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Impacts and mitigation strategies for gully erosion: The Nigerian perspective

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ABSTRACT

The development of gullies and other forms of erosion have become the greatest environmental hazard and disaster rampant in southeastern Nigeria. Gully erosion is most often triggered or accelerated by a combination of inappropriate land use and extreme rainfall events. Geophysical methods such as electrical resistivity techniques has been the most used method in investigating gully erosion prone zones in southeastern Nigeria. Through productive review of existing research this study presents a comprehensive review of the causes and environmental impacts of gully erosion as well as control measures aimed at reducing and mitigating the threats posed by gully erosion within the region. From the study the major causes of gully erosion within the study area include both natural and anthropogenic sources. The study concludes that the most problem of gully erosion in southeastern Nigeria is damage to footpaths, roads and properties, while the least is loss of biodiversity. While control measures have been highlighted to mitigate the causes of gully erosion challenges in the area. These include diversion banks to divert runoff to a stable outlet to ease the flow run-off and stabilization walls should be constructed to prevent the encroaching endemic gully erosion from cutting the road, cultivation of vegetative cover and intensive community based campaigns were advised to minimize and control gully erosion.

***Keywords*:** Gully erosion, southeastern Nigeria, control measures, electrical resistivity techniques, Environmental impacts

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1. INTRODUCTION

Erosion is a world-wide phenomenon and has become one of the greatest environmental disaster facing many towns and villages in south-eastern Nigeria (Adekalu et al., 2007; Okpala, 1990; Igwe et al., 2021; Ebong et al., 2023). Four primary types of erosion resulting from rainfall occur, they are splash erosion, sheet erosion, rill erosion and gully erosion. Splash erosion is the first and least severe stage in the soil erosion process, this is followed by sheet erosion, then rill erosion and finally gully erosion which is the most severe as indicated by Zachar (1982); Toy and Forster (2002); El-Swaify (1990).

Brown (2020) defined gully erosion as the removal of top soil along drainage channels by surface runoff, consisting of an open incised and unstable channel generally more than 0.30m deep. Poesen et al., (2003) on the other hand defined gully erosion as the process whereby runoff water accumulates and also receives in narrow channels and over short periods removes the soil from this narrow area to considerable depth. Gullies have three dimensional natures that are affected by various factors such as surface hydrology, soils, topography, and land use among others.

The most active erosions are generally found along slopes which represent the flanks of paleo-depressions resulting from endogenic processes such as cuestas, fractures and joints (Onu et al., 2012; Gobin et al., 1999). Studies have shown that several areas within the south-eastern parts of Nigeria are susceptible to gully erosion (Ehiorobo et al., 2012; Abdulfatai et al., 2014; Igwe et al., 2023; Okorafor et al., 2017; Ebong et al., 2023). It involves the removal of top soils by surface water runoff along drainage channels (Singh and Hartsch 2019; Jain and Husain 2021). Gully erosion is a well-defined water worn channel (Monkhouse and Small, 1978) and have been recognized as an important environmental threat in many parts of the world (Ionita, 2006; Valentin et al., 2005; Poesen, 2018).

Many gullies grow rapidly to large dimensions making effective control technically difficult or prohibitively expensive (Valentin et al., 2005; Vanwalleghem et al., 2005a; Thomas et al., 2004; Nachtergaele et al., 2002;). Recent research and field studies have shown that gully erosion is one of the most soil degradation processes in most states of the southeast and south-south zones of Nigeria as it causes considerable soil loss and produces larger volume of sediment (Ocheli et al., 2021; Nwosu et al., 2022).

This region is fast becoming hazardous for human habitation (Ike 2017; Okwu-Dekunze et al., 2018). Hundreds of people are directly affected every year and have to be relocated to safer locations (Oluyori and Ojo 2021; Ebong et al., 2023; Jibo et al., 2020). One thing common to the known erosion sites in the country is that most of them begin as rills along slopes and develop gradually with time into gullies.

The man-made activities that has contributed to gully erosion hazard in south-eastern in Nigeria are construction of infrastructure such as road grazing and high population density (Brice 1966; Egboka and Okpoko 1984; Igwe and Orji 2019; Ebong et al., 2023). Most times, gully erosion get accelerated through human and other cultural activities which appear to interfere negatively with natural processes and degrade landforms, Industrial agriculture, deforestation, roads, anthropogenic climate change and urban sprawl are the most significant human activities stimulating erosion (Julien 2010).

