__Minireview Article__

REVIEW OF GULLY EROSION IN ANAMBRA STATE: GEOLOGY, CAUSES,EFFECTS, CONTROL MEASURES AND CHALLENGES ASSOCIATED WITH ITS MITIGATION

ABSTRACT

In southeastern Nigeria, particularly in Anambra state, gully erosion presents a serious environmental challenge. With over 100 gully sites in the state, only about 30 have received measures of control but are still not fully under control. Observations have shown clearly that the underlying geologyexerts major control in the development of gully erosion in the study area. Progressive gullies in certain areas of Anambra state are caused by various factors including topography, soil/water pH, lithology type, deforestation, hydrogeology, and geotechnical rock properties.This erosion activity has resulted in the loss of productive lands, water pollution, sedimentation of waterways, and loss oflives and properties, almost every year. However, several governments agencies have attempted to manage it using concrete structures, stabilization work such as planting a bamboo tree, and cashew trees to increase water intake, pipe structures to channel the water directly to nearby surface water, construction of check dams, embankments, and retention ponds to control the flow of water and sediments. Despite these control efforts, several challenges persist in effectively managing gully erosion in Anambra State. The majority of the concrete structures used to control these gullies have collapsed leading to incessantspreading of the site. Inadequate funding, failure of engineering structures, flooding, the geologic setting of the area, limited technical expertise, population growth, urbanization, lack of public awareness, and lack of proper coordination among stakeholders hinder the implementation of comprehensive erosion control measures. It is recommended that concrete drainage channels should not only be used in controlling these gullies but should also be integrated with other measures to yield a positive result.

keywords: Gully erosion, causes, effect, control, challenges, geology of Anambra state

1. INTRODUCTION

Gully erosion occurs when surface water runoff removes soil along drainage lines. This environmental degradation can result in the loss of useful land that is utilized for farming, domestic, industrial, and other purposes. Additionally, it can cause damage to properties and even lead to loss of life [1], [2],[3]. According to [4], Anambra State in the Southeastern region of Nigeria has the highest number of active gullies, with many of them having failed gully-control measures. The gullies in this area can be described as catastrophic, as they are very deep and wide, with some even stretching for tens of kilometres. In fact, they could be better referred to as canyons [1], [3],[5].Gullies in Anambra State have been attributed to a variety of factors by workers such as [1], [6], [7], [8], and [9]. Some suggest that human activities have influenced natural and geological processes, while others believe that gullies are linked to concentrated runoff processes. [10] points to anthropogenic activities like rapid urbanization, rural-urban migration drift, overpopulation, indiscriminate dumping of household waste in drains, emission of ozone layer-depleting gases/burning of fossil fuels, hazardous industrial waste products, and heavy tropical rains as remote causes of gully erosion and flooding in the area.
[11] believes that roads without proper drainage or catchment pits, unguided cultivations that cause flooding, indiscriminate channelling of flood water on sloped terrain, intense rainfall on metal roofs without drains, large cracks in hills that form flood channels, and poor drainage systems are all contributing factors to gully erosion. [12] and [13] discuss the prevailing factors in the state that contribute to gully erosion, including topography, climate, vegetation, geology, soil, and human factors. [14] points out that annual dynamic fluctuations in the groundwater table are another important factor that enhances gully initiation and growth in the area.
According to [15], topography plays a significant role in the development of gullies in the region. [8] suggests that the sequence of the contribution of soil erodibility factors to gully erosion frequency is slope > plasticity > cohesion > friction > population density, with percentage contributions of 30%, 23%, 20%, 18%, and 9%, respectively. Gully erosion is a major environmental problem that threatens the sustainability of both plants and animals in the world, and a large area of land in Anambra State is at risk. [16] states that only a few of the erosion menace is under control.
[15] notes that an increase in hydraulic heads can enhance gully development through an increase in flow rate, and seasonal expansion and contraction of impermeable clayey and/or shaly materials can also increase the rate of gully development. [1] and [17] attribute gully erosion in Anambra State to the interaction of water flow with geological materials and the chemistry of the water and/or soil, as well as geotechnical properties and other anthropogenic factors.
[15] recommends preventive measures as the best strategy to keep erosion and other environmental problems at bay in Anambra State, while [6] highlights the significance of the underlying geology, specifically the Imo shale, in controlling gully development. The phenomenon of gully erosion is rock-type dependent, with some rocks being more susceptible to erosion than others. Therefore, a brief review of the geology of Anambra State is necessary to understand why gully erosion is more prevalent in some parts of the state than in others [1], [6][18].

