. He was transferred to Government Girls' secondary school Buni Yadi in 1990. Following the creation of Yobe state in 1991, Lazarus A. Mbaya was redeployed to Borno state and posted to Government Girls' secondary school Mirnga. In 1997 he was transferred to Government College Maiduguri and until 2005 when he secured appointment with Gombe state university as Assistant Lecturer with the Department of Geography. Since then Lazarus Abore Mbaya has been a staff of this great university and has enjoyed regular promotions as when due: Lecturer II in 2009, lecturer I in 2012, Senior lecturer in 2015, Reader 2018 and Professor 2021 respectively. In the course of discharging his primary duties Professor Lazarus Abore Mbaya has held various positions and Membership of committees as well as community services both at the Departmental, Faculty and the University at large.

Among positions held includes Departmental SIWES coordinator, Field coordinator, coordinator GENS 203, chairman faculty of Science research and publication committe, Faculty of Science Quality Assurance representative on the University Quality Assurance Committee, Head of Department and Deputy Dean Faculty of Science among others.

Professor Lazarus Abore Mbaya has taught Postraduate students and supervised two PhD students (one from NIMS University of Jaipur Rajasthan India) as co supervisor; five M.Sc students; over 8 Postgraduate Diploma and Masters in Environmental Management in addition to over 30 at undergraduate level respectively. In terms of research output Professor Lazarus Abore Mbaya and others secured three research grants funded by TETFund (IBR). He has / is also been an external examiner of Geography Departments (undergraduate) Nigeria Army University Biu; Postgraduate Taraba State University Jalingo and Federal University of Kashere, Gombe and Department of Environment Science National Open University of Nigeria.

Professor Lazarus Abore Mbaya is an active member of several Professional organizations and academic bodies such as Teachers Registration Council of Nigeria (T R C), Association of Nigerian Geographers (ANGs), Nigeria Environmental Study Team (NEST), Member Nigerian Conservation Foundation (NCF) and International Society for Development and Sustainability

He is happily married and blessed with five children.

INAUGURAL LECTURES OF GOMBE STATE UNIVERSITY

LECTURE SERIES	NAME	TITLE	DATE
1st	Prof. Ibrahim Waziri Abubakar	Western Healthcare System in Northern Nigeria: An outline of its Foundation and Development	27th January, 2022
2nd	Prof. Oluwasanumi Adedimeji Adepoju	The Infrangible Nature of Knowledge: The need for Researchers to be Multipotentialities	15th December ,2022
3rd	Prof. Mahmoud Umar	Public Sector Reforms in Nigeria: The Imperatives of New Public Governance Model	25th May, 2023
4th	Prof. Adewale Olukayode Ogunrinade	Aladura and the Perpetuation of Indigenous Christianity Among the Yoruba	13th July, 2023
5th	Prof. Rasheed Abdulganiy	Academicizing the Hadith: Comprehensive Exploration of Prophetic Guidance in Addressing Human Multi-Dimensional Challenges	26th September , 2023
6th	Prof. Halima Mohammed Abba	Green Solutions for a Sustainable Future	7th March, 2024
7th	Prof. Mohammed M. Manga	A Privileged Nomadic Microbial Warrior: Battles in Health and Medical Education	23rd April,2024
8th	Professor Bulus Wayar	Demographically Undetermined, Territorially Boundless, Linguistically Attritional: The Lifeline of Fulfulde in Africa	28th May, 2024
9th	Professor Seydou Hankouraou	Physics, Health and Sustainable Development	25th June, 2024

10th	Professor Danladi Adamu Bojude	Championing Community Oncology: Saving Lives, Empowering Communities	30th July 2024
11th	Professor Kennedy Poloma Yoriyo	The Lady Mosquito Which Underdeveloped and Kept Africans in A Poverty Vicious Circle	27th August,2024
12th	Professor Sani Adamu	Toxicology Versus Nutrition; Pro-Oxidants Versus Antioxidants; Each, A Coin with Two Sides: Which One Is the Killer?	26th November, 2024
13th	Professor Lazarus Mbaya	The Intractable Environmental Challenges in the Jewel State: Perspectives of a Geomorphologist	17th December, 2024