Also Blanco (2010) and Lobb (2009) have shown that human activities that increase erosion rates include unsustainable agricultural practices such as mono-cropping, farming on steep slopes, the slash and burn treatment of tropical forests together with the use of pesticide and chemical fertilizer which in turn kill organisms that bind soil together. Gully erosion disrupt transportation and communication system, degrade arable land, contaminate water bodies, lead to isolation of settlement and migration of communities (Ehiorobo et al., 2013; Jibo et al., 2020; Bassey 2023). Gullies assume (diverse) destructive dimensions in many parts of the world particularly in the urban environment.

The exposure of tree roots, building foundations, utilities (e.g. electric and telecommunication poles, water pipes) and other structures are evidence of erosion problems in most of Nigerian towns and villages (Emeh and 1gwe, 2017; Akpokodje et al. 2010). It is enormous types of environmental degradation which leads to loss of valuable land used for agricultural, domestic, industrial and aesthetic purposes, as well as loss of property and even human lives (Obiadiet et al., 2011, Ebong et al., 2023, Vanmaercke et al., 2021, Abdulfatai et al., 2014, Igwe et al., 2023).

Field measurements have shown that the development of gullies increases sediment delivery to low lands and water courses. Recent studies (Wasson et al., 2002; Krause et al., 2003; de Vente et al., 2005; Huon et al., 2005) indicate that gully erosion is the most important factor responsible for generating of sediments, approximately about 10 and 95% of the overall sediments were produced at catchments level while a reduce amount of 5% of the entire catchments area often occupy by gully channel. In addition, the enlargement of gully channel enhances the overflow of fluvio-clastic sediments in the landscape and these consequently add to the menace of natural calamity such as flooding.

Wilkinson et al., (2015) reported that gully erosion contributes approximately 40% of all fine sediment to the Great Barrier Reef lagoon. (Poesen et al., 1996, 2003; Vanmaercke et al., 2012) reported that approximately 30–40% of additional catchment sediment yields are derived from stream-bank erosion. Furthermore, gullies can indirectly contribute to sediment loads by increasing the runoff and sediment connectivity between upland areas, valley bottoms and river networks or lakes (Poesen et al., 2003). The nature and type of sediments, and anthropogenic factors such as indiscriminate disposal of refuse may also contribute to the gully erosion development (Igwe et al. 2020).

These higher sediment loads and increased connectivity can result in a plethora of problems, including (muddy) floods (Verstraeten and Poesen, 1999), reservoir capacity losses due to sediment deposition (Haregeweyn et al., 2006), channel aggradation (Benda et al., 2003) and reduced water quality (Owens et al., 2005). As such, gully erosion is a great concern in many regions worldwide (Valentin et al., 2005; Poesen, 2018). It is a key process of land degradation and desertification (Vanmaercke et al., 2011), posing a significant threat to various ecosystems and ecosystem services (Kroon et al., 2012, 2016). Sediment from eroding gullies does not necessarily go straight to creeks and rivers. Larger soil particles such as sand and silt are readily deposited and move downstream as a series of pulses during larger floods. However, gully erosion from soils with a high percentage of clays—dispersive soils—can produce very small clay particles that remain in suspension and can result in turbid water.

Over the years, tremendous contributions regarding the understanding and behaviour of gully erosion and possible control measures have been documented by many scholars (James et al., 2007; Valentin et al., 2005; Poesen et al., 2003; Marzolff and Poesen, 2009; James et al., 2007; Li et al., 2003; Casasnovas, 2003. Recently, studies of gully erosion hazards have dominated discussion among earth and soil scientists and geographers (Abdulfatai et al. 2014; García-Ruiz et al. 2017; Igwe et al. 2017; Allen et al. 2018; Ocheli et al. 2021). Geophysical techniques like electrical resistivity tomography, DC-electrical resistivity sounding and ground penetration radar have been employed to solve several environmental, engineering, hydrogeological and hydrologic problems (Ebong et al. 2017, 2021b; Olabode and Adeniji 2022). The electrical resistivity technique is very popular due to its low cost, ease of application, and getting a fast result in comparison with the other methods (Lech et al., 2020; Virupaksha and Lokesh, 2021; AL-Awsi and Abdulrazzaq, 2022).

John et al., (2015) studied the external and internal structures of erosion sites in parts of Abia state, Nigeria to evaluate gully erosion sensitivity of sediments. The geophysical method employed was the VES technique using the Schlumberger electrode configuration. Results showed that the resistivity of the erosive materials range between 812.0 Ωm to 3,738 Ωm, while the depth ranges were between 16.6 m to 90.7 m.

