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An Assessment of Gully Erosion Expansion at Ikeduru Local Government Area, Imo State, Nigeria

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ABSTRACT: *The study investigates the assessment of gully erosion expansion in Ikeduru LGA, Imo State, Nigeria (2017 to 2022). The specific objectives of the study are to determine the demographic structure of the respondents from Ikeduru LGA; examine the adverse socio-economic and environmental impacts of the gully erosion on the various land uses in the study area between 2017-2022; analyze the geotechnical indices for the soil samples in the study area; measure the rate of gully expansion at the study area; and examine indigenous approaches in mitigating gully expansion in the study area. A Tayo-Yamane sampling technique was used to select one hundred (100) respondents for the study. Descriptive statistics, t-tests, and correlation analysis were used to test the five hypotheses. The study revealed the adverse socio-economic and environmental impacts gully erosion had on the indigenes of Ikeduru LGA and also the geotechnical indices of the soil samples of the study area, its causes, and approaches to mitigate against gully erosion, especially barrier, and a sound drainage system. The study thus concludes that our environment is a part of our social and economic survival, and what happens within the environment in which we live can negatively impact our survival. More so, for greater effectiveness, the solution to the impact of gully erosion is to treat it urgently. Among the recommendations is that there should be a massive public awareness campaign on the problems and consequences of gully erosion and that environmental laws and severe penalties for offenders be enacted. This will go a long way in making the inhabitants adhere to environmental best practices, thereby mitigating the menace.*

Keywords: Erosion, Ikeduru, Gully, Geology, Environment, Soil

INTRODUCTION

Over the years, there has been a tremendous increase in environmental problems, mainly in the human environment. Among these multi-faceted ecological issues that plague the global community is gully erosion. A gully is the removal of the topsoil along drainage channels by surface water runoff. Similarly, it describes the washing away soil particles from one geographical space to another by a high water flow at the peak of a heavy downpour or after (Eni et al., 2020). According to Obiefuna and Jibrin (2012), Gully initiation is the outcome of localized erosion by surface runoff and soil eluviation linked to intense rainfall episodes, and it is readily observable in the field because of its striking morphological expression on the landscape. It is soil erosion comprising an open, incised, and unstable channel, generally 30cm deep or more (Bongdap, 2020).

Gully erosion may occur in a variety of ways, with diverse methods, modes, and circumstances of development, some of which are directly tied to the underlying geology and the severity of surface processes working on the surface geology and soil cover (Abdulfatai et al., 2014). It may occur due to man's activity on the land surface, such as tin mining, construction, grazing, deforestation, and farming. This may begin at a small area of land and will continue to move by slumping the sidewalls until it has taken over a large portion. Gully erosion occurs most often in areas where the contributing effects of land use, climate change, and slope interaction are prominent (Bongdap, 2020).

Gully erosion is a major environmental problem in Nigeria (Ogbonna and Hiroshi, 2014; Albert et al., 2006). It affects nearly every part of the country but is more aggressive in the southeastern part, resulting in land degradation and destruction of lives and properties. Some of the gully erosion sites reported in Nigeria include Abariba (Abia State), Efom Alaye (Ekiti State), Nsukka and Ugwuaba area of Enugu state, and Agulu Nanka gully site of Anambra State (NEST, 1991). The continuous upsurge of gully erosion in southeastern Nigeria has resulted in the most significant environmental hazard and disaster. Recent reports revealed about 2,800 active erosion sites in the South-East of Nigeria. This is problematic as the menace posed by gully erosion has undermined and minimal agricultural productivity, sustainability, and management.

On the other hand, the availability of farmlands for agricultural production and construction activities has significantly been reduced by losses caused by the attendant issues of gully erosion. For instance, soil erosion has adversely affected food security and agricultural productivity within southeastern Nigeria. This calls for an urgent need to control and manage soil erosion.

Recent reports have revealed the negative impact of gully erosion. Roads, drainage systems, and transportation infrastructure are destroyed. Destruction of Other Infrastructure is one of them. In Anambra State, for example, the World Bank-funded Greater Onitsha Water Scheme was completely destroyed by floods and gully erosion from the Nkpor-Onitsha areas. The destruction of historical monuments and archaeological artifacts is, among other things, a source of socio-psychological distress and constant fear of the unknown. The Federal Ministry of Agriculture estimates that erosions in Nigeria wash away over 40 million tons of soil annually (Federal Republic of Nigeria, 2007). This devastating situation has attracted regional and national attention, as they impede the movement of goods and persons from one region to another within the country, further leading to the loss of other valuable infrastructure. Considering these scenarios, studies that address gully erosion will help with environmental sustainability, hence the basis for this current study.

STATEMENT OF PROBLEM

The rainfall behavior in Nigeria's southern and eastern regions is generally heavy and aggressive. The eastern area, located north of the equator in the humid tropics, has two different seasons: rainy season (April-October) and dry season (November-March). The average annual temperature is between 26-27◦C. In the south and central parts of the state, the rainy season lasts about 7 or 8 months, but towards the far north, it reduces to about six months. The rains are of high intensity and of a bimodal pattern with two peaks in July and September and 2-3 weeks of little or no rain (called August Break) in between (Essien and Essien, & NIMET 2012). The dry season gives rise to the post-season characteristics of a maximum rainfall regime. The months with the heaviest rainfall are usually June and July for the first rainfall maximum and September for the second maximum. The annual rainfall ranges from 2,000mm on the northern fringe to over 3,000mm along the coast (Essien and Essien, & NIMET 2012). The type of the rainy cycle plays a considerable role in rainfall erosivity. Rainfall erosivity refers to the propensity for rain to produce erosion. It is also determined by the physical properties of rainfall (Onwualu et al., 2006). Obi and Salako (1995) found that raindrop diameters in the Guinea savannah ecological zone of West Africa ranged from 0.6 to 3.4 mm. The average drop size (D50) for 28 rainfall events varied from 1.1 to 2.9 mm. According to experimental findings, intensity and energy are most likely associated with erosivity.

The factors that influence gully erosion could be natural or anthropogenic. One of the most important variables influencing gully erosion is rainfall; gully erosion is caused by the amount, kind, and frequency of rainfall (Romkens, Helming, and Prasad, 2002). Pathak, Wani, and Sudi (2005) asserted that rainfall is an important factor in gully erosion; intense rains coupled with soils prone to sealing and crusting generate high runoff volume and concentrated flow. Rainfall erosivity is defined as the aggressiveness of rain to induce erosion to soil (Lal’s, 2001). It is a major contributor to gully erosion (Romkens, Helming, and Prasad, 2002). The higher the amount of rainfall, the higher the number of soil particles that are dissolved, displaced, and moved away, which causes gully erosion (Chimelu, Okeke, Nwosu, Ibe, Ndukwu and Ugwuobi, 2013)

The formation and expansion of gullies have become one of the most critical environmental challenges plaguing many cities and villages in South-South and Southeast Nigeria. New gully sites form during each rainy season as a result of torrential rainfall, the region's underlying geology, severe soil erosion, and undulating topography, as well as the removal of vegetal cover due to urbanization and other anthropogenic factors (Udoumoh et al.,2021). The massive soil loss caused by gully formation causes severe ecological damage, soil fertility depletion, significant loss of soil structure, loss of life, reduced soil biodiversity, decreased agricultural output, food insecurity, disruption of socioeconomic activity, causing untold hardship, as well as surface water pollution in the catchment region (receiving water bodies). There are several such examples around the nation, and it is generally known how socially significant it is when highways are disrupted. Individuals and communities are severely physically and psychologically harmed when intervention initiatives fail. They further stated that as intervention measures fail and gully erosion expands, communication and power lines are broken, churches and schools collapse, roads are washed off, water schemes are damaged, and lines are lost. In southeastern Nigeria, for instance, due to landslides accompanying the flooding, houses were washed into the gullies that sometimes developed with their inhabitants. Additionally, as families are uprooted and forced to flee as refugees, fields and agricultural products are swept away. Social and economic lifestyles are disrupted Egboka (2007).

Gully erosion constitutes a major ecological problem in southeastern Nigeria and requires adequate scientific and technical competence in its prevention and control. Over the years, the gully erosion at the Ikeduru local government area of Imo State, Nigeria, has increased alarmingly, posing a serious environmental concern. A recent pre-survey shows that gully erosion sites have taken over important areas like roads, farmland, residential areas, market areas, etc. Despite this situation, no data and remedies for solving the problems seem to exist.

Recent studies show that gully erosion could result in biodiversity loss and inadequate provision of ecosystem services, affecting human health and the environment. Similarly, there are reports that many lives have been lost as a result of the problem of gully erosion, Frank et al. (2021). Some either fell into these gullies and sustained various degrees of injury or died. Some instances have also been reported where people are drowned in some of the gully sites, Frank et al. (2021). This entails that the issue of gully erosion requires urgent attention to avert the consequent danger to the environment and humans (Frank et al. 2021).

Considering this menace, the current study aims to investigate the level of gully expansion at the Ikeduru local government area in Imo State, Nigeria. This will provide data generated through field measurement and survey that will help to mitigate and control the dangers posed by gully erosion in the area and other erosion sites.

RESEARCH QUESTIONS

1. What is the demographic structure of the respondents from Ikeduru LGA?
2. What are the adverse socio-economic and environmental impacts of gully erosion on the various land uses in the study area between 2017 and 2022?
3. What are the geotechnical indices for the soil samples in the study area?
4. What is the rate of gully expansion in the area?
5. What are the indigenous approaches to mitigating gully expansion?

RESEARCH HYPOTHESIS

1. H_0: The demographic structure of respondents from Ikeduru LGA does not differ significantly.
2. H_0: The adverse socio-economic and environmental impacts of the gully erosion on the various land uses in the study area between 2017-2022 do not differ significantly.
3. H_0: The geotechnical indices for the soil samples in the study area do not differ significantly.
4. H_0: The rate of gully expansion does not differ significantly among the sampling locations.
5. H_0: The indigenous approach in mitigating gully expansion does not differ significantly among the sampling locations.

SIGNIFICANCE OF THE STUDY

Gully erosion poses a serious threat to environmental sustainability and human life. Soil investigation is a prerequisite for any serious environmental work as it is essential to study and understand the engineering characteristics of the underlying soil formation. This will provide necessary information regarding the geology, soil and foundation conditions, drainage characteristics, soil type, groundwater conditions, etc. The information obtained will help us determine whether the soils in the study area possess the characteristics that make the area prone to gully erosion, and it will guide the design engineer in providing an effective erosion control design.

Therefore, the results of this study will provide strategies to lessen and minimize the effects of gully erosion. The geotechnical findings from this study will also serve as a policy-making tool for government agencies such as the Ministry of Environment, Erosion and Ecological Management, and the National Emergency Management Agency. Other agencies that will benefit from the study include non-governmental organizations (NGOs), NIMET, Research Institutes, and the Ministry of Agriculture and Forestry. The study will also help to conserve biodiversity and preserve ecosystem services for a sustainable environment and human survival.

In Nigeria, the southern region has more severe landslides than the northern region, and Gully erosion is the leading source of landslides in Southeast Nigeria (Boniface et al. 2019). Boniface et al. (2019) also reported that Landslides often occur due to the widespread prevalence of huge, deep gullies in the southeast of Nigeria and the yearly effect of floods by precipitation. In the town of Nanka in Nigeria's Anambra State, a significant landslide in 1988 forced more than 50 people to be evacuated. According to an investigation, an over-consolidated, very plastic mudstone layer (PI=67) that likely contains significant amounts of montmorillonite clay was the source of the landslides. The beginning of gullies is brought on by localized erosion by surface runoff associated with high-intensity rainfall events. Typically, erosion is concentrated in regions where forest cover has been removed for agricultural purposes, where vehicle traffic, foot activity (both human and animal), and traffic on roads and off-road areas have unevenly compacted the surface soils.

Additionally, it occurs as soils and sediments rub up against man-made objects, particularly in poorly constructed road culverts and gutters along the side of the road. Gullies can also form at the intersections of permeable sand springs and less permeability deposits in sedimentary layers. Gullies spread via sapping, caving in, and sliding at the gully head and along the walls and sides. Stormwater runoff also transports material downward from the gully's floor.

The elements that cause soil erosion and the development of gullies are erosivity and erodibility. Rainfall, a natural occurrence unaffected and uncontrollable by humans, impacts erosivity, Obi and Salako (2017). Southeast Nigeria frequently experiences significant rainfall intensities. According to Obi and Salako, rainfall events with intensities between 100 and 125mmh-1 are expected to happen more than five times yearly. According to Hudson (1981), erosive storms have an intensity of 25 mm/h.

In contrast, erodibility is influenced by soil characteristics, topography, and land management. Appropriate land management is crucial in Southeast Nigeria, where the region's geotectonic, geology, and geohydrologic features render many regions prone to gully erosion—an illustration. For instance, cuestas, fractures, and joints are frequent characteristics in Southeastern Nigeria's gully-erosion-prone regions and have been recognized as important elements in developing gully erosion and landslides.

SOIL EROSION AND THEORIES OF SOIL CONSERVATION

The increased severity of resource degradation and related soil erosion issues in some parts of sub-Saharan Africa is one of the main modern difficulties facing environmental scientists and policymakers. These issues become more obvious since the area loses around six tons of soil to erosion each year (Steri-Younis, 1986). The rationale for soil preservation is human survival and environmental sustainability. We cannot consider soil conservation just from an economic perspective due to the tenacious nature of the soil. Due to its current and projected production, every parcel of land has a certain market value. However, the inherent worth of land is considerably larger than its monetary value since it can provide human food and clothing for numerous generations. This cannot be quantified in terms of money (Kohnke and Bertrand, 1959). The link between soil loss and land production is the most significant land resource attribute (Mbagwu, 1986).

Different soil conservation methods (SCTs) have been utilized worldwide to prevent soil deterioration, particularly for erosion control. These SCTs include reforestation, mulching, and various ways of soil management, although biological strategies seem to be the most successful. (Keesstra et al., 2016; Carpenter-Boggs et al., 2003).

Biological techniques (BTs) are methods that absorb organic matter and nutrients, enhance soil structure, and employ live, dead, or dormant organisms to lessen or minimize the "splash effect" (direct impact of rainfall on the ground), surface runoff, and erosion. BTs were shown to be the most effective SCTs in a global investigation of the impact of SCTs on the reduction of water erosion and surface runoff by Xiong et al. (2018).

Xiong et al. (2018) compared BTs with soil management methods (STs) and engineering techniques (ETs) and found that BTs were more efficient in minimizing soil and water loss than ETs and STs (e.g., BTs had an efficiency of 88 percent for soil and 55 percent for surface runoff).

In addition to preventing soil erosion, BTs like mulching, reforestation, buffer strips, grain for green, hedgerows, cover crops, exclosures, and strip cropping also preserve, recreate, and sometimes even strengthen the functional relationships between soil, vegetation, fungi, bacteria, and other living things. In other words, BTs provide exceptional synergy between living and nonliving systems, enhancing the ecosystem.