1.1 LOCATION OF STUDY AREA

Anambra State is located within latitude 6^0 48' N and Longitude 6^0 37'E on the North and Latitude 5^0 40'N and longitude 7^0 27'E on the South[1]. It has a total land area of 4,416sqkm[1]. The study area is in South-Eastern Nigeria.

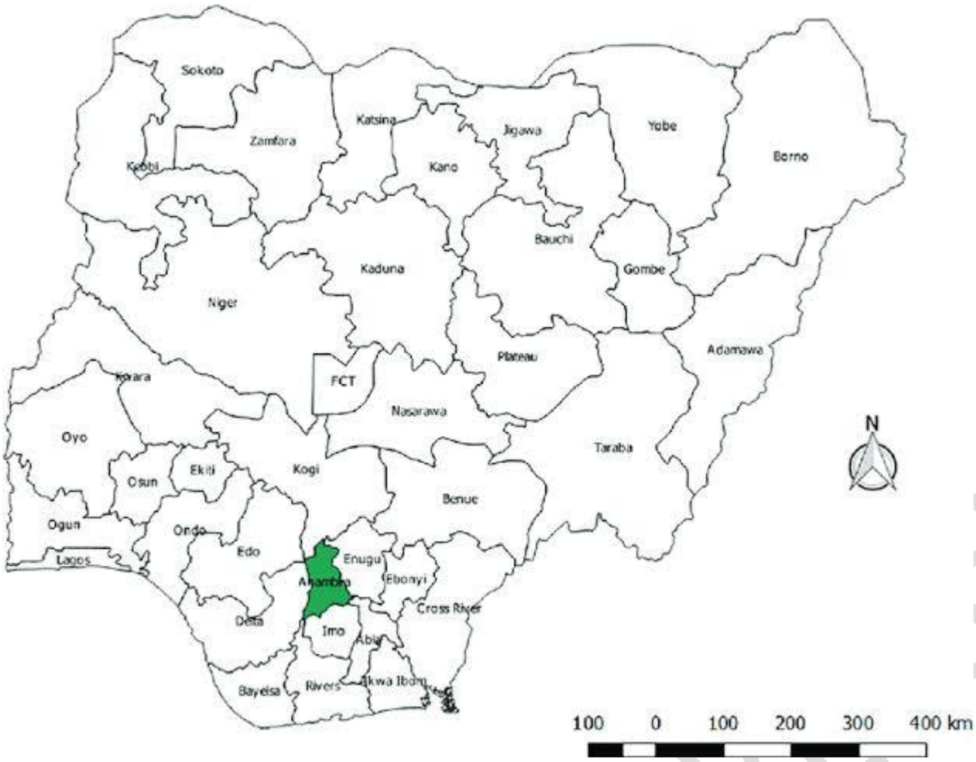

Fig 1: Map of Nigeria showing the study area..