Egbo and Airen (2023) carried out a joint investigation of gully erosion and landslides in Uteh, Edo state Nigeria. Electrical Resistivity Tomography (ERT) and Multichannel Analysis of Surface Waves (MASW) methods of geophysical investigation was used. Their result from 2-D resistivity subsurface imaging reveals presence of topsoil, clay, sand and coarse sand. The shear wave velocity and elastic parameters reveals soil ranging from soft to medium-stiff clays/dry sand/wet sand and medium-stiff to stiff saturated clays/dry sand/wet sand. This shows the susceptibility of the area to gully erosion due to incompetent soil structures.

Akanwa and Ezeomedo (2018) postulated that climate change and variability have escalated flooding and land degradation problems such as gully erosion. Their study at Akpo, Anambra, Southeastern Nigeria, made use of field survey, remote sensing, and GIS to detect hazard-prone areas and conduct gully characterization. Their findings indicated that the surface soils were more erodible than the subsurface. Furthermore, gully length, maximum elevation, elevation gain, and maximum slope were correlated to a large distribution of gullies, aided by the generation of a sufficient volume of runoff.

Ocheli et al., (2021) carried out geologic and geotechnical investigations of part of the Anambra Basin, southeastern Nigeria to determine the implication for gully erosion hazards. Their study revealed that gully erosions are more pronounced in the study area with poor vegetation cover and a high degree of slope steepness. Grain size analysis revealed that the soils of the Nanka Formation have an average sand content value of 90.90% (sandy) and silt content value of 3.0% (low fine portions). The plasticity index of the fine portions indicates that the soils are weak plastic, with a mean value of 5.29%. The soils have an average cohesion value of 0.30 kg/cm^2 indicating a very weak cohesion. The soils are highly permeable; with an average value of 2.67×10^{-3} cm/s. The compaction test further revealed that the soils are loosely compacted.

Wang et al., (2016) studied the spatial distribution of the gullies of the overall basin in northeast China. The methods employed were Unmanned Aerial Vehicle (UAV), remote sensing data and the 3D photo-reconstruction. Their results showed that the sub-meter image revealed a strong ability in the recognition of various gully types and the topographic factors of elevation, slope and slope aspects exerted significant influence on the gully spatial distribution at the catchment scale and at a more detailed site scale.

Nwosu et al., (2022) worked on geospatial data analysis for flood and erosion characterisation: a case study of southern Anambra Nigeria, their results revealed that the surface unit has a large variation in resistivity ranging from 82.9 Ωm - 5420 Ωm and an average value of 1005.1 Ωm has an average thickness value of 1.13m. The soil competence data and the rose diagram all buttress the fact that the soil is highly erodible.

Okoyeh et al., (2013) carried out several ERT, VES-profiles where Schlumberger electrode array was used to delineate the depth to water table in attempt to investigate the wide spread gully erosion problems in Anambra State, Nigeria. Result showed that the vertical electrical sounding captured the shallow surface that is dominated by high resistivity sandy material underlain by low resistivity clayey materials. It was inferred that both the overland and subsurface flow processes are responsible for gully erosion problems confronting the area.

Nwilo et al., (2011) worked on assessment and mapping of gully erosion hazard in Abia State, Nigeria.

Geographic Information System (GPS) approach was used as the method. The result showed that gully erosion sites were well dispersed around false bedded sand stone geological formation and slope characteristics was ascertained to the greater than 15^o which encourage gully erosion activities. It was inferred that GIS approach allows for overlays of these factors, allowing identification and location of gully erosion sites and infrastructures which are affected. However, the causes of erosion in the study area are both anthropogenic (human causes) and natural factors.

Lazzari et al., (2006) used geophysical techniques, such as GPR and ERT in order to analyse the anthropic hazard due to cave distribution in Rabatana, southern Italy. Results showed an acceleration of underground erosional processes inducing an upward enlargement of cave vaults and sometimes their collapse. It was inferred that the interaction during recent centuries between human activity (caves excavation, birth and growth of an urban area) and the characters of the natural environment were the reasons of a progressive increase in hazard and vulnerability level of several sites in Rabatana.

Egbueri and Igwe (2020) used integrated field survey, hydrological, geotechnical and geomorphological approaches to investigate the impact of hydrogeomorphological characteristics on gullying processes in erosion-prone geological units in parts of Anambra Basin, southeastern Nigeria.