According to the research by Xiong et al. (2018), the effectiveness of SCTs varies depending on terrain, climate, and land use, whether biological, managerial, or engineering. As a result, such factors must be considered in prediction models of erosion, surface runoff, productivity, soil usage, and conservation. This was shown by Chen et al. (2017), who assessed the effectiveness of various terracing types for erosion control under various conditions of use and slopes and came to the following conclusions: (1) bench terraces were the most effective; (2) terraces associated with trees and forests retained the greatest amount of soil and water; and (3) the greatest decreases in erosion occurred on slopes of 11-15 degrees and 26-35 degrees.

According to Winpenny (1991), here are lists of the advantages of soil and water conservation,

- Eliminated losses in agricultural yields caused by soil erosion, loss of soil depth and fertility, or loss of land due to gully erosion; substituted fertilizer savings to sustain yields on degraded soils.

- Value of improved livestock outputs from restored or improved pasture, better use of crop leftovers, or from fodder, trees, or other sources of wood used for construction (timber, poles, fuelwood, feed, fruit, etc) (meat, milk, wool, dung)

A managed mixed regime's ecological advantages result in higher agricultural yields (increased soil organic matter, more soil moisture retention, shading, etc.). To prevent the disastrous effects of soil and water deterioration, farmland erosion prevention is essential in the state of Enugu.

SYSTEM THINKING AND THEORY OF LAND DEGRADATION

When handling intricate issues like soil erosion, system thinking is especially helpful. These issues cannot be resolved by a single person any more than a complex system can be comprehended completely from a single viewpoint. Additionally, as complex adaptive systems are always changing, system thinking is focused on adaptive management and social and organizational learning.

Environmental problems such as soil erosion exist as a system with subgroups and exist in isolation. It could be likened to a cancerous cell that could become widespread and all-pervasive. The major causes of soil erosion could be human interference with climate factors (rainfall), poor geology, undulating topography, and soil nature (Okore et al.,2017). Thus, gully erosion can be addressed holistically by incorporating various measures, including planting vegetative covers like trees and bamboo, digging catchment pits for flood waters in compounds and public open spaces, providing adequate drainage channels for flood water control, environmental education through public enlightenment program, maintaining a sound environmental system and good environmental planning.

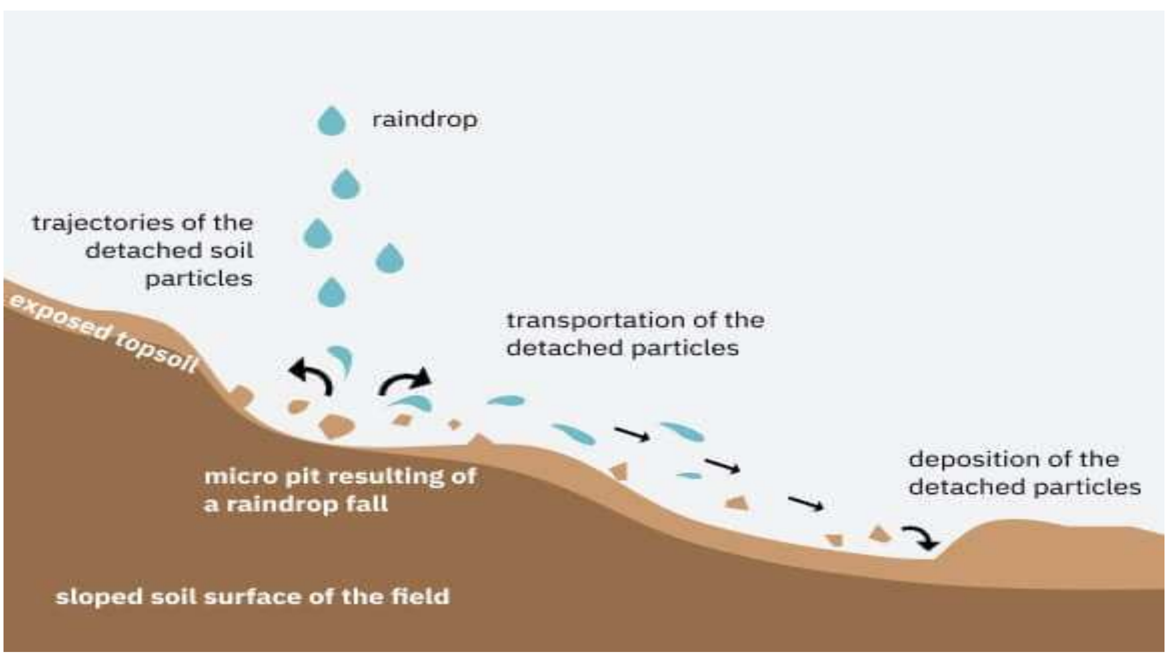
The process of removing surface material from the earth's crust, mostly soil and rock debris, and then having that material moved from the site of removal by natural forces like wind or water is known as soil erosion (Encyclopaedia Britannica, 2020; Brown and Wolf, 1984). Gully erosion can further be defined as the erosion of the soil by flowing water in a well-defined channel, and it is readily observable in the field because of its striking morphological expression on the landscape (Obiefuna & Jibrin, 2012). It is a serious form of land degradation, a major problem facing developing countries, and it is projected to become an even more severe constraint (Bennett, 1930; USAID, 1979). In addition, gully erosion is defined as a decrease in the land's present or prospective uses as well as a reduction or total loss of the soil's productive capacity for use now or in the future (Blaikie and Brookfield, 1987). Maiangwa et al. (2007) emphasized that the causes of land degradation include soil erosion, flooding, deforestation, and agricultural and industrial practices. A gully is any eroded channel deeper than 30cm, and some gullies can be many meters deep.

CAUSE AND EFFECT MODEL OF EROSION

A process (the cause) and another process or condition (the effect) are linked irreversibly by a cause-and-effect connection, in which the first partially causes the second, and the second partially depends on the first (Bunge, 1960). This seems to be an extremely obvious statement, but that is not always the case. Natural phenomena are complicated and intertwined, often overlapping and making it difficult to establish a natural order.

Each area's vegetation, soil depth, gully features, and effects on agricultural fields were assessed, along with the reasons for gully erosion. The findings indicate that gully erosion is influenced by a number of factors, including inadequate rangeland plant cover, excessive grazing, human activity, intense and brief rainfall, inappropriate land use, unsuitable irrigation design, improper water discharge in the channels, and soil characteristics. Gully erosion seriously impairs agricultural fields, resulting in decreased soil quality and quantity, increased surface runoff, decreased soil water-holding capacity, a drop in groundwater levels, and decreased agricultural output. It exacerbated poverty and social issues as well as the movement of people from rural to urban areas. According to Jahantingh et al. (2011), it also seriously damaged building sites, including roads, bridges, and towns.

Fig.1 Process of Gully Development



Source: (Grover, 2022)

The figure above shows that rainfall is the major factor responsible for soil erosion. On a global scale, about eleven million hectares of arable lands are annually lost through erosion processes, which are greatly encouraged by poor resource management. For instance, around a quarter of a million tons of topsoil are washed from the deforested mountain slopes of Nepal alone each year (Meyers, 1985). It is the human activity that causes natural erosion rates to increase many times over. Steep slopes are cultivated without terracing, poorly developed irrigation projects, and livestock overgraze grassland.

Gullies develop when enough surface water concentrates in a flow line with inadequate ground cover, resulting in soil scouring until a deeper channel is formed. The inadequate ground cover can be a small starting point: disturbed soil, a livestock or vehicle track, or a stump. Once started, gullies can spread downslope and upslope (gully head erosion).

Severe gully erosion is usually caused by extreme rainfall from storms and cyclones. With the projected changing climate, summer storms in the southwest are forecast to be more common and severe. When most pastures and crop stubbles are dry and ground cover is reduced, the timing of these storms increases the risk of water erosion. In extreme conditions, not all gully erosion can be prevented.

NATURE, TYPES, AND DISTRIBUTION OF GULLY EROSION

South-eastern Nigeria's soil erosion may be divided into two main categories: anthropogenic (accelerated) and physical (geological or natural) (Ofomata, 1988). The physical environment of a place makes it vulnerable to all sorts of erosion because of its type of geology, soil, terrain, and climate. The worst and most frequent types of erosion are sheet erosion and gully erosion (Akamigbo, 1988). There are several other kinds of erosion.

Table 1: Nature & Types of Erosion

EROSION TYPE	DESCRIPTION
Natural Erosion	Erosion is seen as natural when the earth's surface is eroded by water, ice, or other natural forces under unaltered, natural environmental circumstances such as climate, vegetation, etc. This is a synonym for geologic erosion and has no bad outcome (Akamigbo 1986 and 1998). Chude (2005) asserts that natural erosion is a constant occurrence and an integral aspect of how the landscape is naturally formed. Agriculture does not experience this erosion since some soil is generated in the same location as the dirt is withdrawn. Under the natural climatic circumstances of climate, vegetation, and other factors unaltered by man, the earth's surface is being worn away by water, ice, or other natural processes. Geologic erosion is the same as this and doesn't have a bad outcome (Akamigbo 1986 and 1998). Natural erosion occurs continuously and is an integral element of the natural process that shapes the landscape, according to Chude (2005). As some soil is being created in a place where dirt has been lost, this sort of erosion does not pose issues in agriculture.
Normal Erosion	This is the slow erosion of human-used land that does not significantly outpace natural erosion. Our goal while farming is to save and manage soil well so that the amount of erosion on the farmland doesn't increase over average. Here, there is hardly any loss (Akamigbo, 1998).
Accelerated Erosion	This erosion is occurring far faster than typical natural geological erosion. This is mostly due to the impact of human activity, or in certain circumstances, animal activity and other causes (Akamigbo ibid and ibid). The amount of soil lost and the pace of soil loss are far larger in artificial erosion than in natural erosion. It is called anthropogenic since it is brought on by human actions like clearing forests, burning brush, leveling slopes, gathering stones and sand, etc (Chude, 2005).
Splash Erosion	This is the procedure through which raindrops separate soil particles. This happens when raindrops strike a damp, bare soil surface devoid of vegetation. Extremely heavy rain on some soils can cause a soil particle to leap or rise 2 feet above the ground and travel up to 5 feet horizontally. A strong downpour can splash up as much as 224t/ha. The presence of soil particles on the underside of green vegetables proves that splash erosion occurs even on cropland. Raindrop size and soil structure type both have a direct impact on splash erosion. The disfigured particles are eliminated by sheet erosion and surface runoff. This is the procedure through which raindrops separate soil particles. This happens when raindrops strike a damp, bare soil surface devoid of vegetation. Extremely heavy rain on some soils can cause a soil particle to leap or rise 2 feet above the ground and travel up to 5 feet horizontally. A strong downpour can splash up as much as 224t/ha. The presence of soil particles on the underside of green vegetables proves that splash erosion occurs even on cropland. Raindrop size and soil structure type both have a direct impact on splash erosion. The disfigured particles are eliminated by sheet erosion and surface runoff. This is the procedure through which raindrops separate

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Sheet Erosion	This is the process through which runoff water and other factors remove a reasonably homogeneous layer of soil off the ground's surface. Our agricultural areas are more at risk from this form of erosion because it removes the humus topsoil. Due to its regular, continuous, and slow effect, it frequently passes unnoticed. Because it is difficult for the farmer to see, it turns the land barren and has devastating 26 effects. It can ultimately lead to the topsoil's arable portions being completely removed. The topsoil is eventually stripped of its finer components and plant nutrients due to this sheet erosion process, leaving only coarse, barren materials behind (Akamigbo 1986, 1998, and ChudeAccording to UNEP (2008), sheet erosion is a phenomenon in which a significant amount of surface soil is lost by almost blank sheet flows of surface or near-surface water. Nationwide, sheet erosion occurs but is rarely seen because of its "deceitful" gradual growth. Rainfall flows down slopes and gradually eliminates the top soil layers, disastrously impacting agriculture.
Rill Erosion	This erosion process results in innumerable tiny channels are only a few centimeters deep. Following a rain storm, it mostly happens in recently farmed lands. Rill erosion happens when water from tiny streams that flow across terrain with poor surface drainage removes soil. Rills are frequently observed between rows of crops. Even though tillage may quickly eliminate its effects, this area is the most frequently disregarded, and if it is not filled in, it might lead to gully erosion. Farmers can manage it with ease (1998, Akamigbo)
Gully Erosion	This erosion occurs when water collects in small fissures, rills, or channels. Over a short period, the soil is removed from the channel to significant depths, ranging from 30 to 60 centimeters to 23 to 30 meters or more. Gully erosion, in contrast to sheet erosion, is more noticeable since it leaves an impressive trace on the earth's surface. The visible manifestation of the land's physical decline. 27 Gully growth can occur both uphill and downhill. A little rill can become a massive gully overnight after a severe downpour. Gully erosion is another name for rapid soil erosion, and once it has started, it may be very difficult and expensive to halt. It is very bad in Abia, Imo, Anambra, Enugu, Ondo, Edo, Ebonyi, Kogi, Adamawa, Delta, Jigawa, and Gombe. Anambra and Enugu States alone in the southeast feature approximately 500 active gully complexes, some of which are over 100 meters long, 20 meters broad, and 15 meters deep (UNEP, 2008).
Streambank Erosion	Erosion along the river banks happens during and between rainfall, unlike sheet, rill, and gully erosion, which only happens during or after. As alluvial soils, typically the most productive, are degraded by stream bank erosion, the impact on nearby arable land is dramatic (Akamigbo, 1998).
Wind Erosion	This is the result of the wind moving soil particles. The particles may be as small as sand, which can be displaced by drifting on or near the ground. In the West African dry tropical Zone, where annual precipitation is less than 600 mm, the dry season lasts more than six months, and steppe-type vegetation leaves significant swaths of land exposed, wind erosion is a significant problem. When huge volumes of surface matter are crushed fine during the soil preparation, it might grow elsewhere. The dry season and the first few months of the rainy season, when there is less vegetation on the ground, are when wind erosion is most prevalent in the most impacted areas. This is the result of the wind moving soil particles. The particles may be as small as sand, which can be displaced by drifting on or near the ground. In the West African dry tropical Zone, where annual precipitation is less than 600 mm, the dry season lasts more than six months, and steppe-type vegetation leaves significant swaths of land exposed, wind erosion is a significant problem. When huge volumes of surface matter are crushed fine during the soil preparation, it might grow elsewhere. The dry season and the first few months of the

	rainy season, when there is less vegetation on the ground, are when wind erosion is most prevalent in the most impacted parts of Nigeria (Rose, 1996).