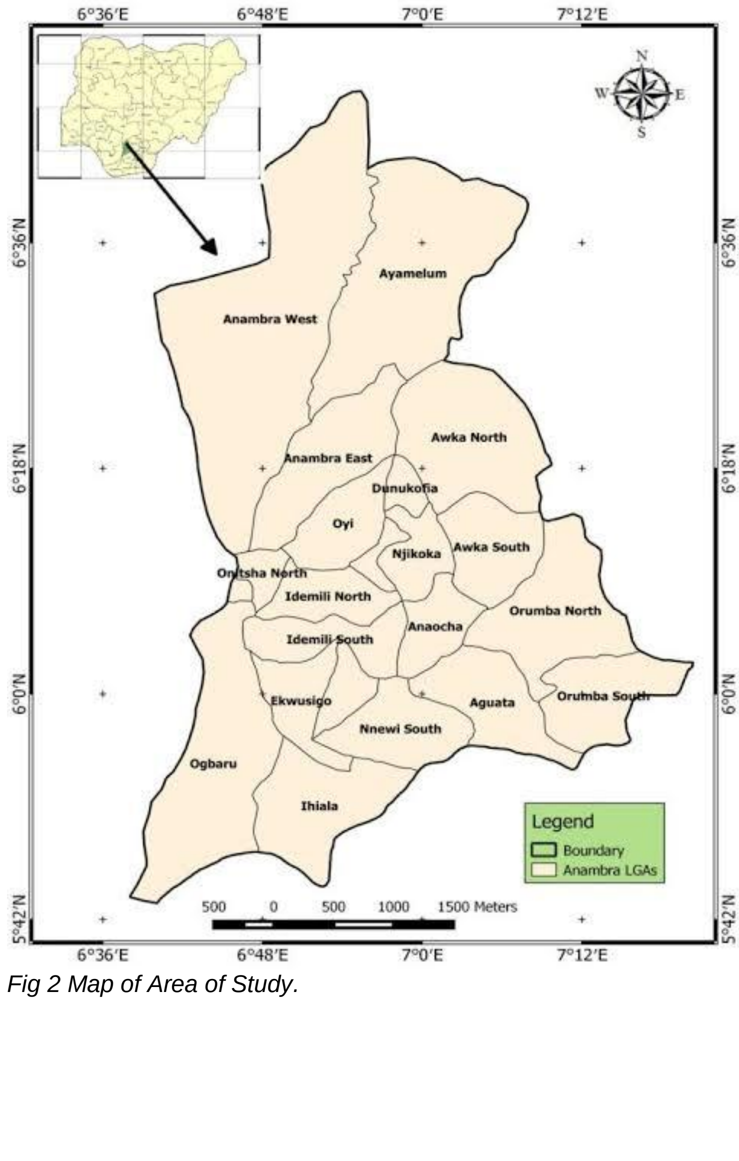

Fig 2 Map of Area of Study.

2. GEOLOGY OF THE STUDY AREA

The study area lies within Anambra Basin and Niger Delta Basin.Anambra Basin is a product of tectonic disturbances in the area.The tectonic disturbance took place during the Santonian upliftment of Albian sediments in the lower Benue Trough. The subsequent deposition of sediments within the basin resulted in the formation of ancient Cretaceous deltas with Nkporo shale, Mamu formation, Ajali sandstone, and Nsukka formation dominating the sedimentary deposits. The distribution of these geologic formations and the general lithostratigraphic sequence has been discussed by many researchers, such as [14], [15],[19], [20],[21],[22],[23],[24][25].

The stratigraphyof the Niger Delta Basinhas been intensively carried out and described by various workers. [19],[20],[26], [27],[28], and [29] have described the stratigraphy and palaeogeography of the Niger Delta. Moreover, [27]subdivided the upper Tertiary Delta Complex into three mega facies that are strongly diachronous and designated them as Akata, Agbada and Benin Formation from the base to the top. [30] in re-describing the lithostratigraphic units showed that the sediment deposition moved southwards in line with the general progradation of the Delta. During the Paleocene, a major transgression extended across entire southern Nigeria, terminating the advance of the Upper Cretaceous Delta and separating it stratigraphically from the modern Niger Delta which began to form in the Eocene. These include the Upper Nsukka Formation (350 m), Imo Formation (1000 m), Ameki Group (1900 m), and Ogwashi-Asaba Formation (250 m) [19], [31], [32],[33],[34].The Ameki Group consists of the Nsugbe Formation, Nanka Sand and Ameki Formation [31], which are lateral equivalents.[31] interpreted the Nanka Sandstone as the facies of a tidally influenced marine shoreline and elevated it from being a member of the Ameki Formation to the status of formation forming part of the Ameki Group. The Ameki Group is conformably overlain by the Ogwashi-Asaba Formation. The Ogwashi-Asaba Formation consists of an interbedding of coarse-grained sandstone, lignite seams, and light-coloured clays of continental origin. [35] referred to the Imo Shale, Ameki Group and Ogwuashi-Asaba Formation as the oldest units of the Niger Delta, which extended into the subsurface where different formation names were assigned to them. [27]described the subsurface Akata Formation as a downdip continuation of the outcropping Imo Shale. The Agbada Formation is also referred to as the down-dip continuation of the outcropping Ameki Group and Ogwashi-Asaba Formation.

The geological setting in the study area is that of layered sequences in which a predominantly sandstone formation (Ameki group) is underlain by a predominantly shale formation (Imo shale) [1],[36], [37],[24].

Stratigraphic succession in the Anambra Basin and Niger Delta Basin (redrawn and modified from [24], [38], [37],[27].