The results shows that hydrogeomorphology and soil engineering properties substantially influence the gullying processes in the area. However, areas underlain by the Nanka Formation have higher gullying intensity than in areas underlain by the Ogwashi and Benin formations due to variations in their hydrogeomorphological characteristics

Ebong et al., (2023) used geophysical techniques, such as electrical resistivity tomography (ERT) and direct current-resistivity sounding (DC-ERS), and ground penetrating radar (GPR) to assess a gully erosion site in Bacoco area of Calabar, Nigeria. The results revealed good contrast in the operative properties (i.e. electrical resistivity and dielectric permittivity) between competent and weak zones along the profiles close to the gully head. Their findings suggest the influence of structural control on gully formation and demonstrate its contribution to the complex interactions with other drivers, such as seepages through porous media and high-energy runoff due to intense rainfall.

Onu et al., (2012) used electrical resistivity, vertical and azimuthal sounding techniques as well as the self-potential method to study the Njaba River gully erosion site at Awo Omamma, south eastern Nigeria.

Results of the study revealed that the azimuths of the major axes of the anisotropy diagrams correlate significantly with the strikes of the geological formations with the coefficient of anisotropy varying from 1.30 to 1.70, indicating that structural in-homogeneities exist. Results of spontaneous potential data indicated that the strike of the gully which is oriented in the NW-SE direction is characterized by low SP values ranging from -50 to -100 mV; and low electrical resistivity values both flanked by a zone of higher SP and resistivity values.

Chikwelu and Chetty (2021) Used electrical resistivity tomography in investigating the internal structure of a landslide and its groundwater characterization in Nanka Landslide, Anambra state Nigeria. The study evaluates the persistent defiance of control measures by an active erosion, spanning a time period of two decades, using geoengineering and geophysical methods. Their results from geophysical models created indicate that this phenomenon was primarily a result of the lithologic formation within the area comprised mainly of clay, loose sands, and sandstone formation with mostly low resistivity values corresponding to the shale layers and groundwater zones.

The aim of this study is to review imparts and mitigation strategies for gully erosion, the Nigerian perspective and to update the review on gully erosion and environmental change. This review study on the potential causes of gullies within the coastal plain Sands will serve as guide to land developers to determine choice areas for certain infrastructure. It will suggest possible remediation and environmental hazard prevention practices that will be suited for the environment. It will also contribute to gully erosion database of Nigeria.

2. LOCATION, PHYSIOGRAPHY AND GEOLOGIC SITTING

Calabar is the capital of Cross River State and it is bounded to the east by the Republic of Cameroun, to the south by the Bight of Benin and to the west the Cross River. The study area lies between Latitudes 04°48′ and 05°06′N and Longitudes 8°16′ and 8°26′E and occupies an estimated landed area of ~ 275 km^2 (Figure. 1) with an average elevation of about 64m above sea level.

The town lies within the coastal mangrove forest region of Nigeria, results of meteorological analysis show that the study area is within the subequatorial region with average temperature of about 25 °C in the rainy season and about 30 °C in the dry season, the total annual rainfall ranges from 1500-3000 mm (Offiong and Edet, 1998). The climatic conditions are the hot and humid conditions controlled by the dry (November–April) and wet (March–October) seasons, respectively. The average relative humidity in the area is approximately 80%.

The intensity of the rainfall causes sediments along the runoff paths to dissolve, and these sediments are transported down the slope. The area belongs to the low land and swampland of south-eastern Nigeria.

The main rivers that are dominate the landscape of the study area; the Calabar and Great Kwa Rivers flowing southwards in the Cross River. The geology of the study area (Figure. 2) is coastal plain sands (Benin Formation) covers the Calabar south, Calabar municipality, Akpabuyo and parts of Odukpani Local Government Area of cross River state. Geologically, the area is composed of Tertiary to Recent, continental fluvialtile sands and clays, known as the coastal plains. This formation is characterised by alternating sequence of loose gravel, sands, silt, clay, lignite and alluvium. Furthermore rocks of the Cretaceous Calabar Flank and Pre-Cambrian Oban Massif underlie it.

The Coastal Plain Sands (Benin Formation) is by far the most prolific aquifer horizon in the area. Alluvial deposits overlie the Benin Formation in the Southern part of the study area (Amah et al., 2016).