Source: Compiled by Author

CAUSES OF GULLY EROSION

Before mitigating the effects of gully erosion, there is a need for a proper understanding of the causes. Identifying the cause of gully erosion in a given area is a first step in control and mitigation measures. Without understanding the causes of the erosion, any control measures taken may be a waste of time and money, which may even worsen the problem (Augustine et al., 2019). Gully erosion may result from various mechanisms, modes, and circumstances, some directly tied to the geological structure and the severity of the surface processes acting on the surface geology and soil cover. (Abdulfatai et al., 2014).

The causes of gully erosion concerning the geologic settings, as suggested by the earlier studies, are numerous. Some of the identified natural causes include tectonism and uplift, climatic factors, and geotechnical properties of soil, among others. Anthropogenic causes include farming, uncontrolled grazing practices, deforestation, and mining activities (Abdulfatai et al., 2014).

Studies on soil erosion in Nigeria concluded that forest clearing was the main driver of soil erosion. Similar ideas were shared by subsequent researchers, including those who suggested that the gully erosion in southeastern Nigeria started with removing vegetation cover (Nwachukwu and Onwuka, 2011). Erosion predominates in areas subjected to bush burning, continuous cultivation, and mining on hillside slopes, all of which are common and long-term traditional practices in southeastern Nigeria (Nwachukwu and Onwuka, 2011). Akpokodje and Akaha (2010) reported that the initiation and development of gullies are facilitated by natural processes such as rainfall, topography, and soil structure.

A study reported that the major causes of soil erosion include human interference, climatic factors (rainfall), poor geology, undulating topography, and soil nature (Okore et al., 2017). They recommended control measures such as cultivating vegetative cover, proper soil and water conservation practices, crop management techniques, and intensive community-based campaigns.

Ajayi et al. (2019) reported that anthropogenic activities commonly cause soil erosion. These human activities include dumping refuse in water, soil excavation, poor siting of fences, deforestation, bush burning, road construction, and residential buildings without drainage. On the other hand, Bongdap (2020) identified continuous and heavy rainfalls and mining activities as the causes of gully erosion in Plateau State, Nigeria.

RESEARCH GAP

Available reports center on causes and approaches to mitigating and controlling gully erosion. However, minimal reports focus on the geotechnical investigation of these gully sites. Also, reports on rainfall characteristics and the nature and distribution of gullies are limited. Most workers have not paid attention to the level of gully expansion at Ikeduru LGA. Hence, this study provides necessary information for enhanced planning, management, and control of gully erosion in the area.

STUDY AREA

The study area is the Ikeduru local government area in the West of Imo state. It is located on longitudes 70 04 'E and 70 14 and latitudes 5o 29 N and 5o 39 N (see figure 2). Ikeduru has boundaries with Isiala Mbano on the North, Owerri North Local Government Area on the South, and Aboh Mbaise and Ahiazu local government areas on the West. The gully site is at Ugirike link road connecting Ama-Imo and Mbaise communities. The headquarters of Ikeduru is at Iho. The LGA is made of 17 communities, namely Avuvu, Atta, Eziama, Amakohia, Ngugo, Ikembara, Akabo, Abazu, Uzoagba, Amaimo, Inyishi, Iho, Okwu, Umudim, Ugiri, and Eziama (See Figure 3.2). Each community experiences a different degree of erosion, ranging from sheet erosion to severe gully erosion, and they share common cultures, boundaries, and markets.

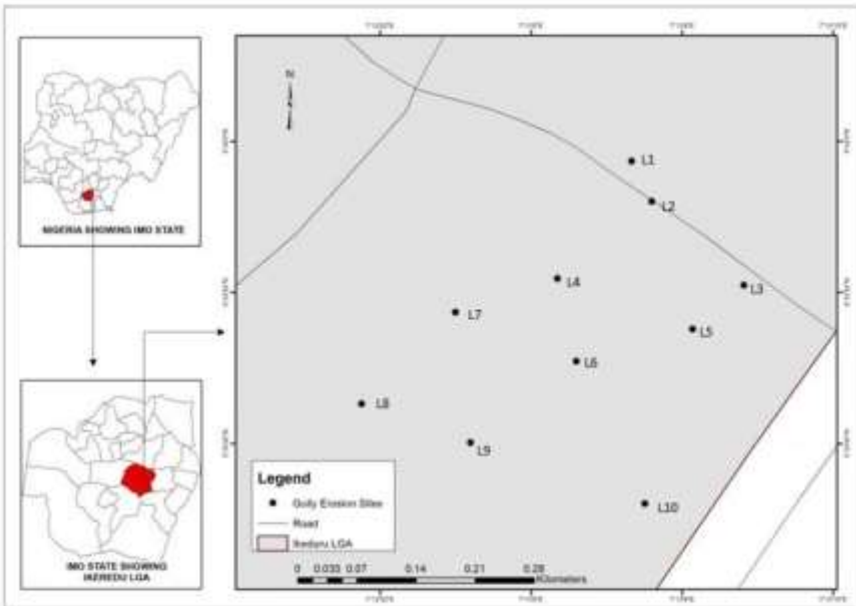
The population of Ikeduru is 199,316 people, according to the National Population Census (NPC, 2007). It is in the humid tropics with over 2000mm of rainfall per annum and a mean annual temperature of about 27◦c. The rainy season in this region starts in March or April and ends in between October & November.

Ikeduru is from the Tertiary geological epoch and has unconsolidated and sandy coastal plain sands. The area is drained by a series of rivers and streams: Mbaa, Oramirikwa, and Okitankwo. These are the major water resources in the area. These rivers are characterized by dry valleys, usually covered by flood during the rainy season when the aquifer is recharged. The economic activities of the people include farming and trading.

Each of the gullies is located within latitudes 5° 33’ 46.19‟N and longitudes 7° 13’ 31.19‟E 94 m for Trial Pit 1, latitudes 5° 33’ 44.48‟N and longitudes 7° 13’ 31.72‟E 90 m for Trial Pit 2, latitudes 5° 33’ 43.03‟N and longitudes 7° 13’ 32.93‟E 82 m for Trial Pit 3, latitudes 5° 33’ 41.23‟N and longitudes 7° 13’ 29.93‟E 99 m for Trial Pit 4, latitudes 5° 33’ 50.60‟N and longitudes 7° 13’

13.84‟E 78 m for Borrow Pit 1, latitudes 5° 34' .88‟N and longitudes 7° 13' .07‟E 96 m for Borrow Pit 2 in the tropical rain forest zone of Nigeria. The study region has more than 2500mm of rainfall annually and a mean maximum temperature of 27 °C. January and February saw early precipitation, while the rainy season officially begins in March and ends in November every year. The duration of the dry season is four to five months. The months of July through October have the most rainfall, with August seeing a brief reprieve in precipitation known as the "August break." The location is easily accessible via federal highways from Okigwe - Owerri Road.

Figure 2: Map of the study area showing sampling locations



Source: (Arch GIS, 2021)

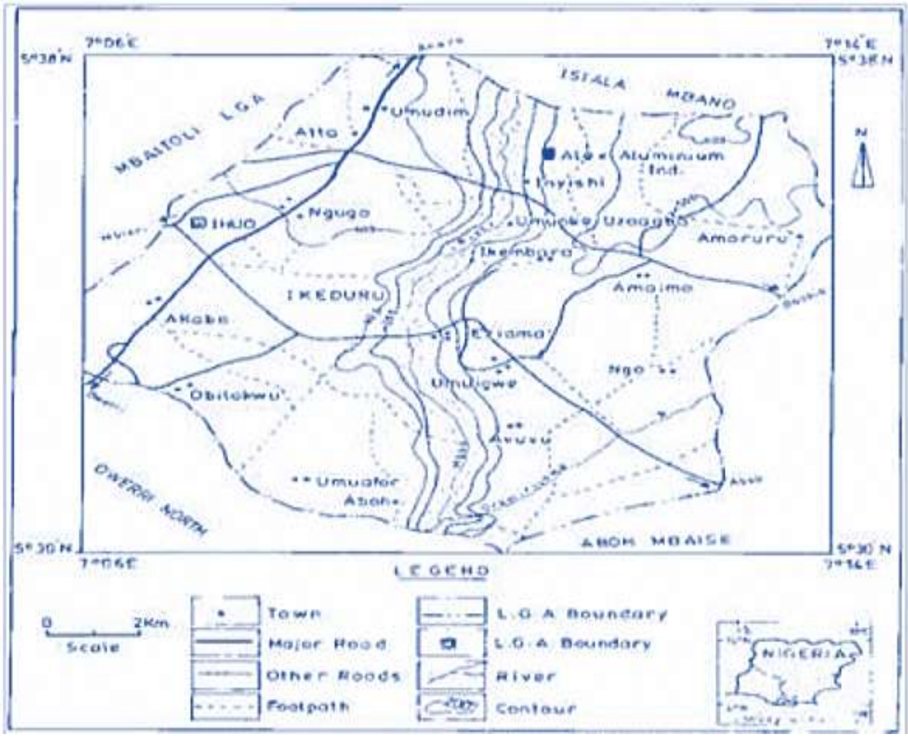
Table 2: Gully Erosion Site Measurements

Gully erosion measurement points	GPS readings
Point 1	N 5°33′ 6′′ E7°14′ 16′′
Point 2	N 5°33′ 59′′ E7°13′ 5′′
Point 3	N 5°33′ 57′′ E7°13′ 6′′
Point 4	N 5°33′ 42′′ E7°13′ 29′′
Point 5	N 5°33′ 44′′ E7°13′ 29′′
Point 6	N 5°33′ 43′′ E7°13′ 30′′
Point 7	N 5°33′ 43′′ E7°13′ 31′′
Point 8	N 5°33′ 42′′ E7°13′ 32′′
Point 9	N 5°33′ 42′′ E7°13′ 32′′
Point 10	N 5°33′ 41′′ E7°13′ 33′′

Source: (Field Work, 2022)

Table 2 above shows the exact locations and measurement points for the 10-gully erosion in the study area. These points are the linking roads commuters, businessmen, and women use for their trades and businesses from Ugiri-ike to Aforu-oru in Ahiazu Mbaise in Ikeduru LGA, Imo State.

Fig 3. Map showing communities in Ikeduru



Source: (Chukwuocha et al 2014)

CLIMATE AND VEGETATION OF STUDY AREA

The climatic condition of Ikeduru LGA is that the average daily temperature is 27◦C. Average annual rainfall is 1750 – 2000mm, while relative humidity oscillates between 71.6 – 86.6%. According to the USDA soil classification scheme, the soil type is Ultisol, derived from the coastal plain sands (Benin Formation) (Gordon Amangabara et al., 2014). Influenced by the topography (relief is about 240m), rainfall distribution is uneven and mainly concentrates in the rainy season. In addition, the undulating gradient and frail geology make the soils of Ikeduru susceptible to erosion.

GEOLOGY OF STUDY AREA

The basins of the Anambra and Niger Rivers comprise the research area's geology. The major crustal blocks extended and sank during the Gondwana supercontinent's lower Cretaceous breakup era, giving rise to the Anambra River Basin, a NE-SW trending syncline that is a component of the Central African Rift System. The distributaries of the Anambra, Idemili, and Njaba Rivers, which run from east to west and obstructively drain into the River Niger, which flows southward into the Atlantic Ocean, are all part of the nearly north-south trending River Niger, which includes the River Niger Basin. Likewise, the Imo and Cross Rivers, along with their tributaries, run southward and empty into the Atlantic Ocean in the eastern region. Soon after the sporadic Upper Cretaceous rifting, more plate activity in the lower Tertiary restarted the tectonic motions that formed the Anambra Basin and other places. Geologic formations like Missions Hill and Abakaliki Hill are hills that extend from northeast to southwest. The majority of the hills are made of sandstones and volcanic rocks. It is found that some streams originated from these hills that recharge the rivers that drain the area. There are several locations where folded Cretaceous limestone and shale outcrops may be found. A dendritic drainage pattern is created in the region by the natural flow patterns of rivers and their tributaries. The waters of these lakes, rivers, tributaries, and distributaries, as well as the groundwater components, flows, and fluxes they contain, greatly influence the genesis, development, and dynamics of landslides and gullies in southeast Nigeria. The area's geology is a major factor in the causation of gully erosion and massive landslides in several communities. In denudation, the sand-filled sections of the Ajalli Sandstone, Ameki Formation, and Nanka Sands are frequently exposed as sand outcrops. There may occasionally be underlying and overlaying shaley elements in these sandy formations, which might serve to hold the sandy units together. These geologic formations have aquifers or saturated groundwater components, and the pore water pressure in these aquifers facilitates the movement of sedimentary materials and groundwater flows. These Formations' sedimentary units occasionally produce escarpments or cuestas that can fold, fault, and fracture with joint fractures and planes of weakness, all of which promote landslides and gully erosion. Blocks of rocky sands and shale sedimentary units may separate and slip into the gully troughs downslope.

RESEARCH DESIGN

This study adopted fieldwork and survey research design. The fieldwork, which involved geotechnical investigation, was done in two parts: fieldwork and laboratory tests, while the field survey centered on physical observation and measurement of the gully catchments.

The fieldwork consisted of manually excavating four Nos. Trial Pits and two Nos Borrow Pits. Both were excavated and sampled using manual labor to achieve the required sample collection volume. The trial pits were intended to provide information about the underlying soil formation's physical characteristics and obtain soil samples for laboratory analysis, while the borrow pits were for control analysis. Disturbed soil samples were collected in the gullies at varying depths, labeled and wrapped in clean polythene bags, and conveyed to the laboratory for testing. Borrow pit soil samples were collected at exposed points, labeled, wrapped, and conveyed to the laboratory for control tests.

The samples were used for soil classification tests, wrapped in clean polythene bags, sealed to prevent moisture loss, and labeled. All the soil samples were conveyed to the laboratory for testing.

For laboratory testing, Representative soil samples were collected from the boreholes, tightly sealed, and transported to the laboratory, where they were subjected to further visual inspection and the following tests:

(1) Atterberg limits (Liquid and Plastic) and the plasticity index (PI) were also determined.

(2) Specific gravity

(3) Natural moisture content

(4) Bulk density

(5) Mechanical sieve analysis

(6) Quick Undrained Triaxial Tests.

(7) Compaction Tests

(8) Cbr Tests

The aims of the soil investigation comprise the following:

- To establish the index properties of the soil within the proposed project site;
- To classify the soil based on the index properties;
- To ascertain the soil's carrying capability.
- To compare the geotechnical properties of the trial pits concerning the control pits.

One hundred (100) copies of the questionnaire were provided to some of the people in the research area; of those copies, more than 100% were successfully returned.

This study adopted content, context, and construct validation to ensure the questionnaire was appropriate for the study. A step-by-step method was used to design and administer the survey questionnaire. A draft questionnaire was previously identified in the literature. A pilot survey was conducted to make sure the questionnaire was appropriate for the study and properly addressed the study topic. Hence, the questionnaire instrument was tested for reliability and validity using Cronbach's alpha and co-efficient, which gave 0.81 from the pilot survey.