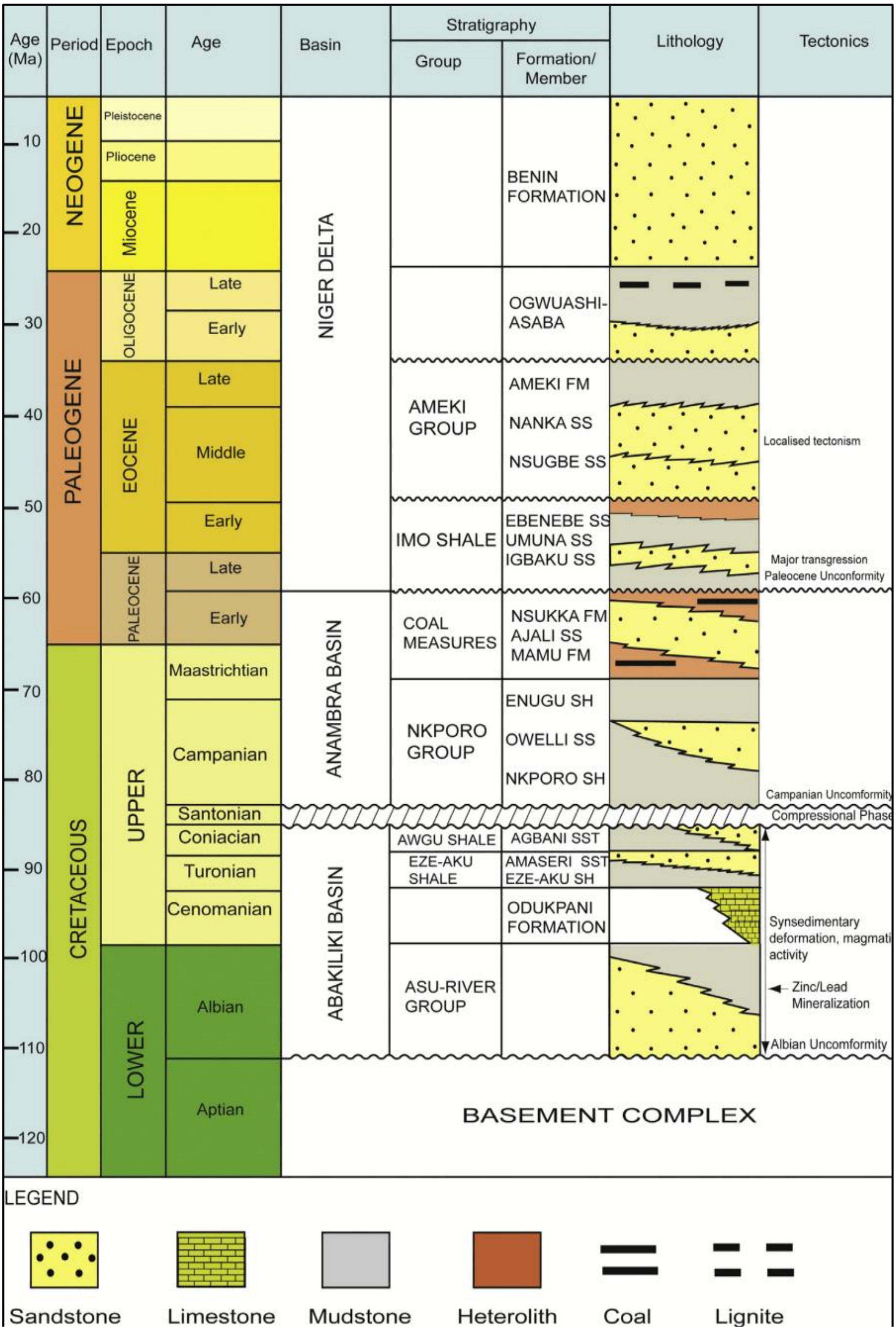

Fig 3. The stratigraphic succession of the Anambra Basin and the Niger Delta [37]

2.1 Imo Shale

The Imo Shale (Palaeocene –Lower Eocene) is the oldest stratigraphic unit in Niger Delta Basin.It is a transgressive sequenceof (fine grain) dark grey shale and outcrops on the plane of the Mamu River[1]. No active gullies are found in this formation. This is because the formation is impermeable, cohesive and resistant to weathering. Imo shale is known to have low permeability, which means that it has limited ability to allow water to pass through. When water encounters shale outcrops, it tends to accumulate on the surface rather than infiltrate into the ground. This reduces the volume and velocity of water runoff, mitigating the erosive force that typically leads to gully formation. Shale exhibits cohesive properties due to its fine-grained composition. The cohesiveness of Imo shale helps bind its particles, making it resistant to erosion by flowing water, even if water runoff occurs, it has limited ability to dislodge and transport the shale particles, preventing the development of new gullies. Imo shale is relatively resistant to weathering compared to sandstone formation (Ameki Group).Imo shale exerts a major control on gully development by decreasingthe infiltration rate and increasing the erodibility of the overlying formation (Ameki Group).