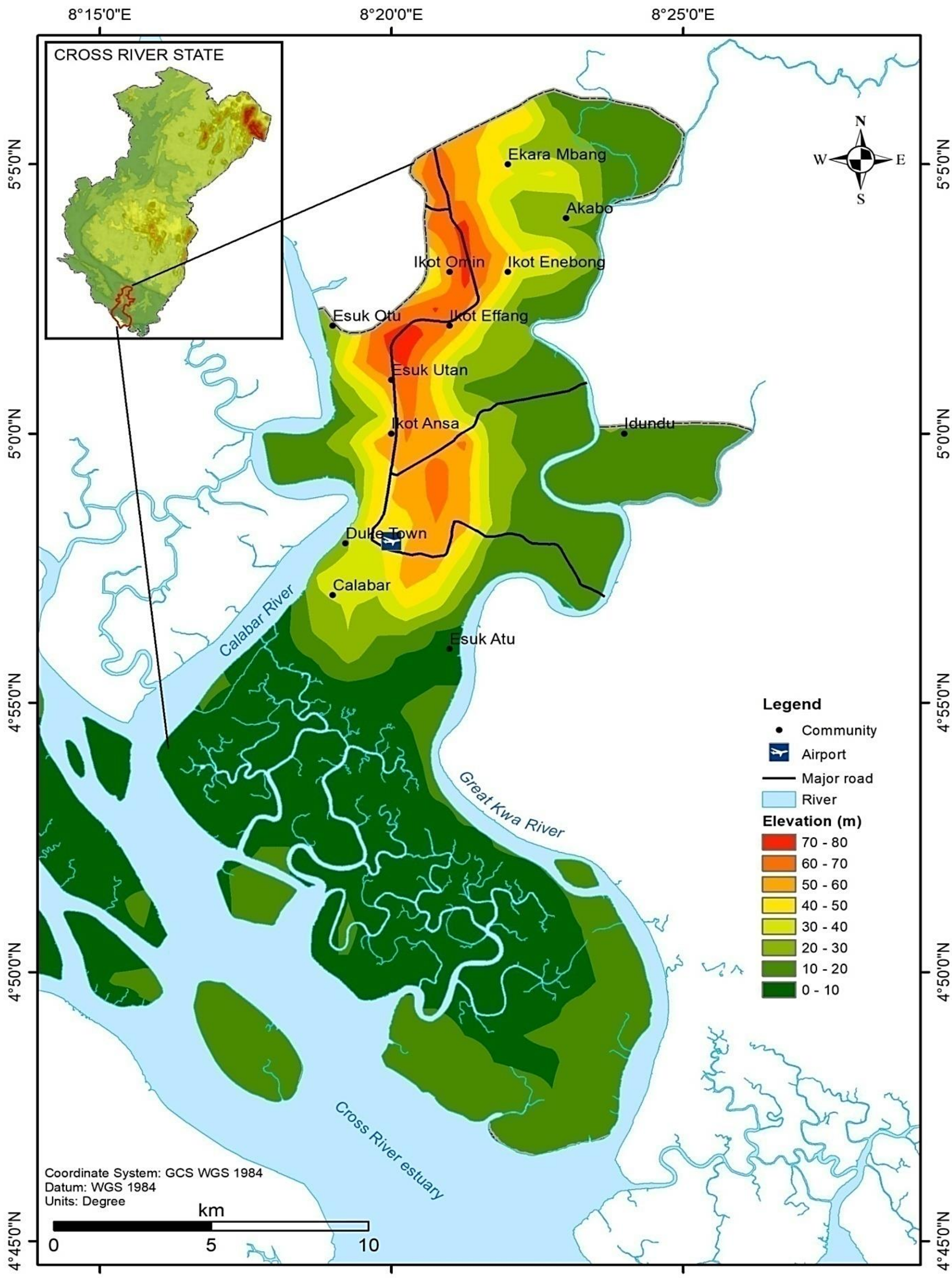

Fig. 1. Digital elevation map of Calabar

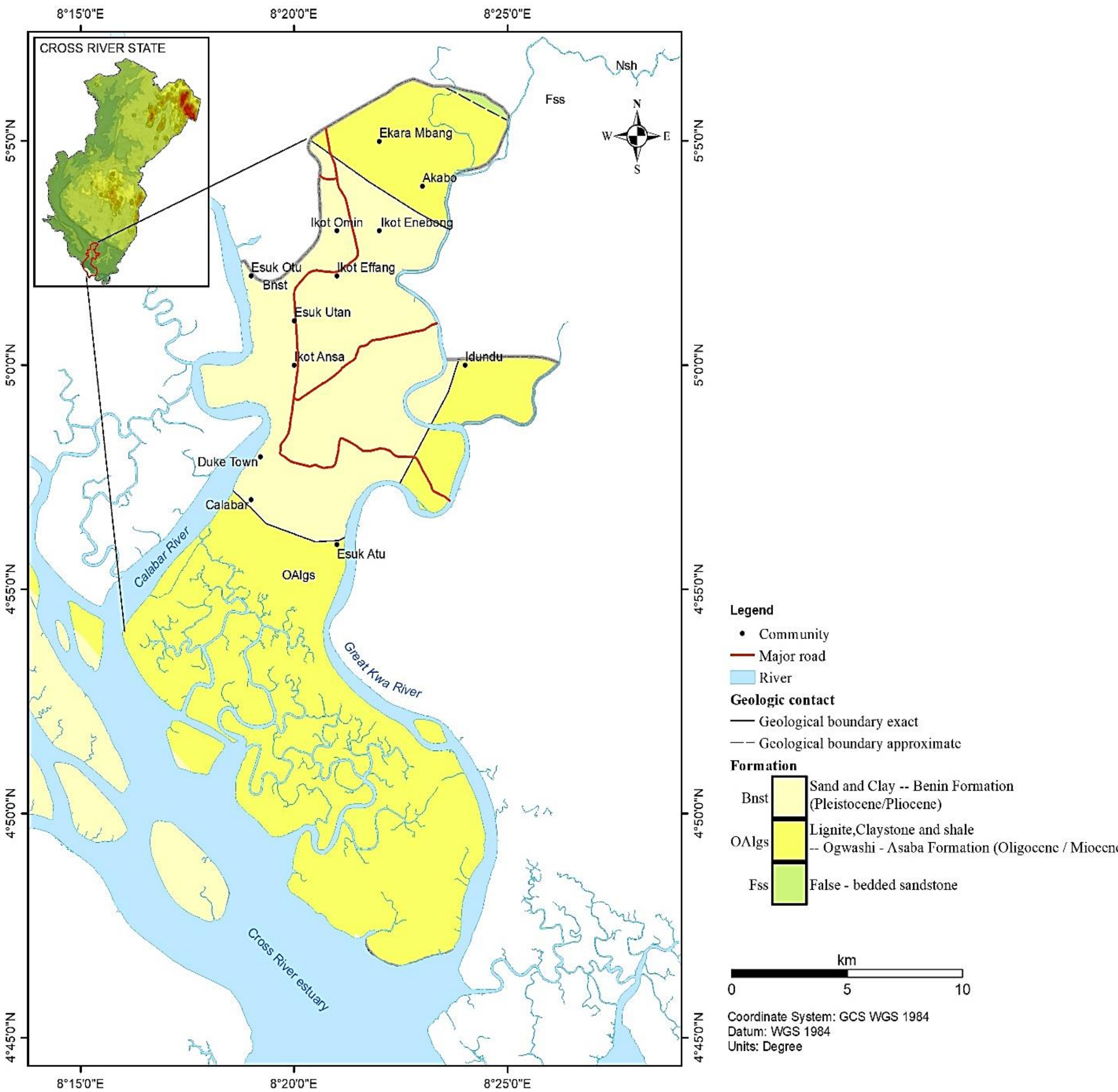

Fig. 2. Geologic map of Calabar

3. CAUSES OF GULLY EROSION

From the various studied literatures, gully erosion, in Nigeria, are more predominant in the sedimentary terrains and perhaps in the basement/sediment contact areas. This accounts for why its occurrences is more skewed to the southeastern Nigeria where most of the gullies take the advantage of the loosely consolidated and sometimes friable rocks (Abdulfatai et al., 2014; Ebong et al., 2023; Igwe et al., 2018). According to Igwe (2012), the rainfall of southern Nigeria is heavy and aggressive and the nature of the rainfall regime contributes significantly to erosivity of rainfall (potential, ability and strength of raindrops to cause soil disturbances that result in soil erosion) thus generating large volumes of runoff that initiate the development of waterways and channels that result in gullies. Egede (2013), Ezeabasili et al., (2014), Ebong et al., (2023) and Abdulfatai et al., (2014) collectively reported that soil erosion in the southeastern region of the country heightens, elevates and increases during the rainy season as a result of streams of runoff generated within this period. Salako (2006) also reported that land degradation in many tropical regions occur because of high rainfall erosivity and poor soil conservation practices within the rainy season especially. Ebong et al., (2023) reported that the complex interaction of geological and hydrogeologic forcing mechanisms (i.e. seepages through porous media, high-energy surface water runoff due to intense rainfall coupled with structural influence arising from underlying faults) to constitute the mechanism responsible for the recurring gully incision. According George et al., (2008), Osadebe and Akpokodje (2007), Onu (2005) and Teme and Youdeowei (2004); the southeastern region of Nigeria is susceptible to gully erosion due to the nature of the soil, topography and geology.