The statistical software package SPSS Version 20 was used for data analysis. The data were shown using the frequency distribution and additional descriptive statistics. Charts and tables. When appropriate, inferential statistics were employed to assess the data, including descriptive statistics, a Person's product correlation coefficient, two sample T-tests, and a Z-test. A 95% confidence level and a significance level of $p<0.5$ were established.

DATA PRESENTATION AND ANALYSIS

The data presented and analyzed here are rainfall characteristics from the year 2010-2021, nature and distribution of the gully sites, data on the perception of the stakeholder concerning the demographic structure of the respondents, the socio-economic and environmental impacts of the gully erosion of the sample locations, the geotechnical investigation from fieldwork and laboratory analysis in the study area, the rate of gully erosion expansion and approaches in mitigating against gully expansion. After that, the research hypotheses were tested with the study research questions.

Demographic Review

In line with the study's first objective, "to determine the demographic structure of respondents from Ikeduru LGA," tables 3-7 were used to achieve this objective.

Table 3: Age Structure of Respondents from Ikeduru LGA

S/N	Response	No.	%
1	21-30 years	48	48
2	31-40 years	32	32
3	41-50 years	13	13
4	Above 50 years	7	7
TOTAL		**100**	**100**

Source: Fieldwork, 2022

Table 3 of the survey shows that 48% of participants are in the age range of 21 to 30 years old, while 32% are between 31 and 40 years old, respectively. Those representing 13% and 7% each are between the ages 41 and 50 and above 50 years, respectively.

Table 4: Gender of Respondents from Ikeduru LGA

S/N	Response	No.	%
1	Male	54	54
2	Female	46	46
	TOTAL	**100**	**100**

Source: Fieldwork, 2022

Table 3 reveals that 54% of the respondents from Ikeduru LGA are male, while the remaining 46% are female, which comprises the gender structure of the respondents.

Table 5: Cross-tabulation on sex-duration of stay

Issues Raised	**Outcome**				**TOTAL**
Sex * Length of Stay	< 2 years	2-5 years	6-10 years	> 10 years	
Male	24	10	20	-	54
Female	-	16	10	20	46
TOTAL	**24**	**26**	**30**	**20**	**100**

Source: Fieldwork, 2022

Table 5 reveals that out of the 54% of males in the area, 24%, 10%, and 20% of respondents have stayed less than two years, 2-5 years, and 6-10 years in the area, respectively are male, while out of the remaining 46% of female residing in the area. 16% and 10% of the respondents have stayed 2-5 years and 6-10 years, respectively, and 20% of residents above ten years are female.

Table 6: Educational level of Respondents from Ikeduru LGA

S/N	Response	No.	%
1	Primary	10	10
2	Secondary	50	50
3	Tertiary	12	12
4	No formal education	28	28
TOTAL		**100**	**100**

Source: Fieldwork, 2022

Table 6 demonstrates that half of the participants have completed secondary education. While 10% are only educated up to the primary level. 12% and 28% of the remaining respondents are educated up to tertiary level and have no formal education, respectively.

Table 7: Occupation of Respondents from Ikeduru LGA

S/N	Response	No.	%
1	Civil Servant	10	10
2	Farmer	45	45
3	Site workers	30	30
4	Student	10	10
5	Other	5	5
TOTAL		**100**	**100**

Source: Fieldwork, 2022

Table 7 reveals that most respondents, totaling 45%, farm on these gully-eroded lands daily. In comparison, 30% are site workers, and 10% of each of the remaining respondents are civil servants and students, respectively, with visitors making up 5%.

Socio-Economic and Environmental Review

In line with the study's second objective, "to examine the adverse socio-economic and environmental impacts of the gully erosion on the various land uses in the study area between 2017-2022", Tables 8-10 were used to achieve this study objective.

Table 8: Social Impacts of Gully Erosion Expansion in Ikeduru LGA

S/N	Item	No.	%
1	Destruction of ancestral homeland	55	55
2	Loss of source of water supply	18	18
3	Frightful scenic environment	15	15
4	Experience of trauma	12	12
5	Loss of relatives	-	-
	TOTAL	**100**	**100**

Source: Fieldwork, 2022

Table 8 shows that 55% of respondents constitute those who suffered the destruction of their ancestral homeland. In comparison, 18%, 15%, and 12% each of the respondents constitute those who experienced a loss of a source of their water supply as a result of destroyed boreholes, those who find the gully site frightful and experience trauma respectively as a result of the gully erosion.

Table 9: Economic Impacts of Gully Erosion Expansion in Ikeduru LGA

S/N	Item	No.	%
1	Loss of building & furniture	5	5
2	Loss of farmland	50	50
3	Loss of planted crops	25	25
4	Loss of economic trees	10	10
5	Loss of monetary contributions	10	10
	TOTAL	**100**	**100**

Source: Fieldwork, 2022

Table 9 shows that 50% of the respondents lost their farmlands due to the gully erosion. 20% constitute those who lost monetary contributions due to the gully site. In comparison, 10% of each respondent lost economic trees planted crops, buildings, and furniture due to the gully erosion expansion.

Table 10: Environmental Impacts of Gully Erosion Expansion in Ikeduru LGA

S/N	Item	No.	%
1	Reduced access to lands	60	60
2	Changes in overland flow causing sedimentation	8	8
3	Increased rates of erosion exposing subsoil materials	18	18
4	Sedimentation of waterways & supplies	14	14
5	Increased pollution from agricultural & chemical effluent in incised waterways	-	-
	TOTAL	**100**	**100**

Source: Fieldwork, 2022

Table 10 reveals that 60% of the respondents had reduced access to their lands due to the gully erosion. 14% indicated that their borehole pipes had been washed out and exposed due to the gully erosion. At the same time, 18% and 8% of respondents constituted increased exposure to the subsoil materials and the sediment changes in the overland flow, respectively.

Soil Samples in the Study Area and their Geotechnical Indices

Tables 11-12 were used to achieve the third research objective, which is "to analyze the geotechnical indices for the soil samples in the study area." The high elevation and gently steep slope, combined with the geotechnical properties of the soils, were the initial conditions that triggered landslides and gully formations in the study area, resulting in the large lateral extents, widths, and depths of the gullies, as shown by the field and geotechnical evaluations of the soils in Tables 11 and 12.

Table 11: Field measurements for gullies in the study area

S/N	Longitudes (E)	Latitudes (N)	Elevations (m)	Lateral extents (m)	Depth (m)	Width (m)	Slope Angle (^{O})	Description
1	05°33′ 6′′	07°14′ 16′′	350.0	88.5	72.7	32.3	35	Steep Slope (SS)
2	05°33′ 59′′	07°13′ 5′′	323.0	82.5	50.4	30.7	14	Moderate-Slope
3	05°33′ 57′′	07°13′ 6′′	310.0	83.5	35.5	54.8	09	Gentle Slope
4	05°33′ 42′′	07°13′ 29′′	265.4	78.5	69.5	22.7	12	Moderate-Slope
5	05°33′ 44′′	07°13′ 29′′	180.6	86.0	40.6	72.6	16	Moderately (SS)
6	05°33′ 43′′	07°13′ 30′′	220.0	80.5	20.5	55.9	08	Gentle (SS)
7	05°33′ 43′′	07°13′ 31′′	280.2	40.5	41.0	62.5	32	Steep Slope (SS)
8	05°33′ 42′′	07°13′ 32′′	315.0	42.0	77.0	24.5	07	Gentle (SS)
9	05°33′ 42′′	07°13′ 32′′	120.0	93.0	31.2	42.0	08	Gentle (SS)
10	05°33′ 41′′	07°13′ 33′′	22.8	69.0	28.4	51.8	11	Moderate-Slope
			μ=238.7 SD=104	**μ=74.4 SD=18.6**	**μ=46.68 SD=20**	**μ=44.98 SD=17.1**	**μ=15.2 SD=10.1**	**Remark: Gentle Steep Slope**

Source: Fieldwork, 2022

Slope failures, fractures, and fracture slopes of varied degrees occur in the research region because of the clay sands' high permeability, non-plasticity, poor cohesion, low shear strength, and frictional angles between grains. The high permeability values indicate that the clay sands units P1, P6, and P8 in the research region transport an adequate amount of water into the underlying high plasticity and low permeability P2 and P3 (coarse grain clay) layers under heavy rainfall, run-off, and infiltration processes. Aforu Ugurike's sand-clay border develops a high pore-water pressure. As a result, the clay layers will expand, and sliding, shrinking, and swelling actions will occur along with the creation of an upward pull on the units of coarse to medium sand that is above them. The research region saw several slope collapses, debris soil slides, and gully formation as a result of the clay layer's alternating cycles of swelling and shrinking over the wet and dry seasons. Along with other landslide activity in the study region, it also causes new, fairly steep slopes to form at the base of the Aforu Ugurike sands. A number of landslides in the study region are caused by the coarse-grain clay units (P2 and P3), which act as gliding planes in addition to having extremely poor permeability and separating the sand units in the vicinity. The study area's inadequate drainage systems are unable to handle the extra runoff that occurs during the wet seasons. The extra water flow becomes confined in small, concentrated streams, which subsequently erode away at the surface of the soil to produce gullies of all shapes, sizes, and scales.

Table 12: Results of the geotechnical indices for the soil samples in the study area

Source: Fieldwork, 2022

S/N	**Longitudes (E)**	**Latitudes (N)**	**Samples Location (P)**	**Cohesion (KN/m^2)**	**Angle of Internal Resistance $(^{O})$**	**Coefficient of Permeability (m/s)**	**Liquid Limit (LL)**	**Plastic Limit (PL)**	**Plastic Index (PL)**	**Grain size**
1	05°33′ 6′′	07°14′ 16′′	P1	23	21	4.6 X 10^{-4}	43	24	19	Sandy clay
2	05°33′ 59′′	07°13′ 5′′	P2	20	23	4.0 X 10^{-4}	38	NP	NP	Coarse-grained sand
3	05°33′ 57′′	07°13′ 6′′	P3	19	21	3.6 X 10^{-4}	34	18	16	Sandy clay
4	05°33′ 42′′	07°13′ 29′′	P4	22	22	4.2 X 10^{-4}	40	31	9	Sandy clay
5	05°33′ 44′′	07°13′ 29′′	P5	23	22	4.2 X 10^{-4}	41	17	24	Sandy clay
6	05°33′ 43′′	07°13′ 30′′	P6	34	25	4.8 X 10^{-4}	46	36	10	Sandy clay
7	05°33′ 43′′	07°13′ 31′′	P7	34	22	4.2 X 10^{-4}	41	33	8	Sandy clay
8	05°33′ 42′′	07°13′ 32′′	P8	34	21	4.3 X 10^{-4}	45	32	13	Sandy clay
9	05°33′ 42′′	07°13′ 32′′	P9	34	21	4.2 X 10^{-4}	40	34	6	Sandy clay
10	05°33′ 41′′	07°13′ 33′′	P10	34	23	4.2 X 10^{-4}	42	35	7	Sandy clay
				μ=27.7 SD=6.8	**μ=22.1 SD=1.3**	**μ=4.2 X 10^{-4} SD=0.3 X 10^{-4}**	**μ=41 SD=3.4**	**μ=26 SD=11.5**	**μ=11.2 SD=7.0**	

Gully Expansion Rates

The gully sites where the sample points were taken have been subjected to natural and anthropogenic activities that have depreciated the site's terrain over the years. Research was carried out to examine the level of environmental degradation that has affected the site within five years (2017-2022). This data set is used to achieve objective four, “to measure the rate of gully expansion at the study area” of the study.

Fig 2: Satellite Image of Gully 2017

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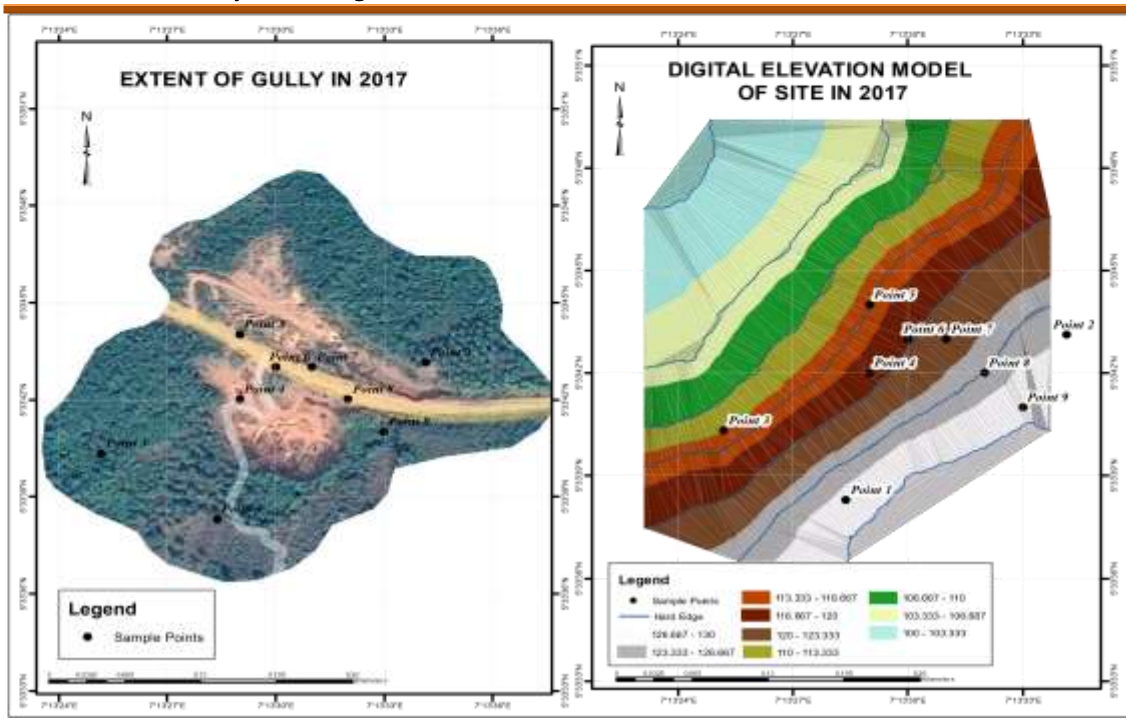
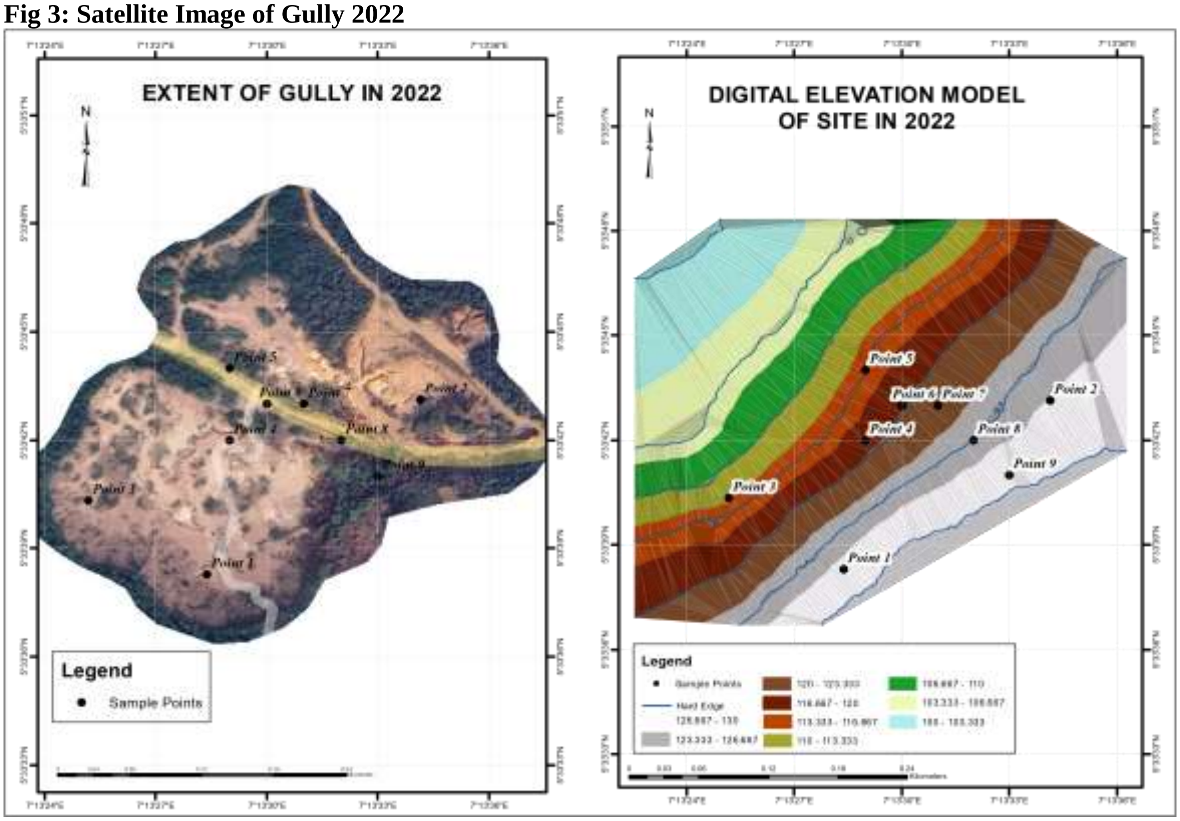