2.2 Ameki Group

Ameki formation, Nanka sandstone, and Nsugbe Sandstone are the members of the Ameki group which is one of the oldest stratigraphic units of the Niger Delta Basin [21],[39],[40].The Ameki Formation consists of alternating sandy shale, clayey sandstone, fossiliferous shale (consisting of molluscs, foraminifera, and corals), and fine-grained argillaceous sandstone with thin limestone bands. The Ameki Group is conformably overlain by the Ogwashi-Asaba Formation[37]. The Ogwashi-Asaba Formation consists of an interbedding of coarse-grained sandstone, lignite seams, and light-coloured clays. The Ameki Formation (Middle–Upper Eocene) is a regressive sequence. Active gullies of enormous magnitude are found in this unit[1],[36]. This is because the formation is very permeable and therefore increases infiltration and percolation, allowing water to infiltrate easily.This porous and very permeable formation is underlain by an impermeable formation known as Imo shale[1]. Gully erosion is more prevalent in the Ameki group compared to shale formation due to the contrasting properties and characteristics. The Ameki Formation often consists of unconsolidated sandy and loamy soils which are more prone to erosion. Ameki formation often exhibits a steeper slope compared to shale formation. Steep slopes accelerate the speed and force of water runoff increasing erosive energy and promoting gully formation.