The geologic setting, tectonic and upliftment, geotechnical properties of soil, mining activities, farming, deforestation, and overgrazing operations have been widely reported to be the major causes of gully erosion in southeastern Nigeria (Brice 1966; Egboka and Okpoko 1984; Igwe and Orji 2019; Bassey 2023). It is observed that most of the residents engaged in farming as a means for survival. Thus, activities such as tillage, and other land use increase run off thus washing away of the top soil which is always to root of gully erosion. Adegboyega (2012) quipped that human activities such as construction works involving haphazard erection of buildings on steep terrains, ineffective or uncompleted drainage projects encouraged concentration of runoff and gullies. In most states within the southeastern region of Nigeria human interference with the environment through continuous excavation of borrow-pits and anthropogenic activities result in removal of soil vegetative cover are pivotal to gully erosion. Gully erosion can be caused in a number of ways, having different mechanisms, modes and conditions of formation; some of which are directly related to the underlying geology and the severity of the surface processes operating on the surface geology and soil cover. Ezechi and Okagbue (1989) summarized the types of gully erosion with respect to their modes and conditions of formation, and common advance mechanism (Table 1).

4. ENVIRONMENTAL IMPACTS AND IMPLICATIONS OF GULLY EROSION

The observed environmental impacts of gully erosion in the Southeastern Nigeria as well as those revealed in literature are enormous. Gully erosion usually has unpredictable impacts that are often serious and flashy (Nyssen et al., 2004). Gully erosion really hampers socio-economic activities in affected areas of the world. Gully erosion depletes the inorganic nutrients like nitrogen, phosphate, potassium and calcium present in the soil. It also carries away the organisms living in the soil, as a result of which the soil performs poorly.

This is because plant growth is stunted and crop yield declines. Again, because of gully erosion, related loss of productivity and increased population growth, the per capital food supply has been reduced over the past ten years and continues to fall. The loss of farmlands is also a major consequence of gully erosion in these areas (Abdulfatai et al., 2014; Igwe et al 2023). Gully erosion has given rise to infertile and barren land that may need to be reclaimed.

The problem with gully erosion is it’s difficult to fully reclaim the lost land (Bassey 2023).

Table 1. Gully types, modes and conditions of formation and common advance mechanism (Ezechi and Okagbue, 1989).

Gully type	Modes and conditions of formations	Common advance mechanism
Base level	Groundwater flow	Slope undermine, sliding and Slumping
Scarp	Runoff and slope change	Slope undermining. Sliding/ slumping, toppling
Fracture	Runoff and shrinkage fracture	Collapsing, also block failure
Incidental	Runoff concentration and vulnerable soil exposure by man	Common sliding/slumping.

This usually brings untold hardship to the inhabitants if the land is still inhabitable but has been severely affected. It has also affected commercial and many economic activities. A lot of industrial activities and industries have been affected by erosion menace. Cracking of houses and falling of buildings into gully sites are common features in the erosion prone areas. These properties whose value cannot be quantified accurately here have been destroyed and others are under treat by this menace especially houses and other properties located close to the gully sites (Figure 3a).

However, due to the wanton destruction caused by this endemic phenomenon, residents and their livestock have been relocated to safer areas (Ebong et al., 2023; Nest 2011; Igwe et al., 2023; Bassey 2023). People have lost their life investments into gullies in areas like Ikot Anwatim, Bacocco, EdimOtop, Nyanhasang, Ikot Nkebre and so on in Calabar southeastern Nigeria. Gully erosion has resulted in the separation of adjacent villages and towns as it may involve collapse of the bridges linking them together (Figure 3b).

Fig. 3. (a) Residential buildings under threat by gully at Bacocco calabar, **(b)** Road cut by gully erosion Ikot Nkebre calabar

This has had negative impacts on such areas since some facilities such as schools, hospitals and water supplies shared by the affected neighbouring communities may become inaccessible. Transportation of farm produce has also been affected and this also often leads to loss of agricultural products especially the perishable ones. Traders who also go to these areas for their trade are also cut off from their normal day to day business (fig3c). Many other small surface water schemes from springs and streams have been polluted or contaminated silted up and destroyed (Egboka et al 2019). Many of the streams and rivers have suffered severe pollution and siltation; the waters turn flood red or brownish in colour; there sandbars in the rivers or even some of the streams are totally-silted up. The plant and animal lives suffer damages or death while some plants wither away and their leaves turn brown.

5. CONTROL MEASURES TO MITIGATE GULLY EROSION

From the review literatures, currently, no adequate preventive or control measures to alleviate this challenge exist, and the gully area is increasing in size (i.e. width and length) every year during the rainy seasons (Ebong et al 2023). Poesen & Valentin (2003) observed that innovation in gully erosion control research is very limited compared to innovation in gully erosion process research. Control measures to stem gully erosion that are incipient are most effective when erosion is still at an early stage of sheet or rill erosion which is amenable to low technology intervention (Ike 2017). Proper land use and watershed management can be used to reduce Surface water runoff and control infiltration in order to dampen erosive forces and reduce the erodibility of soils. Plant roots reduce gully erosion in improving soil physical properties such as structural stability and infiltrability (Li et al., 1992; Li, 1995).