Source: Google Earth Satellite Imaging

Fig 3: Satellite Image of Gully 2022



Source: Google Earth Satellite Imaging

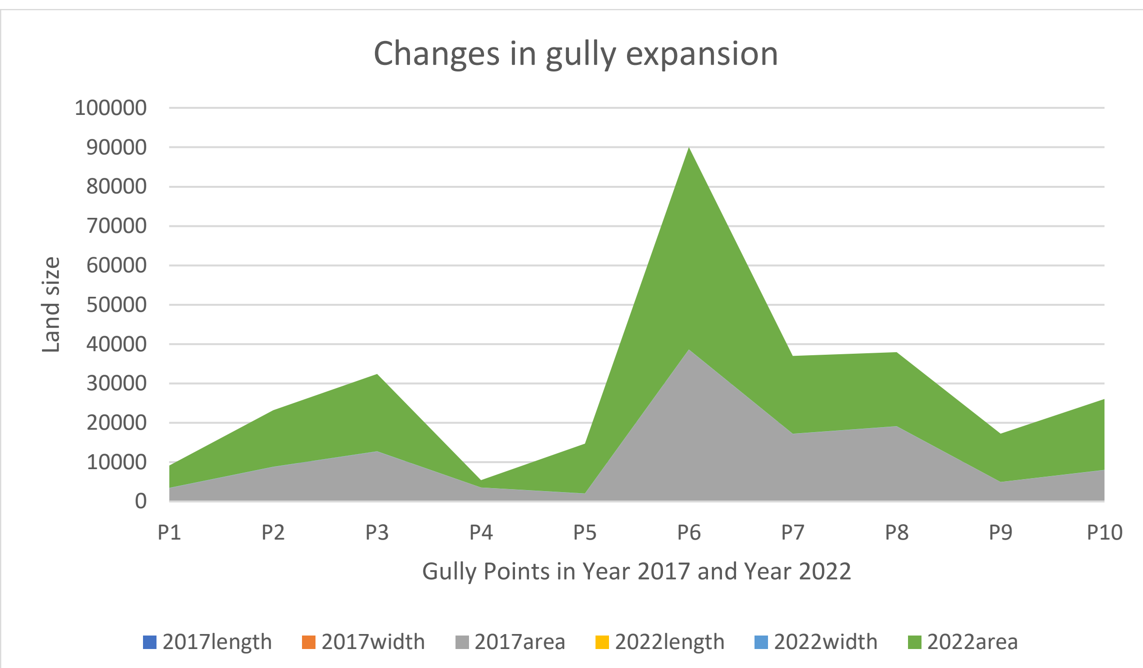
In line with the fourth objective of the study, which is "**to measure the rate of gully expansion at the study area**" **"** Table 13 was used to achieve this objective of the study.

Table 13: Changes in the 10 gullies between 2017 and 2022

Gully ID	2017 length (km)	2017 width (m)	2017 area (m^2)	2022 length (km)	2022 width (m)	2022 area (m^2)
1	0.08	38.9	3340	0.13	56.4	5679
2	0.19	42.2	8703	0.22	54.14	14370
3	0.21	49	12622	0.34	59.3	19659
4	0.09	35.9	3470	0.06	22.7	1871
5	0.07	31.3	1923	0.21	58	12661
6	0.8	42.63	38508	0.9	54.68	51462
7	0.3	30.35	17116	0.5	39.42	19791
8	0.5	31.9	19027	0.4	47.89	18824
9	0.32	13.2	4895	0.51	22.29	12287
10	0.28	30.7	7924	0.36	48.3	18024
	μ=0.28 SD=0.22	**μ=34.61 SD=9.77**	**μ=11753 SD=11082**	**μ=0.36 SD=0.24**	**μ=46.31 SD=13.85**	**μ=17463 SD=13374**

Source: Fieldwork, 2022

In 2010, 10 gullies covering 0.28 km2 were mapped. The mean gully length was 0.28 km, with an SD of 0.22 km. The mean width was 34.61 m (SD 9.77 m), and the mean area was 11,753 m2 (SD 11,082 m2). A total of 10 gullies in 2022, covering 0.51 km2, were also mapped. Coordinate points of the ten visited gullies corresponded with mapped gully polygons digitized from satellite data, thus representing 100% accuracy of gully identification for the visited sites. Table 13 shows changes in the ten old gullies. The ten gullies in 2022 had a mean length of 0.36 km (SD 0.24 km), a mean width of 46.31 m (SD 13.85 m), and an average gullied area of 17463 m2 (SD 13374 m2). Total land area under gully occupation in the study area in 2022 was 0.64 km2. Changes in gully sizes were not consistent throughout the research region; apparent decreases in gully sizes were occasionally seen despite reported increases.



In Fig. 3.6, the overall gully size at the site has increased from 2.11 hectares in 2017 to 5.39 hectares in 2022. This is partly due to the anthropogenic activities of the people living within the site area. Ten (10) gullies were identified in Aforu Ugurike in Ikeduru LGA to determine changes in gully dimensions, and the 2017 values were subtracted from the 2021 and 2022 values. Although the 2021 satellite data only covers 34% of the study area, it was used to understand stepwise changes in gully sizes where possible. Two different measurements were performed for 2022 gully dimensions:

a) Gullies mapped in the 2017 satellite imagery ('old' gullies)

b) Gullies were identified for the first time in the 2021 or 2022 imagery ('new' gullies).

At a resolution of 30 meters, geomorphic variables were obtained from the Digital Elevation Model (DEM) of the Shuttle Radar Topography Mission (SRTM). The DEM provided the gully heads' maximum slope and relative relief values. Maximum slope values aid in understanding the locations of the steepest slopes within a zone where the erosive force of surface run-off would be most noticeable. Within a zone of interest, relative relief represents the difference between the greatest and lowest elevation values. Using a pour point analysis in ArcGIS, the DEM was utilized to define gully watersheds and pinpoint the locations that contributed to the gully upslope. However, from the result of the DTM (Digital Terrain Model) carried out on the gully site, there is no significant difference in the value of the highest and lowest regions of the terrain. This implies that the socio-economic and environmental activities that cause the expansion of the gully concentrate on its widening.

Indigenous Approaches to Mitigating Gully Expansion

In line with the fifth objective of the study, which is "to examine indigenous approaches in mitigating gully expansion in the study area," tables 14-15 were used to achieve this study objective.

Table 14: Causes of Gully Erosion Expansion in Ikeduru LGA

S/N	**Response**	**SD**	**D**	**N**	**A**	**SA**	**No.**	**Yes/No/Not Sure**
1	Natural or human activities	24	22	-	46	8	100	**Not sure**
2	Poor Soil texture, structure, and slope	20	40	20	10	10	100	**No**
3	Rainfall	10	-	-	40	50	100	**Yes (1st)**
4	Human deforestation	38	60	2	-	-	100	**No**
5	Overgrazing	31	59	10	-	-	100	**No**
6	Excessive cultivation	60	35	5	-	-	100	**No**
7	Bush burning	65	25	10	-	-	100	**No**
8	Construction works	10	-	20	-	70	100	**Yes (2nd)**
9	Population increase	50	20	-	-	10	80	**No**
10	Others	-	-	-	-	20	20	**Yes (3rd)**

Source: Fieldwork, 2022

In Table 14, the study reveals how respondents feel about the causes of gully erosion expansion in their LGA. The respondents feel that rainfall, construction work, and other causes, such as lack of drainage systems, are the major causes of gully erosion expansion in their LGA.

Table 15: Mitigation approaches of Gully erosion expansion in Aforu Ugurike Ikeduru LGA

S/N	**Response**	**SD**	**D**	**N**	**A**	**SA**	**No.**	**Yes/No/Not Sure**
1	Sandbag embankment	2	18	6	20	44	90	**Yes**
2	Broken stone embankment	26	40	14	10	-	90	**No**
3	Planting of trees and grasses	20	38	22	-	10	90	**No**
4	Landfills	-	30	27	30	3	90	**Yes**
5	Construction of drainages	8	20	40	12	10	90	**Yes**
6	Good land management and agricultural practices	10	30	30	10	10	90	**No**

7	Other approaches	-	-	-	-	10	10	**Yes**

Source: Fieldwork, 2022

Table 15 shows respondents' feelings about gully erosion expansion mitigation approaches in their LGA. The respondents feel that they use sandbag embankments, landfills, and the construction of drainage systems more as their mitigation approaches to gully erosion expansion in their LGA. While some feel other mitigation approaches, they embark on dirt-filling mechanisms (using their waste refuges to fill the gullies).

A very loose soil compaction increases its susceptibility to erosion and landslides. High rainfall, surface water diversion, human activities, and socio-economic and environmental activities influenced the study area. During the rainy season, lush vegetation covers the slopes of gullies and landslides. Because of overgrazing and drought, the gully and landslide slopes are nearly completely naked throughout the dry season. During the study area's rainy season, heavy rainfall, runoff, and soil erosion weaken the slopes by separating the soil's lateral base, which causes the slopes to become steeper. The influence of elevation and vegetative/land cover on the primary cause and ongoing spread of gullies and landslides in the study region is demonstrated by the digital elevation model and the land cover map created from Arch GIS 30 m data.

Table 16: Rainfall Distribution Characteristics between 2010-2021

Month Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2010	49.1	73.9	118.7	161.5	256.7	218.3	270.5	302.7	609	354.5	100.5	0	2515.4
2011	39.1	0	53.2	354.2	47.3	391.8	382.7	356.4	344	246.5	116.5	5.5	2337.2
2012	5.5	62	206.4	172.2	140.8	385.4	301.7	348.7	430.8	213.4	22.6	14.8	2304.3
2013	27.9	90.4	241.7	265.6	0	391.5	131.5	293.5	372.4	40.9	0	0	1855.4
2014	92.6	136.9	73.3	278.1	277.4	439.5	379.2	476.4	123.8	50.6	0	0	2327.8
2015	9.8	10	7.1	213.2	185.2	256.9	650.1	641	571.1	273.3	119.7	23.9	2961.3
2016	-88.8	42.5	107.1	182.6	245.2	498.3	402.9	521.1	193.9	349.8	24	0	2478.6
2017	0.9	2.8	157.5	216.8	248.1	373	489.9	289.4	333.7	214.9	79.5	17.6	2424.1
2018	0	58.7	90.2	177.8	291	293.9	464.3	315.5	218.8	176.6	73.7	22.3	2182.8
2019	37.1	34.3	45.9	99.6	298.8	185.9	468	438.2	622.2	284.3	111.7	0	2626
2020	59.6	12.5	72.2	115.9	361.5	339.2	484	381.6	460.9	292.4	26.7	15.8	2622.3
2021	21.1	74.6	68.7	238.4	252.7	395.3	350	502	573.2	228	1.5	-88.8	2616.7
Mean	21.16	49.88	103.50	206.33	217.06	347.42	397.90	405.54	404.48	227.10	56.37	0.93	2437.66
SD	44.01	41.14	68.27	71.25	106.18	92.16	130.79	110.84	169.66	100.02	48.53	29.78	274.30

Source: Fieldwork, 2022

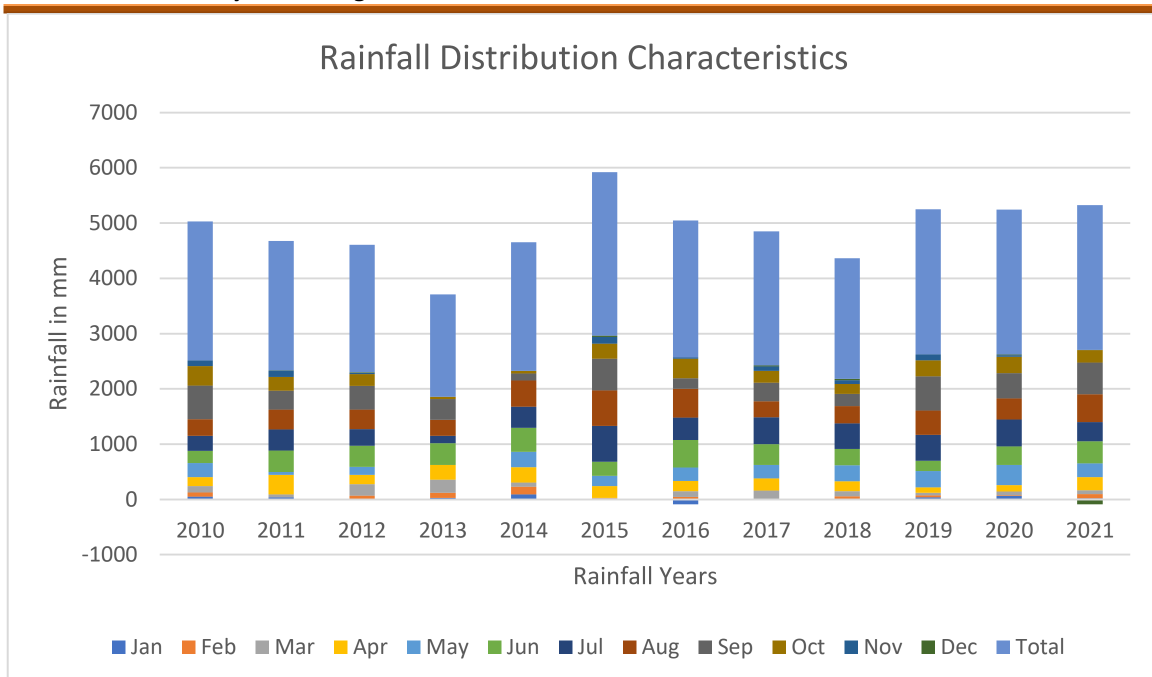


Table 16 shows the rainfall variability of 12 years, particularly monthly and annual rainfall.