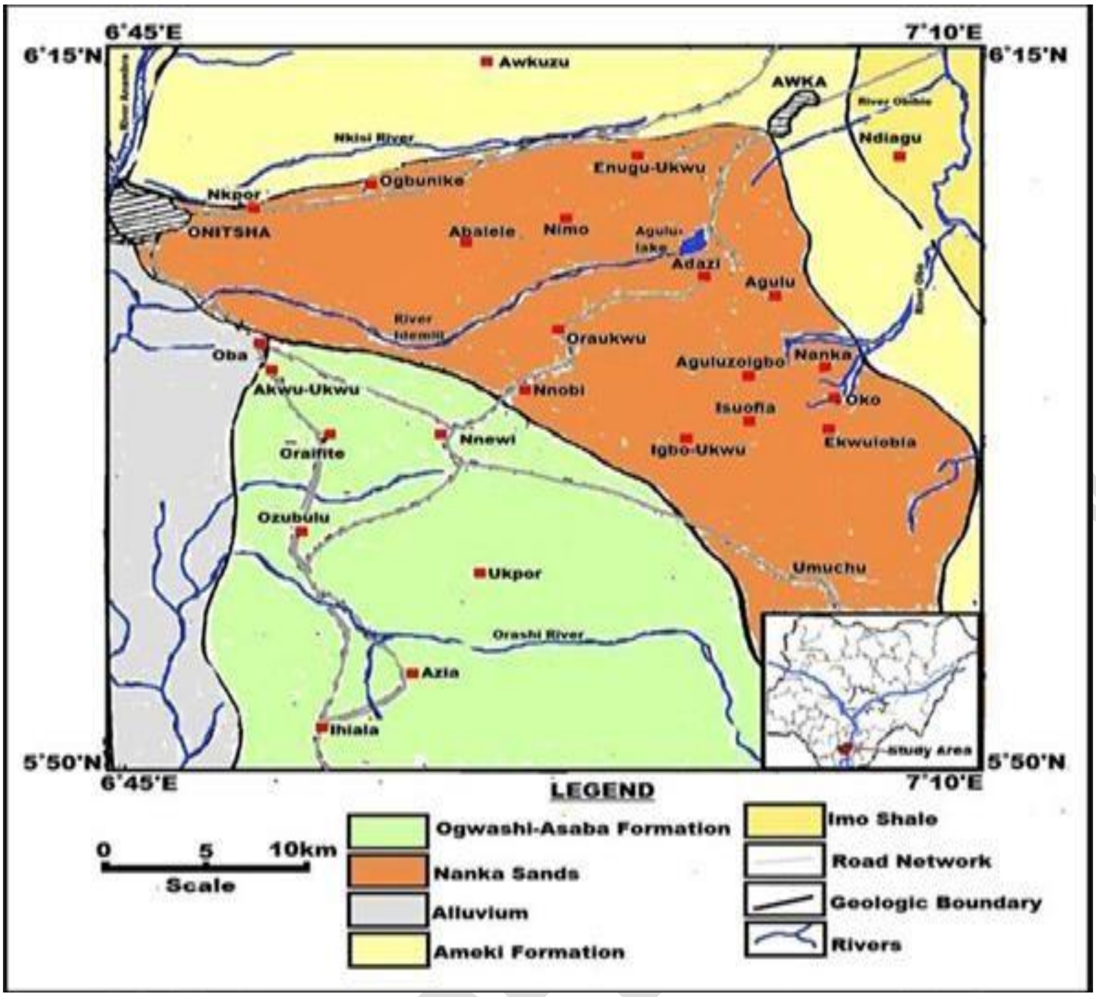

Fig 4: *Geologic mapshowing the geology of the study area [41].*

3.0 CAUSES OF GULLY EROSION IN ANAMBRA STATE

As previously noted by [18], the Anambra State has seen an increase in gully erosion, which has led to numerous researchers investigating the underlying causes. Consequently, there is a wealth of literature available on the topic from the region. The literature suggests that gully erosion in Anambra State is caused by a combination of factors, including the type of lithology in the area, topography, pH of soil/water, heavy rainfall, and anthropogenic factors. [1], [4], [7], [6], [8], [14], [42], [43], [45], [48], [49].

.3.1 Type of lithology/Hydrogeological condition of the area

The study area of Anambra State experiences gully erosion due to its geological setting [6]. The hydrogeology of certain areas affects the rate and pattern of surface water runoff. Sandy geologic formations, specifically those in the Amaki Group, are more easily eroded than shaley ones, such as the IMO shale [7]. The interaction between soil strength and groundwater contributes to gully erosion in areas like Nnaka and Ekwulobia [1]. During rainfall, the Ameki group's top unit becomes porous and highly permeable, causing water to flow vertically to reach the impermeable Imo shale. This reduces infiltration and percolation, saturating the topsoil with water and increasing runoff. As a result, the soil becomes easily eroded along drainage lines [7], [8]. The rocks' unconsolidated, friable, and loose nature also enhances their erodibility, as the bond holding sand grains together is weak [43], [48]. Additionally, the movement of groundwater can weaken soil and rock stability, leading to excessive erosion in certain parts of Anambra State [44].

Table 1: Particlesizedistributionoftheselectedsites [41]

Site	Sand(%)		Clay (%)		Silt(%)	
	TopSoil	SubSoil	TopSoil	SubSoil	TopSoil	SubSoil
Agu-Awka	80.51	74.23	6.19	24.33	13.3	9.0
Agulu	84.01	70.99	10.43	23.36	5.56	5.56
Nanka	69.31	72.01	24.27	23.49	6.42	4.50
Ekwulobia	69.91	75.11	10.99	18.11	19.1	6.78
Ogidi	97.70	93.40	2.2	6.49	0.10	0.11

3.2 Topography of the area

The erosion of hilly or mountainous terrains with steep slopes and sandy areas can lead to the formation of escarpments. These areas, such as Agulu, Nanka, and Alor-Oraukwu in the state, are highly susceptible to erosion due to the continuous geomorphic evolution of the landscape. The vegetation in this region is determined by the topography and geologic factors. The landform is divided into two parts, with the southern part being higher at an elevation of 240-390m, while the northern and southeastern parts are low-lying at 40-140m [1], [7]. According to [8], areas with high susceptibility to erosion are usually along steep slopes, which coincide with the boundary of two major soil types, shale, and sand. In some parts of the Anambra state, gully activities occur due to the gradual cutting of the sandstone Formation (Ameki group) down to the water base level at the underlying shale Formation, the Imo shale [8], [43], [48].