Fig. 3. (c) Gully erosion at Nyanhasang calabar

The importance of proper land use management for erosion control in the area had been reported (Igwe, 1999; Igwe et al., 2018; Abdulfatai et al., 2014). Some of the immediate control measures that were alluded to by previous studies included: provision of collection system for roof rain water runoff and its subsequent reuse; reduction of surface runoff from impervious surface; drainage of surface runoff, including the establishment of interception, division and primary (trunk) drains and the construction of interception ponds; planting of grasses on available favourable surfaces to reduce the amount of bare soils exposed to the erosive force of the rains, and to control infiltration; forestation in the areas more susceptible to gully formation and the planting of local cover crops such as indigenous leguminous plants. In addition, information on the causes of gully erosion and how it can be prevented are scarce. Many of these communities are not aware of the major causes of gully erosion and how it can be prevented, or how their actions are contributing to the problem.

Gully erosion can be control when communities engage in more public awareness initiatives and put in place structures that can govern and implement best land practices (Ezezika and Adetona, 2011). By ensuring that the public is more aware of the gully erosion problem and the best mitigating practices, as well as by putting in place proper legislative and administrative measures for land management practices, the initiation and reoccurrence of gully erosion may be prevented (Okagbue and Uma, 1987). Katherine et al., (2002) stated that understanding gully erosion mechanism is very important to design the gully erosion measurement system and develop its control. They observed that the use of vegetation to control erosion has been practised in many countries for centuries.

They enumerated some factors to consider when using vegetation to control erosion which include texture and layering of materials, existing vegetation and surface and groundwater movement from upslope and so on. Yifan et al., (2011) reported that the control of gully erosion can be divided into three approaches. The first is to try to stabilize the gully using the vegetation cover method, the second is to control the runoff flow from upstream of the gully and the third is to build some soil conservation works inside the gully to restore the hydraulic balance of the gully. There are two essential components to managing the erosion problem: rehabilitating the landscape to control the source of soil loss, and reducing sediment flow through the gully system. Thus certain measures have been highlighted to mitigate the causes of gully erosion in the area. These include diversion banks to divert runoff to a stable outlet to ease the flow run-off and stabilization walls should be constructed to prevent the encroaching endemic gully erosion from cutting the road.

6. CONCLUSIONS

Geophysical methods such as electrical resistivity techniques has demonstrated its proficiency in investigating vulnerable area where formations could yield easily to gully erosion hazards. Loose sand materials creates zones of weakness that triggers collapse of overlying materials with continuous underground flow thus causes gully erosion. Gully erosion is most often triggered or accelerated by a combination of inappropriate land use and extreme rainfall events. Under many circumstances gully erosion is the main source of sediment at the catchment scale. Once formed gullies can continue to generate sediment long after the triggering causes have ceased. The causes of gully erosion in south eastern Nigeria include both natural and anthropogenic sources. The study concludes that the most problem of gully erosion in south eastern Nigeria is damage to footpaths, roads and properties, while the least is loss of biodiversity. The following measures are suggested as possible strategies to assist the public, government, researchers, land developers and affected communities in mitigating the causes, development and consequences of gully erosion in the South eastern Nigeria

i) The gully walls around the affected area should be stabilised with concrete works, drains and other engineering structures that can help in reducing the driving forces.
ii) Geotechnical advice on the suitability of restraining works and other geotechnical designs, e.g., pile works, anchoring works and cast in place pile works that can bind mass movement should be sought and implemented.
iii) Introduction of vegetation in affected communities should not just be limited to planting of woody trees whose canopies intercept raindrops and form larger ones that have more kinetic energy to detach soil particles, but should include planting of grasses that would absorb the kinetic energy of the larger raindrops formed by the canopies.
iv) Deep rooted native trees, e.g., African oil beans, mahogany, Indian bamboo and shrubs that have extensive root systems and high transpiration rates should be planted in the area so that they can help in stabilising the banks.
v) Public awareness: the government, non-governmental organizations and community leaders must regularly inform the public especially those from affected communities to adopt farming and other forms of human activities that will not exacerbate gully initiation.
vi) Environmental regulations which discourage cementing of residences of individuals within gully erosion prone communities should be established
vii) Thus, the above suggested strategies can be used to mitigate gully erosion challenges in the study area

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