Table 17: Rainfall Anomalies

Year	X(mm)	μ - X
2010	73.9	-68.66
2011	5.5	-0.26
2012	5.5	-0.26
2013	27.9	-22.66
2014	50.6	-45.36
2015	7.1	-1.86
2016	-88.8	94.04
2017	0.9	4.34
2018	22.3	-17.06
2019	34.3	-29.06
2020	12.5	-7.26
2021	-88.8	94.04
μ	**5.4**	

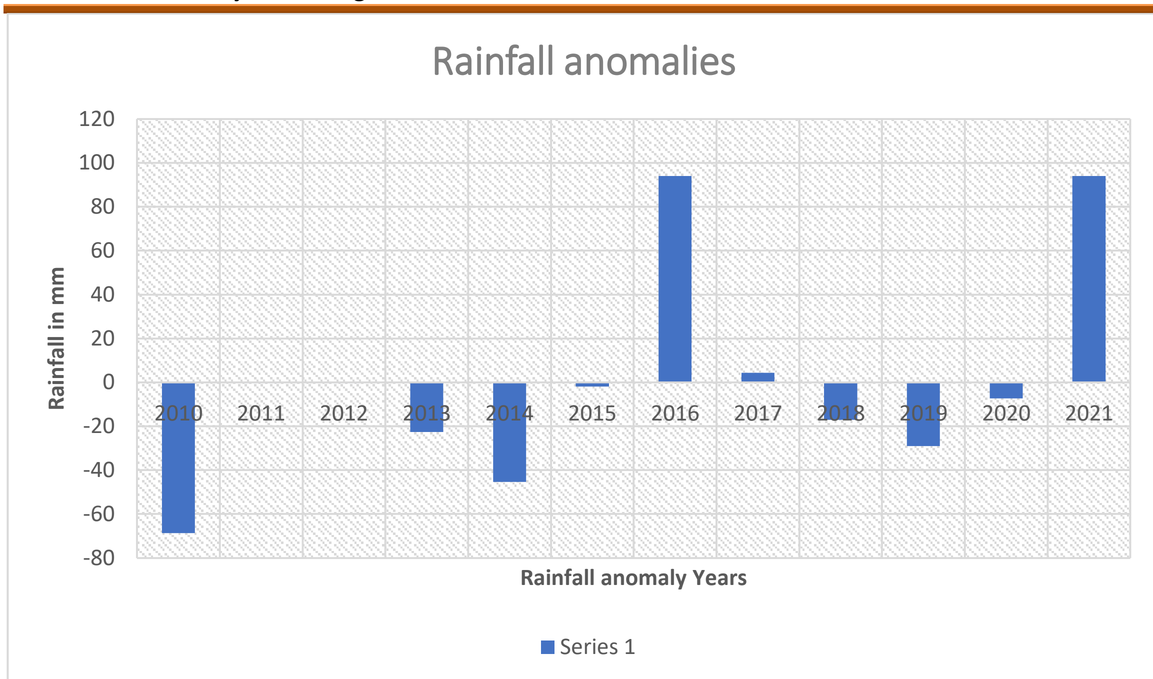
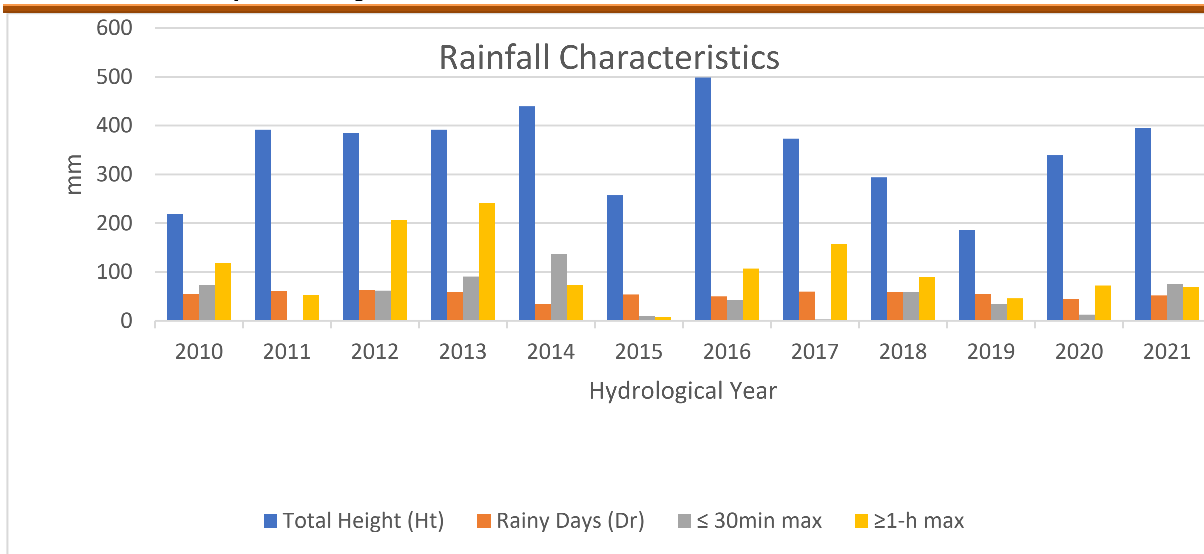


Table 18: Rainfall Characteristics between 2010-2021

Hydrological Year	Ht	Dr	≤ 30min max	≥1-h max
2010	218.3	55	73.9	118.7
2011	391.8	61	0	53.2
2012	385.4	63	62	206.4
2013	391.5	59	90.4	241.7
2014	439.5	34	136.9	73.3
2015	256.9	54	10	7.1
2016	498.3	50	42.5	107.1
2017	373.0	60	2.8	157.5
2018	293.9	59	58.7	90.2
2019	185.9	55	34.3	45.9
2020	339.2	45	12.5	72.2
2021	395.3	52	74.6	68.7
MEAN	**347.4**	**53.9**	**49.9**	**103.5**
SD	**92.2**	**8.1**	**41.1**	**68.3**

Source: Fieldwork, 2022 *(Main characteristics of rainfall events in the study area: total height (Ht), rainy days (Dr), maximum ≤ 30min max intensity, maximum ≥1-h height (Hmax 1 – h).*

Rainfall characteristics in Table 15 revealed that of the 12 years under study, only five years (2010, 2015, 2018, 2019, and 2020) had total annual rainfall less than the mean annual (347.4mm), while the seven years received more than the mean annual total, representing 58.3%. This implies that only 41.7% of the 12 hydrologic years have relatively low rainfall compared with the mean total height of 347.4mm. However, this amount is high in an urban environment with increasing sealing surfaces. The mean annual rainfall days (Dr) showed 54 days, with a maximum of 63 days (2012), a minimum of 34 days (2014), and a standard deviation of 8.1. This showed low variation in rainfall days. However, this does not imply that the higher the number of rainy days, the higher the amount of rainfall expected, as shown in Table 15. Rainfall duration of ≤ 30min for 2010- 2021 showed a mean of 49.9mm with a standard deviation 41.1. This is also represented graphically.



Data from the digital terrain model in fig 3.4 - 3.7 shows the rate at which the gullies expand. The gully site where the sample points were taken has been subjected to natural and anthropogenic activities that have depreciated the site's terrain over the years. Research was carried out to examine the level of environmental degradation that has affected the site within five years (2017-2022). This data set was used to achieve all the objectives discussed in the study.

T-test analysis of the Demographic Structure of the Respondents
Objective 1
H_0: The demographic structure of respondents from Aforu Ugurike Ikeduru LGA does not differ significantly.

Table 19: Two sample T-tests & conference intervals analyzing the demographic structure of respondents from Ugurike Aforu Ikeduru LGA.

	N	Mean	Standard Deviation	Standard Error Mean
Descriptive Statistics	100	17.52	23.68	12.92

Source: Researcher's computation, 2022.

95% CI is (9.25) T-Test T= -0.026 P=0.64 DF= 99. The test shows that the mean scores do not differ since P equals 0.64, i.e., greater than 0.05. Therefore, from the decision rule, the P value is greater than 0.05. We accept null hypotheses and, thus, conclude that the demographic structure of respondents from Aforu Ugurike Ikeduru LGA does not differ significantly.

Correlation analysis for Socio-economic and Environmental Impacts of Gully erosion expansion
Objective 2
H_0: The adverse socio-economic and environmental impacts of the gully erosion on the various land uses in the study area between 2017-2022 do not differ significantly.

Table 20: Summary of correlation analysis for social-economic and environmental impacts of gully erosion expansion in Aforu Ugurike Ikeduru LGA

Statistical Technique	N	X^2 Value	df	Level of Sig.	Critical Value	Decision
Person's Product Correlation Coefficient	100	0.616	4	0.10 0.05	1.671 1.333	Accept H_o

Source: Researcher's computation, 2022.

A relationship between the degree of the negative socioeconomic and environmental repercussions has a calculated correlation analysis of 0.616. The critical values at 0.10 and 0.05 are 1.671 and 1.333, respectively. If the computed chi-square value (0.616) is higher than the critical values at 0.05, which is 1.333, and at 0.1, which is 1.671, the decision rule is to reject Ho. Since the computed value is smaller than the crucial levels, Ho is thus acceptable. Hence, it is concluded that "The adverse socio-economic and environmental impacts of the gully erosion on the various land uses in the study area, between 2017-2022 do not differ significantly".

T-test analysis of the Geotechnical indices for the Soil samples in the study area
Objective 3
$H_{0:}$ The geotechnical indices for the soil samples in the study area do not differ significantly.

Table 21: geotechnical indices for the soil samples in the study area using Two sample T-tests & conference interval comparing among the sampling locations.

	N	Mean	Standard Deviation	Standard Error Mean
2017	10	27.0	6.75	2.13
2022	10	22.1	1.29	0.29

Source: Researcher's computation, 2022.

95% CI for mu 2017 - mu 2022: (0.26, 0.52) T-Test mu 2017= mu 2022 (vs not =): T= 2.696 P=0.03 DF= 9.
The test shows that the mean scores differ since P equals 0.03, i.e., less than 0.05. Therefore, from the decision rule, the P value is less than 0.05. We reject the null hypotheses and, thus, conclude that the geotechnical indices for the soil samples in the study area differ significantly.

Correlation analysis of the Rate of Gully expansion among the sampling locations.
Objective 4
H_0: The rate of gully expansion does not differ significantly among the sampling locations.

Table 22: Summary of correlation analysis for the rate of gully expansion among the sampling locations in Aforu Ugurike Ikeduru LGA

Statistical Technique	N	X^2 Value	df	Level of Sig.	Critical Value	Decision
Person's Product Correlation Coefficient	10	0.919	4	0.10 0.05	0.687 0.981	Accept H_o

Source: Researcher's computation, 2022.

The association between the sampling locations' rates of gully extension and the correlation analysis calculated for it is 0.919. 0.687 and 0.981 are the critical values at 0.10 and 0.05, respectively. If the computed chi-square value (0.919) is less than the crucial values at 0.05, which is 0.981, and at 0.1, which is 0.687, the judgment rule is to reject Ho. Therefore, Ho is accepted since the calculated value is lesser than the critical values. Hence, it is concluded that "The rate of gully expansion does not differ significantly among the sampling locations."

T-test analysis for Indigenous Approach in Mitigating Gully Expansion
Objective 5
H0: No appreciable differences exist in the sampling areas' indigenous methods for preventing gully extension.

Table 23: Two sample T-tests & conference intervals comparing the indigenous approach in mitigating gully expansion among the sampling locations.

	N	Mean	Standard Deviation	Standard Error Mean
2017	7	-12.84	11.10	4.20
2022	7	10.0	17.32	6.55

Source: Researcher's computation, 2022.

95% CI for mu 2017 - mu 2022: (-2.57, 26.02) T-Test mu 2017= mu 2022 (vs not =): T= 1.528 P=0.17 DF= 6. The test shows that the mean scores do not differ since P equals 0.17, i.e., greater than 0.05. Therefore, from the decision rule, the P value is greater than 0.05. We find that there is no substantial difference in the indigenous method in limiting gully growth among the sampling areas if we accept the null hypothesis. Of all the hypotheses, only hypothesis three (3) was rejected. The other four hypotheses were accepted according to the computations of the research.

CONCLUSION

The demographic makeup of respondents from Aforu Ugurike Ikeduru LGA was compared, as were the negative socioeconomic and environmental effects of gully erosion in the study area, the type and distribution of gully expansion, the geotechnical indices for the soil samples in the study area, the causes of gully erosion, and strategies to prevent gully erosion expansion. The analysis showed that anthropogenic activities such as natural or human activities, poor road construction practices, urbanization, heavy rainfall, and poor drainage channels were the major causes of gully erosion. The research also examined the data collected in order to verify the proposed hypotheses. The genesis, related processes, and consequences of gully and landslide risks in Aforu Ugurike and its surroundings have been assessed. According to field observations, the study area's landslides and gully erosions were caused by a combination of factors, including heavy and extended rainfall, geomorphological features, a poorly built structure, high slope instability, inappropriate land use, and the steepness of the slope. Landslides and gully erosion were also caused by the unconsolidated character, low cohesiveness, high permeability, and poor plasticity of the soil that is found under and above the clay lithological strata. From the analysis of the socio-economic and environmental impact of gully erosion in Aforu Ugurike Ikeduru Local Government Area, the study concludes that our environment is a part of our social and economic survival, and what happens within our environment can negatively impact our survival. More so, for greater effectiveness, the solution to the impact of gully erosion is to treat it.