3.3 The pH of the soil/water

The formation and growth of gullies in Anambra State are influenced by chemical weathering [1],[41],[42]. The geochemical composition of rocks and soil affects their geotechnical properties [44]. In some parts of Awka, water chemistry is controlled by sodium bicarbonate and mixed types, with the predominant water type being sodium bicarbonate (NaHCO3) [45]. The high percentage of sodium water suggests the possibility of ion exchange reaction and mineral dissolution, which could cause soil grains to loosen and host rocks to disintegrate [45]. Surface water and groundwater in some areas of the study region have pH values ranging from 5.53 to 6.58mg/l with an average value of 5.99 and 5.48 to 6.4mg/l with an average value of 6.31mg/l, indicating slightly acidic water.The slightly acidic nature of the water may be due to carbon dioxide dissolved in rain water and decayed organic matter in the soil[41], [45], [46].

The acidic nature of both surface and groundwater plays a significant role in the decomposition of cement that holds rock particles together. This leads to erosion through mass wasting and excess runoff [1], [14], [41]. Unfortunately, this acidic water can also cause damage to engineering structures such as dams and concrete drainage channels built to control gullies. Erosion sites are often located near densely populated small towns and villages, as mentioned in [1]. In areas like Nnaka, the soil's pore spaces contain slightly acidic water that attacks the binding cement, causing the soil to loosen. This makes the soil highly reactive, causing ions such as Ca+, Na+, and Mg+ to be leached out by rainfall and carried to the ocean, where they form salts with chlorine and other elements [1], [41], [45], [46].

Table 2: range of values for physiochemical parameters for surface water and groundwater [45]

Hydrochemical surface water samples			Groundwater samples		WHO(2012) sandand
Parameters\location	Range	Average	Range	Average	
p^H	5.53-6.58	5.99	5.58-6.4	6.30	.5-8.0
Total hardness	10.52	3.5	13-70	31.71	<100
TDS	16-150	63.16	22.3-140	50.9	600
Bicarbonate mg/l	3.14-65	37.85	8.0-50	25.49	-
Sulphate mg/l	2.0-4.53	3.81	<1-5.0	8.49	250
Chloride mg/l	3.78-35	22.28	4.2-40	15.09	250
Nitrate mg/l	0.47-7.49	4.73	4.95-23.9	11.61	50
Magnesium ppm	0.09-3.12	1.56	0.69-5.0	2.96	20

Calcium pmm	0.83-4.07	3.40	2.4-8.0	3.50	0.003
Iron ppm	0.03-0.78	0.38	<0.1-0.26	0.23	0.3
Sodium ppm	0.02-4.680	2.27	0.3-4.15	2.6	200

Table3:Resultsofother physicochemical propertiesoftheselectedsites in the study area [41]

Site	pH		SR(cm/μs)		SOMC(%)		LOI(%)		CEC($cmol_c$/kg)	
	TopSoil	SubSoil	TopSoil	SubSoil	TopSoil	SubSoil	TopSoil	SubSoil	TopSoil	SubSoil
Agu-Awka	6.48	6.56	0.00065	0.00030	2.25	1.83	39	34.5	0.20	0.44
Agulu	6.72	6.43	0.0357	0.00357	2.30	1.64	42	25	2.08	0.34
Nanka	5.87	7.13	0.0133	0.033	1.16	1.67	58.5	42.5	2.08	0.29
Ekwulobia	6.78	6.38	0.0074	0.0087	1.30	1.23	47/.0	46	1.15	0.31
Ogidi	6.48	6.39	0.0052	0.0500	2.08	1.41	50.5	28	2.11	0.42

SR– SoilResistivity; **SOMC**– Soilorganicmattercontent;**LOI**–Lossonignition;**CEC**–CationExchangeCapacity

3.4 Deforestation/Heavy Rainfall

When deforestation occurs, the soil is left exposed to the elements and rainfall. This can lead to soil compaction and erosion along drainage lines [1], [7]. Soil becomes more erodible as compaction increases, as it reduces water infiltration and increases surface runoff [1], [7]. This indicates that the soils in Anambra state meet the Federal Government's requirements for non-weak soils. However, high compaction values in the state indicate a high susceptibility to erosion. As compaction increases, so does a soil's erodibility and bulk density [8].

***Fig 5**: Onset of gully erosion triggered by deforestation and topsoil excavation [1].*

3.5 Other Anthropogenic Factors

Poorly terminated urban drill terminals and inadequate outlet structures at the end of drains are among the most common human-caused factors that lead to gully erosion [6], [8]. When run-off is concentrated through a culvert or drain outlet into a lower ground basin, it creates a waterfall, which can result in a gully-head [6], [8]. This gully head can recede and grow larger, eventually swallowing up the drainage channel and putting stress on the environment, potentially leading to soil erosion and landslides [7].