This research has indicated that gully erosion is developing alarmingly, expanding to 13374 m2 per annum between 2017 and 2022. Gully erosion devastated a total land area of 51462 $m^{2,}$ and it is expected to claim a total land area of 159407 m2 by 2025 if no effective control measure is adopted to address it. Using soft wares such as ArcGIS10.1, Surfa10, and Global Mapper has proved effective in mapping and determining the extent of gully erosion menace at a near-accurate level. Consequently, there is an urgent need to address the disaster to alleviate its impact on the existing land uses.

RECOMMENDATIONS

In addressing the gully erosion menace discussed in the study, the following guidelines are recommended:

1. It is recommended that the erosion channels be redirected from high-risk locations to low-risk ones, and concrete culverts should be constructed to channel the erosion water.
2. Roads should have routine maintenance in order to maintain drainage and clean culverts to prevent flooding, and diversion should be installed at drains and culverts where runoff velocity can cause erosion.
3. There should be a massive public awareness campaign on the problems and consequences of gully erosion, as well as enacting environmental laws and serious penalties for offenders. This will go a long way in making the inhabitants adhere to environmental best practices, thereby mitigating the menace.
4. In order to solve the issue, the community should be urged and counseled to contribute their fair share through customary methods and other cultural practices like agro-forestry systems, cover crops on farms, street tree planting, and other regional elements that can lessen gully erosion.
5. To assist builders and real estate developers in creating anti-erosion buildings, the government must map the whole region and create gully erosion hazard/risk maps.

REFERENCES

Abdulfatai, I. A., Okunlola, I. A., Akande,W. G., Momoh, L. O. and Ibrahim, K. O. (2014). Review of Gully Erosion in Nigeria: Causes, Impacts and Possible Solutions. Journal of Geosciences and Geomatics, 2(3) 125-129

Abdulfatai, I.A, Okunlola, I.A, Akande, W.G, Momoh, L.O and K.O. Ibrahim, (2014), Review of Gully erosion in Nigeria: Causes, Impacts, and Possible Solutions. Journal of Geosciences and Geomatics 2(3): 125-129.

Abegbunde, A.A, Adeyinka, A.A, Olawumi, P.O and O.A. Oluodo, (2006), An Assessment of the socio-economic impacts of soil erosion in south-eastern Nigeria: A paper presented at shaping the Change XXIII FIG Congress Munich, Germany, October 8-13, 2006 pp. 12-17.

Adekalu, K. O, Olorunfemi I. A, and J.A. Osunbitan (2007). Grass mulching effect on infiltration, surface runoff, and soil loss of three agricultural soils in Nigeria. Bioresource Technology, 98 (4): 912- 917.

Ajayi, A. S., Ibrahi, R., Brai, M. A. and Seghosime, S. (2019). Overview of the Anthropogenic Causes of Soil Erosion in Auchi, Edo State, Nigeria. Merit Research Journal of Agricultural Science and Soil Sciences, 7(8): 087-090.

Akpokodje, E.G., Tse, A. C. and Ekeocha, N., (2010) Gully Erosion Geohazards in Southeastern Nigeria and Management Implications. Scientia Africana, 9 (1): 20-36.

Aksoy, E., Ozsoy, G., and M. S. Dirim (2009). Soil Mapping Approach in GIS using Landsat Satellite Imagery and DEM data. African Journal of Agricultural Research, 4 (11): 1295-1302.

Amangabara, G.T. (2012) Analysis of Selected Gully Erosion Control Works in Imo State.Hydrology for Disaster Management. Special Publication of the Nigerian Association of Hydrological Sciences.

Anejionu, O.C.D, Nwilo, P.C and E.S. Ebinne (2013) Long-term Assessment and mapping of erosion hotspots in southeastern Nigeria. A paper presented at FIGP Working Week 2013 Environment for Sustainability Abuja, Nigeria, 6th –10th May 2013.

Anyadike, R.N.C. (2002) ―Climate and Vegetation‖ in Ofomata, G.E.K [ed], A Survey of the Igbo Nation. African First Publishers Limited Onitsha: pp. 73.

Arambepola, N. and Iglesias.G. (2009) Effective Strategies for urban flood risk management. Asian Disaster Preparedness Center, Bangkok. www.adpc.net European Scientific Journal July 2017 edition Vol.13, No.20 ISSN: 1857 –7881 (Print) e - ISSN 1857- 7431 263 13.

Asdak, C., (2009). Hydrology and Watershed Management. UGM Press, Yogyakarta.

Asiabaka, C. C. and Boers, M. (1988), An Analysis of the Existing Traditional Methods of Farming and Erosion Control Among Farmers in Southeastern Nigeria. Report of the Erosion Research Centre, FUTO, Owerri, Nigeria pp.23-42.

Bai, Z.G., Dent, D.L., Olsson, L and M.E. Schaepman (2008). Global Assessment of land degradation and Improvement, Identification by Remote sensing. Report 2008/01, ISRIC, Wageningen pp. 26-36.

Balasubramanian, A. (2017). METHODS OF CONTROLLING SOIL EROSION. 10.13140/RG.2.2.22542.97609.

Barbier, E.B., 1997. The economic determinants of land degradation in developing countries. Phil. Trans. R. Soc. Lond. B, Biol. Sci., 352: 891-899.

Barry Richmond&#39’s quote is from this article on System Dynamics/Systems Thinking: Let’s Just Get on With It. Available on https://www.thwink.org/sustain/glossary/SystemsThinking.htm

Bennett, H.H., 1930. The problem of soil erosion in the United States. Ann. Assoc. Am. Geogr., 21: 147-170.

Blaikie, P. and H. Brookfield, 1987. Defining and Debating the Problem. In: Land Degradation and Society, Blaikie, P. and H. Brookfield (Eds.). Methuen, London.

Bongdap, N. N. (2020). Gully Erosion, Definition, Causes, Effects, and Prevention.

Chen XQ, Li Y, Gao Q, Jia ST (2019) Distribution characteristics of geo-hazards in Ganxi Valley after the Wenchuan earthquake. Environ Earth Sci 65(4):965–973.

Chiemelu, N., Okeke, F., Nwosu, K., Ibe, C., Ndukwu, R., and A. Ugwuotu, (2013). The role of surveying and mapping in erosion management and control: A case of Omagba erosion site, Onitsha, Anambra State, Nigeria. Journal of Environment and Earth Sciences 3 (11): 11-18.

Chukwu, G.O (2007) Land Suitability Classification of southeastern Nigeria wetlands for Azolla. Scientific Research and Essays 2(12): 512-515. Scientific Research Journal (SCIRJ), Volume V, Issue IX, September 2017 36 ISSN 2201-2796 www.scirj.org © 2017, Scientific Research Journal

Chukwu, G.O, Chude, L.A and I.E Ekpo (2009), Wetland of southeastern Nigeria: Extent and characteristics. Nigerian Journal of Agriculture, Food and Environment 5(2-4): 42-46,

Chukwuocha N., Amangabara G.T., Amaechi C. (2014). Determination of the erodibility status of some soils in the Ikeduru local government area of IMO state, Nigeria. International Journal of Geology, Earth and Environmental Sciences. Vol. 4 (1) January-April, pp. 236-243.

Daniels, S., Agnew, C., Allott, T. and Evans, M. (2008). Water table variability and runoff generation in an eroded peatland, South Pennines, UK. Journal of Hydrology, 361(1-2), 214-226.

Debora, O. and Ikenna, E. O. (2019). Adjustments to Hazards of Gully Erosion in Rural Southeast Nigeria: A Case of Amucha Communities. Applied Ecology and Environmental Sciences,7(1):11-20.

Dominati, E., Patterson, M. and A. Mackay, (2010). A framework for Classifying and Quantifying the Natural capital and Ecosystem services of soils. Journal of Ecological Economics 69 (9):1858-1868.

Eboh, E. C. and J. I. Lemchi. (1994). Population pressure and indigenous land tenure in Eastern Nigeria: Implications for land tilting. Journal of Rural Development and Administration. 26 (3): 77 – 82.

Egboka, B.C.E (2004). Distress call and a plea to the senate committee for urgent Actions Against Floods, Soil/Gully erosion/landslides, and Disasters in southeastern Nigeria, paper presented to the senate committee on Environmental; roads/Erosion senate delegation.

Egboka, B.C.E, (2009) Keynote address delivered at The Anambra State Erosion Control Summit Holding at Suncity Exclusive Hotels, Awka, on Tuesday 17th November 2009 14.

Egboka, B.C.E, Nwakwor G. I,and I.P Orajaka (1990). Implications of palæo- and neotectonics in gully erosion-prone areas of southeastern Nigeria. Natural Hazards, 3: 219-231.

Egboka, B.C.E. and Okpoko, E. I. (1984) “Gully erosion in Agulu Nanka region of Anambra State, Nigeria”. IAHS Publ., No. 144, pp. 335 – 347

Egboka CE, Akudo EO, Hycienth ON (2019) Gully erosion and landslides in southeastern Nigeria: causes, consequences, and control measures. Glob J Eng Sci 2(4):1–11.

Egboka, B.C.E., Nwankwor, G. and Orajaka, I. (1990). Implications of palaeo-and neotectonics in gully erosion-prone areas of southeastern Nigeria. Journal of Natural Hazards, 3(3): 219-231.

Egede, E.A (2013). Threats and Mitigation of Soil Erosion and Land Degradation in Southeast Nigeria. Journal of Environment and Earth Science 3(13): 95-102.

Elizabeth I. O., Anthony, E. A., Egboka, B. C. E. and Okeke, H. I. (2014). An Assessment of the Influences of Surface and Subsurface Water Level Dynamics in the Development of Gullies in Anambra State, Southeastern Nigeria. Journal of Earth Interactions,18(4): 1-20

Eni, D. I and Udoh, U. I. (2020). The Devastating Effect of Gully Erosion Menace on Urban Infrastructures in Calabar Metropolis, Nigeria. Global Journal of Human-Social Science: Geography, Geo-Sciences, Environmental Science & Disaster Management, 20(2)

Eswaram, H., R. Lal and P. F. Reich. (2001). Land degradation: an overview in Response to Land Degradation, eds. E. M. Bridges, I. D pp.132-143.

Eze, H.I (2007), Effect of rainfall intensity and energy in Gully Development in Northeastern Enugu State, Nigerian Journal of Technology 26 (1): 91 – 96.

Ezeabasili, A.C.C, Okoro, B.U and E.J. Emengini (2014). Relative erodibilities of some soils from Anambra Basin. Sky Journal of Soil Science and Environmental Management 3 (8): 83 – 90.

Ezechi, J.I and C. O. Okagbue (1989), A genetic classification of gullies in eastern Nigeria and its implications on control measures. Journal of African Earth Sciences 9: 711-718.

Ezemonye, M.N and Emeribe, C.N, (2012). Rainfall Erosivity in Southeastern Nigeria. Ethiopian Journal of Environmental Studies and Management, 5 (2): 11-17.

Ezezika, O.C and O. Adetona (2011). Resolving the gully erosion problems in southeastern Nigeria: Innovation through public awareness and connectivity-based approaches. Journal of Soil Science and Environmental Management 2 (10): 286-291.

FAO (2011). The State of Food Insecurity in the World, special world report of FAO-UN, Rome, 2011: 11-14. [25] FDLAR (1990), Federal Department of Land Resources: The reconnaissance soil survey of Nigeria. Soil Report 5:377-389.

Federal Republic of Nigeria. 2007. Official Gazette: Legal Notice on publication of the details of the National and State provisional totals 2006 Census breakdown. Government Notices Nr 21. Nr. 24. Vol. 94. Lagos, Nigeria: Federal Republic of Nigeria.

Frankel, C. (2001) 'Mixed Messages' in Starkey, R. and Welford, R. (ed.) Business & amp; Sustainable Development, London: Earthscan Publications Ltd.

Gelagay, H. S and A.S. Minale, (2016), Soil Loss estimation using GIS and remote sensing techniques: A cast of Koga watershed, Northwestern Ethiopia. International Soil and Water Conservation 4: 126-136.

George, N.A, Obot, I. and Akpanetuk, N (2008). Geoelectrical investigation of erosion and flooding using the lithologic compositions of erosion and flood-stricken road in Ukanafun Local Government Area, Akwa Ibom State, Southern Nigeria. Disaster Advancement., 1 (4): 46-51.

Goodwin, N. R., Armston, J. D., Muir, J. and Stiller, I. (2017). Monitoring gully change: A comparison of airborne and terrestrial laser scanning using a case study from Aratula, Queensland. Journal of Geomorphology, 282, 195-208.

Goudie, A. S. and Boardman, J. (2010). Soil erosion. Geomorphological hazards and disaster prevention, Cambridge University Press, Cambridge, 177-187.

Grover N. (2022). Splash Erosion- Agriculture Notes. Prepp Community by Collegedunia

Gunawan G., Dwita S., Herr, S., and W. Sulostiowemi, (2013), Soil Erosion Estimation based on GIS and Remote Sensing for Supporting Integrated Water Resources Conservation Management, International Journal of Technology, 2 (3): 147-156.

Hacisalihoglu, S., Oktan, E. and Z. Yucesan (2010) Predicting Soil Erosion in Oriental Spruce (Picea orientalis) stands in Turkey's eastern Black Sea region. African Journal of Agricultural Research 5 (16): 2200-2214.

Hazell, P.B.R. and E. Llutz, 1999. Integrating Environmental and Sustainability Concerns into Rural Development Policies. In: Agriculture and the Environment: Perspectives on Sustainable Rural Development, Lutz, E. (Ed.). The World Bank, Washington, DC. Brown, L.R. and E.C. Wolf, 1984. Soil Erosion: Quiet Crisis in the World Economy. Worldwatch Institute, Washington, DC., USA., ISBN-13: 9780916468606, Pages: 49.

Hewett CJM, C Simpson, J Wainwright, S Hudson (2018). Participatory approaches to the communication and visualization of erosion-associated risks to infrastructure: the CAVERTI tool. Land Degradation and Development, 29, 1282-1294. Doi; 10.1002/Idr.2900.

Hudson, N.W. (2016). Soil Conservation. New York: Cornell University Press.

Humberto, B. and R.Lal (2008). Principles of Soil Conservation and Management. Springer and Company Limited 13-18 pp. [31]

Ibitoye, M and S. Adegboyega (2012), Indigenous Approach to Soil erosion in southwest Nigeria. A paper presented at Knowing to Manage Territory, Protect the Environment, Evaluate the Cultural Heritage held at Rome, Italy, 6-10th May 2012.

Idowu, O.J and Oluwatosin, G.A. (2008), Hydraulic Properties in relation to the morphology of a tropical soil with hardened plinthite under time land use types. Tropical and Sub-tropical Agro Ecosystems 8 (4): 145-155.

Igbokwe, J.I, Akinyede, J.O, Dang, B. Alaga, T., Ono, M.N, Nnodu, V.C and L.O. Anike, (2008), Mapping and Monitoring of the impact of gully erosion in southeastern Nigeria using satellite remote sensing and geographic information system. International Archives of Photogrammetry, Remote Sensing and Spatial Information 38: 113-126.

Igbokwe, J.I., Ojiako, J.C. and V.C. Nnodu, (2003). Monitoring, Characterization and Controlling of Floodwater Erosion Using Remote Sensing Techniques. Proceedings of the Technical Session of the 38th Annual General Meeting and Conference of Nigerian Institution of Surveyors, Lokoja pp. 123- 134.

Igwe, C. A. (2012). Gully Erosion in Southeastern Nigeria: Role of Soil Properties and Environmental Factors, Research on Soil Erosion, Danilo Godone, Silvia Stanchi, IntechOpen, DOI: 10.5772/51020.

Igwe, C.A., (2012), Gully Erosion in Southeastern Nigeria: Role of Soil Properties and Environmental Factors; InTech Open Science, pp.157-171.

Imasuen, O.I., Omali, A.O. and Ibrahim, I. (2011). Assessment of environmental impacts and remedies for gully erosion in Ankpa Metropolis and environs, Kogi State. Nigeria. Advances in Applied Science Research, 2 (5):372-384.

Indraranta B et al. (2008) "Investigating Erosional Behaviour of chemically stabilized Erodible soils; Geocongress 2008, New Orleans, Geosustainability and Geohazard Mitigation GSP178, Reddy, K.R, Khire MV, Alshawabkeh, AN (eds). 670-677. jotscroll.com/forums/3/posts/159/gully-erosion-definition-causes-effects-and-prevention.html. Accessed on May 13th, 2020.

Jing, K., Wang, W.Z., and Zhang, F.L., (2005), Soil Erosion and Environment In China, Science Press, Beijing, pp. 355.

Junge, B; Abaidoo, R., Chickoye, D. Stahr, K., and Lal, R. (2008). Research Report on Soil Conservation in Nigeria: Past and present on-station and on-farm initiatives. Soil and Water Conservation Society, Ankeny, Iowa, USA, pp. 12-16.

Lal, R. (2001). Soil Degradation by Erosion. Land Degradation and Development 12 (2): 519 – 539 Leyla Acaroglu Tools for Systems Thinkers: The 6 Fundamental Concepts of Systems Thinking. Available on https://medium.com/disruptive-design/tools-for-systems-thinkers-the-6-fundamental-concepts-of-systems-thinking-379cdac3dc6a

Maiangwa, M.G., Ogungbile, A.O., Olukosi,. J.O. and Atala, T.K. (2007). Land Degradation: Theory and Evidence from the North-West Zone of Nigeria. Journal of Applied Sciences, 7: 785-795. https://scialert.net/abstract/?doi=jas.2007.785.795

Meyers, N. (1985). The Gaia Atlas of Planet Management, Gaia Books Limited, London. Wachter, D., 1992. Land Titling for Land Conservation in Developing Countries? The World Bank, Washington, DC. USAID (United States Agency for International Development), 1999. Environmental and Natural Resource Management: A Report to Congress. US Government Printing Office, Washington, DC.

Nachtergaele, J., Poesen, J., Vandekerckhove, L., Oostwoud Wijdenes, D., & Roxo, M. (2017). Testing the ephemeral gully erosion model (EGEM) for two Mediterranean environments. Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group, 17-30.

National Population Commission Population census of the Federal Republic of Nigeria 2007 Imo state Statistical tables.

Nich. I. O. and Okekeogbu, C. J. (2011). Erosion problems and their impacts in Anambra state of Nigeria: (a case of nanka community). International Journal of Environment and Pollution Research,5(1): 24-37.

Nwachukwu, M. A. and Osoro, E. (2013). Assessment of environmental hazards: Linking borrow pits, gully erosion, and road failure. Journal of Civil Engineering and Construction Technology, 4(6):199-210.

Nwachukwu, O.I and M.I. Onwuka (2011). Land Degradation and Food crisis-causes, impact and soil conservation efforts in Nigeria: Globalization and rural development in Nigeria. Ike Nwachukwu and Ken C.Ekwe (eds). Michael Okpara University of Agriculture Umudike, Nigeria 231-232 pp.

Obiadi, I.I, Nwosu, C.M, Ajaegwu, N.E, Anakwuba, E.K, Onuigbo, N.E, Akpunonu, E.O and O.E Ezim (2010), Gully Erosion in Anambra State, southeast Nigeria: Issues and Solutions. International Journal of Environmental Sciences 2 (2): 796– 804.

Obidimma, C. E. and Olorunfemi, A. (2011). Resolving the Gully Erosion Problem in Southeastern Nigeria: Innovation Through Public Awareness and Community–based Approaches. Journal of Soil Science and Environmental Management, 286-287.

Obiefuna, G.I. and Jibrin, A. (2012). Geological and Geotechnical Assessment of Selected Gully Sites in Wuro Bayare Area NE Nigeria. Research Journal of Environmental and Earth Sciences, 4(3), 282-302

Ofomata, G.E.K. (1985). Soil Erosion in Nigeria.The Views of a Geomorphologist University of Nigeria Inaugural Lecture Series No.7 University of Nigeria Press Nsukka, Nigeria.

Ogboi, E. and H. Odeh, (2012), Erosion problems in Ika environs: causes and forms. Journal of Environmental Science and Management, 4: 53-61.

Ogbonna, J. U. (2012). Examining the vulnerability of gully erosion in the Old Imo State using logistic regression models and GIS. American Journal of Geographic Information Systems. 2: 35 – 42.

Ogbonna, J.U, Alozie, M, Nkemdirim, V and M.U Eze (2011). GIS analysis for Mapping Gully Erosion impacts on the Geo-formation of the old Imo State, Nigeria. ABSU Journal of Environment, Science and Technology 1: 48-61. Scientific Research Journal (SCIRJ), Volume V, Issue IX, September 2017 37 ISSN 2201-2796 www.scirj.org © 2017, Scientific Research Journal

Ogbonna, J.U. (2009). Macro-analytic study of the impact of gully erosion in Old Imo State of Nigeria. American Journal of Geographic Information Systems, 1(2): 23-32.

Ogbonna, J.U. (2009). Macro-analytic study of the impact of gully erosion in Old Imo State of Nigeria. American Journal of Geographic Information Systems 1 (2): 23– 32.

Ogbonna, J.U. and Ijioma, M.A., (2010). Mapping Gully Erosion Susceptibility in Old Imo State, Nigeria using Probability and Statistics Model. American Journal of Geographic Information Systems 3 (3): 45 – 50.

Ogbonnaya, I. and Hiroshi, F. (2010). Environmental and Socio-Economic Impact of Erosion in Nigeria, West Africa. International Journal of Erosion Control Engineering, 3(1)102-109.

Oguike, P.C. and Mbagwu, J.S.C. (2009), Variations in some physical properties and organic matter content of soils of coastal plain sand under different land use types. World Journal of Agricultural Sciences 5 (1): 63-69. [48] Okagbue, C.O and Uma, K.O (1987). Performance of gully erosion control measures in southeastern Nigeria. Forest Hydrology and Watershed Management, 167 (4): 163 -172.

Okin, G.S. (2002): "Toward a Unified View of Biophysical Land Degradation Processes in Arid and Semi-arid Lands". In Global Desertification: Do Humans Cause Deserts? Edited by J.F. Reynolds and D.M. Stafford Smith. Dahlem University Press pp. 95-97.

Okorafor, Okore & Okay, & Akinbile, Christopher & Oluwakunmi, & Adeyemo, Adebayo & Jonathan, (2017). Soil Erosion in South Eastern Nigeria: A Review.

Okorie, P. E. (1999) "Gully afforestation, principles and practice" seminar paper presented at forestry research institute of Nigeria, Ibadan. Okorie, P.E. (1992a) "Plants for Erosion Control" J. of erosion and Environmental sciences 14: Pp. 207 o- 220

Okoye, A.C. (2016) The Need for Integration of Waste Management Systems into Anambra State Capital Master Plan.Environmental Review; Vol.5, No 2, Pp128-133 15.

Okoye, C. O, Emengini, E. J. and Onwuzuligbo, C. (2014). Environmental Sensitivity Index Mapping and Assessment of Gully Erosion Sites in Anambra State–Nigeria. Journal of Environment and Earth Science; 4(10):32-46.

Okpala A.O (1990). Nigerian population growth and its implications for economic development. Scandinavian Journal of Development Alternatives, 9 (4): 63-77.

Onu, D. O. (2005). Determinants of farm–level soil conservation and erosion control adoption and utilization behaviors in the ecologically vulnerable areas of Imo State, Nigeria. Journal of Rural Development 24 (4): 521 – 543.

Onu, D.O. (2006). Socioeconomic factors influencing farmers' adoption of Alley farming Technologies under intensified agriculture in Imo State Nigeria. The Philippine Agricultural Scientist. 89 (2): 521 – 543.

Osadebe, C. C. and Enuvie, G. (2008). Factor Analysis of Soil Spatial Variability in Gully Erosion Area of Southeastern Nigeria: A Case Study of Agulu- Nanka- Oko Are. Scientia Africana, 7(2): 45.

Osadebe, C.C, and Akpokodje, E.G (2007). Statistical analysis of variability in properties of soils in gully erosion sites of AguluNanka-Oko area, southeastern Nigeria. Journal of Mining Geology 43 (2): 197-202.

Over 2,800 active erosion sites in South-east Nigeria available on https://www.premiumtimesng.com/regional/ssouth-east/274938-over-2800- active-erosion-sites-in-southeast-Nigeria-group.html

Pan C, L Ma, J Wainwright, Z Shangguan (2016). Overland flow resistances on varying slope gradients and partitioning on a grassed slope under simulated rainfall. Water Resources Research 52, 2490-2512.

Pimentel, D., (2006). Soil erosion: a food and environmental threat. Environment, Development and Sustainability 8 (1): 119-137.

Poesen, J., Nachtergaele, J., Verstraeten, G. and Valentin, C. (2003). Gully erosion and environmental change: Importance and research needs. Catena, 50(2-4).

Powlson, D. S., Gregory, P. J., Whalley, W. R., Quinton, J. N., Hopkins, D. W., Whitmore, A. P., Hirsch, P. R. and K.W.T. Goulding (2011). Soil Management in Relation to Sustainable Agriculture and Ecosystem Services. Food Policy Guidelines 36 (2): 72-87.

Quinton, J.N (2014), Soil Erosion Modeling. Encyclopedia of Agrophysics, Springer 746-747pp.

Rahman, E.L., M.A. Abd, Ali, R.R, Hussain, M.A and M. A. ElSemey (2009), Remote Sensing and GIS-based physiography and soils mapping of the Idku-Brullus Area, North Delta, Egypt: Egyptian Journal of Soil Science 49 (3): 209-432.

Salako, F.K (2006). Rainfall Temporal Variability and Erosivity in Sub-humid and Humid Zones of Southern Nigeria. Land Degradation and Development 17 (5): 541-555

Sang, K.L, (2004), Soil and Water Conservation, Science Press, Beijing, China; 845-846 pp.

Sebastian, A., Bora, L., Steve, L. and H. Bernd (2014) Conventional and Organic Farming: soil erosion and conservation potential for row cultivation. Geoderma 12:23-32.

Sender, G.C., Rose, C.W., Hogarth, W.L., Parlange J.Y and I.G. Lisie, (2002), Mathematical Soil Erosion Modeling, Water Interactions with Energy Environment, Food and AgricultureEncyclopedia of Life Support Systems 2: 1-3.

Senge, P.M. (1990), The Fifth Discipline, London: Random House

Shelton, D. and Kiss, A. (2005) Judicial handbook on Environmental Law, ISBN: 92-807-2555-6, Earth Print Limited Orders Dpt. United Kingdom, © United Nations Environment Programme, 16. The Lawyers Role in the Society (http://www.thelawyerschronicle.com/the-lawyers-role-in-thesociety/) retrieved on 23/02/17

Stokes, A., Norris, J. E., Van Beek, L. P. H., Bogaard, T., Cammeraat, E., Mickovski,

S. B. and Fourcaud, T. (2008). How vegetation reinforces soil on slopes. In Slope stability and erosion control: ecotechnological solutions. Springer Netherlands. pp. 65-118).

Teme S. C and P. O. Youdeowei (2004), Geotechnical investigations for design of foundations for erosion and flood control structures at Unwana Beach, Afikpo, Ebonyi state, Southeastern Nigeria. Fifth International Conference on Case Histories in Geotechnical Engineering, April 13-17, 2004. 1: 9. New York, N.Y

Ubuoh, E.A, Akhionbare, W.N, Onweremadu, E and O.A Onifade (2013), Characterization of Soil Quality in erosion-prone environment of Ukpor, Nnewi-South L.G.A of Anambra State, Nigeria. International Journal of Advances in Applied Sciences 2(1):1-8.

Ufot, U.O., Iren, O.B., and C.U. Chikere-Njoku (2016). Effects of Land Use on Soil Physical and Chemical Properties in Akokwa area of Imo State, Nigeria. International Journal of Life, Science and Scientific Research, 2 (3):1-6.

Umar, K. A., Justin, U. and Braimoh, J. (2016). Investigating the Causes and Impacts of Gully Erosion in Auchi, Nigeria. Journal of Geography, Environment and Earth Science International 4(4): 1-13.

Ume, N. C, Enwereuzor, A.I., Egbe, C. A, Ike, M.C. and S. J. Umo (2014). Application of Geographic information system and remote sensing in identifying the impacts of gully eroding in Urualla, Ideato North, Local Government area, Imo state. Nigeria Global Research Journal of Science 3 (3):1-8.

Umeugochukwu, P.O, Ezeaku, P.I and V.O. Chude (2013). Impact of Soil Erosion on Land Degradation in UGA Southeastern Nigeria. Nigerian Journal of Soil Science 22 (1): 26 -36.

Umoru, C.I., Shuaibu, A. M., Abdullahi, I.N. and Umar, M.U. (2015). Geotechnical Assessment of Gully Erosion at Ankpa Area, North Central Nigeria. IOSR Journal of Applied Chemistry, 8(12): 36-48.

United Nations Environment Programme (UNEP), 1982. World Soil Policy, United Nations Environment Programme. Nairobi, Kenya. Pigou, A.C., 1920. The Economics of Welfare. 1st Edn., Macmillan and Co., London, UK., pp: 147-176.

Wachter, D., 1992. Land Titling for Land Conservation in Developing Countries? The World Bank, Washington, DC.

Woldemariam, G.W.; Iguala, A.D.; Tekalign, S.; Reddy, R.U. Spatial Modeling of Soil Erosion Risk and Its Implication for Conservation Planning: The Case of the Gobele Watershed, East Hararghe Zone, Ethiopia. Land 2018, 7, 25.

Zheng, F. L, Yang, Q. K and Z.L Wing,(2004).Water Erosion Prediction Model. Research Journal of Soil and Water Conservation 11 (4): 13-24.

Zingg, A.W. (1940): " Degree and length of land slope as it affects soil loss in runoff&quot. Agric. Engineering, Vol. 21, pp. 59-64