4. Effect of Gully Erosion

The negative effects of gully erosion in Anambra state are significant for both humans and the environment. It causes water pollution, loss of arable land for farming, discoloration of water, sedimentation of waterways, and property dissection, which leads to management difficulties and destruction of both life and property[47]. Gully erosion has resulted in the loss of a vast area of farmland, with many others at various stages of destruction. This leads to a significant decrease in agricultural productivity, ultimately leading to food shortages and impacting farming. In addition, when a gully is located near an unconfined aquifer, the dirty water from the gully can recharge the aquifer, leading to contamination [1] [6].

Fig 6: *A Gully Site in Umuchiana, Aguata, showing the dissection of the access road [12]*

Fig 7:*Gully site at Obinagu village showing loss of productive land [7].*

5.1 CONTROL

In order to effectively control gully erosion, two approaches need to be taken: addressing issues in the catchment and stabilizing the gully walls. Civil engineering works such as constructing concrete embankments and grouting can stabilize the walls [1]. To prevent developers from erecting structures along natural drains without appropriate channelling or alternative drains, it is recommended to enact and enforce necessary legislation [15]. Workshops, seminars, and symposiums should be organized to educate communities in Anambra state, while environmental campaign awareness, construction of stormwater sock away, good farming practices, and construction of control dams, ditches up the valley, and earth dams of adequate capacity should be encouraged [10].

Applying simple grouting and stabilization at an early stage of development can effectively control gullies [1]. Pipeline structures can be used to control excess runoff and channel water to nearby surface water. Materials used for construction in slightly acidic areas should be acid-resistant [1]. Developing agroforestry nurseries with erosion control species for distribution to rural areas is recommended [7]. Adopting tree-planting techniques and extensive afforestation programs can also effectively control gully erosion [50].

The "catch them young" approach should be emphasized, using agro-forestry practices and other preventive techniques in areas not yet seriously affected by soil and gully erosions [7]. Retarding structures such as sedimentation weirs, wooden groynes or wicker-work fences, diversions, and berms can be used to control gullies in Nanka, Adazi-Nnukwu, and Agulu [50]. Controlling groundwater levels by installing wells and dewatering facilities at strategic locations is necessary to check gully erosion, as the hydrogeology of the area influences the development and growth of the gully [1]. Gully-prone areas should be delineated, and human activities such as agriculture and civil works should be controlled as they act as gully triggers and catalysts [1].

Fig 8:*Control measure put in place to check gully erosion [1].*

5.2 Challenges Of Controlling These Gullies

Various attempts by both state and federal governments to control gullies have been made, but they are still facing challenges due to lack of funds, ineffective engineering structures, geological conditions of the area, lack of awareness among the public, an increase in rainfall, inadequate funding for recommended control measures, failure to adhere to proposed drainage designs, and improper land use practices cited in sources [8], [18][49]. Large sums of money, running into the hundreds of millions of naira, are required to control these gullies. Concrete structures have been used to control numerous gully sites, such as Awka, Mbaukwu, Agulu, Nanka, Ekwulobia, Nnewi, Nnewichi, AdaziNnukwu, and Nsugbe Erosion Sites, by both the state and federal governments [18]. However, a closer inspection indicates that many of these concrete structures have failed, leading to the continual widening of the controlled sites. Failed structures can be found at St. Theresa's Catholic Church Gully Erosion Control Project in Agulu, Umuchu Gully Erosion Control Project, and Nnewichi Gully Erosion Control Projects [18]. Concrete structures are prone to failure when used in deep gullies that are heavily impacted by groundwater, particularly when the gully floors are in highly permeable and friable sands. This can be attributed to the geological setting of the area, which consists of the Ameki group and the Imo shale.

CONCLUSION

Gully erosion is a major problem in Anambra state, caused by both natural and human factors. Nearly 70% of the land in the state is at risk, but only 3% of the erosion is being controlled. Using concrete drainage structures alone is not always effective in controlling deep gullies with high water currents. To solve the problem, experts recommend using a combination of solutions, including better concrete structures, channelization, and afforestation. Addressing the issue requires the collaboration of government agencies, local communities, researchers, and other stakeholders. This includes investing in erosion control measures, capacity-building programs, and sustainable land use policies. It is also important to integrate climate change adaptation strategies to minimize future erosion risk. By taking these steps, Anambra state can protect its resources, communities, and ensure a sustainable future.

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