Minireview Article

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

ABSTRACT

Gully erosion is a severere environmental challenges faced by many parts of southeastern Nigeria particularly, Anambra state. Anambra state has more than 100 gully sites and about 30 gully sites have received measures of control but not yet subdued. Observations have shown clearly that the underlying geology of the area exert major control in the development of gully erosion in the study area. The causes of progressive gullies in some parts of Anambra state is as a result of the topography, the pH of the soil/water, type of lithology, deforestation, hydro-geology and geotechnic properties of rock in the affected area. This erosion activity has resulted in the loss of productive lands, water pollution, sedimentation of water ways, loss of lives and properties, almost on a yearly basis. However, several governments agencies have attempted managing it using concrete structures, stabilization work such as planting of bamboo tree, cashew tree to increase water intake, pipe structures to channel the water directly to a 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. Majority of the concrete structures used to control these gullies have collapsed leading to incessant spreading 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, lack of proper coordination among stakeholders hinder the implementation of comprehensive erosion control measures. It is recommended that concrete drainage channels should not only been used in controlling these gullies, it should 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 is the removal of soil along drainage lines by surface water runoff. It is an environmental degradation which leads to loss of valuable land used for farming, domestic, industrial and other purposes, as well as loss of lives and properties [1], [2], [3]. [4] stated that in all the Southestern state, Anambra State has the most active gullies many of them with failed gully-control works. Gullies in Anambra State and Southeast Nigeria would modestly be described as catastrophic, many of the gullies in Anambra state are very deep and wide with depth and width exceeding tens of kilometres, they would better be called canyon [5], [1], [3]. Several workers such as [1], [6], [7], [8], and [9] have attributed the development of gullies in Anambra State to the influence of human activities on natural and geologic processes while others suggested that gullies are linked with concentrated runoff processes. [10]attributed that anthropogenic activities like rapid urbanizations, rural-urban migration drift, over population, indiscrimate dumping of household waste in drains, emission of ozone layer depleting gases/ burning of fossil fuels, hazardous industrial waste products, heavy rains of the tropic that eventually leads to the forming and growth of gullies due to the transformation and redistribution processes of natural soil/rock elements has been identified as the remote causes of gully erosion and flooding in the study area. [11] stated that these gullies are caused by roads without proper drainage or catchments pits, unguided cultivations that cause flooding, indiscriminate channeling of flood water on sloped terrain, especially in loose soil structure area Intense rainfall on metal roofs without drains, which congregate to form large, unguided water channels Large cracks in hills that form flood channels especially on loose soil ecological terrain Grading of roads, thereby reducing road levels and creating waterways poor drainage systems. [12] and [13] discussed the pre-vailing gully erosion–inducing factors in the state to include topography, climate, vegetation, geology, soil, and human factors. [14] pointed out that annual dynamic fluctuations in the groundwater table are another important factor that enhances gully initiation and growth in the area. [15] stated that topography seems to exert significant influence on the development of gullies in the area. Gully erosion remains one of the world's biggest environmental problems threatening the sustainability of both plants and animals in the world. A large area of the land in Anambra state is at risk of gully erosion, but only a few of the erosion menace is under control [16]. [15] stated that an increase in hydraulic heads can enhance gully development through an increase in flow rate. Seasonal expansion and contraction of impermeable clayey and/or shaly materials can also increase the rate of gully development [15]. [17], [1]stated that gully erosion in the Anambra state are caused by the interaction of the flow of water with geologic materials and the chemistry of the water and/or soil, geotechnical properties of the rocks in the affected area and other anthropogenic factors.

[15] opine that Preventive measures will continue to be the best strategy to keep erosion and other environmental problems at bay in Anambra State.

Available literatures have clearly shown that the underlying geology (Imo shale) exerts a major of control on gully development and, more often than not, the process is rock type dependent as some rocks are more susceptible to erosion than the others [6].

There is therefore a need to briefly review the geology of Anambra state with a view to recognizing why the phenomenal gully erosion is more prevalent in one part of the state than in the other [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 [7].

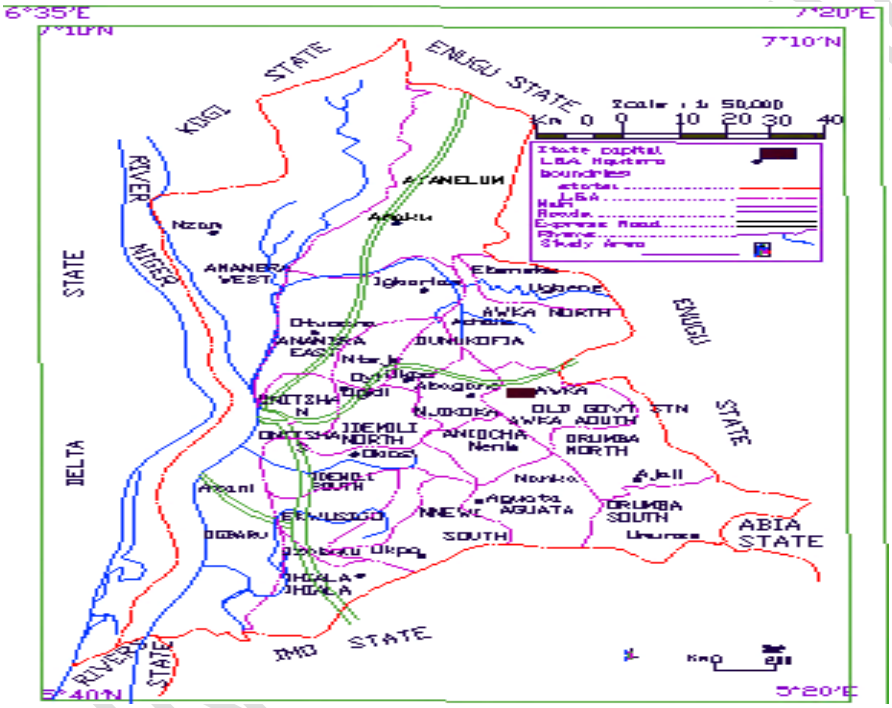

Fig 2 Map of Area of Study [18]

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 [19], [20], [14], [15], [21], [22], [23], [24] [25].

The stratigraphy of the Niger Delta Basin has been intensively carried out and described by various workers. [19], [26], [27], [20], [28], and [29] have described the stratigraphy and paleogeography 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 top. [30] in re-describing the lithostratigraphic units showed that the sediment deposition

moved southwards in line with general progradation of the Delta. During the Paleocene, a major transgression extended across the 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 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 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) [36] [37], [1], [24].

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

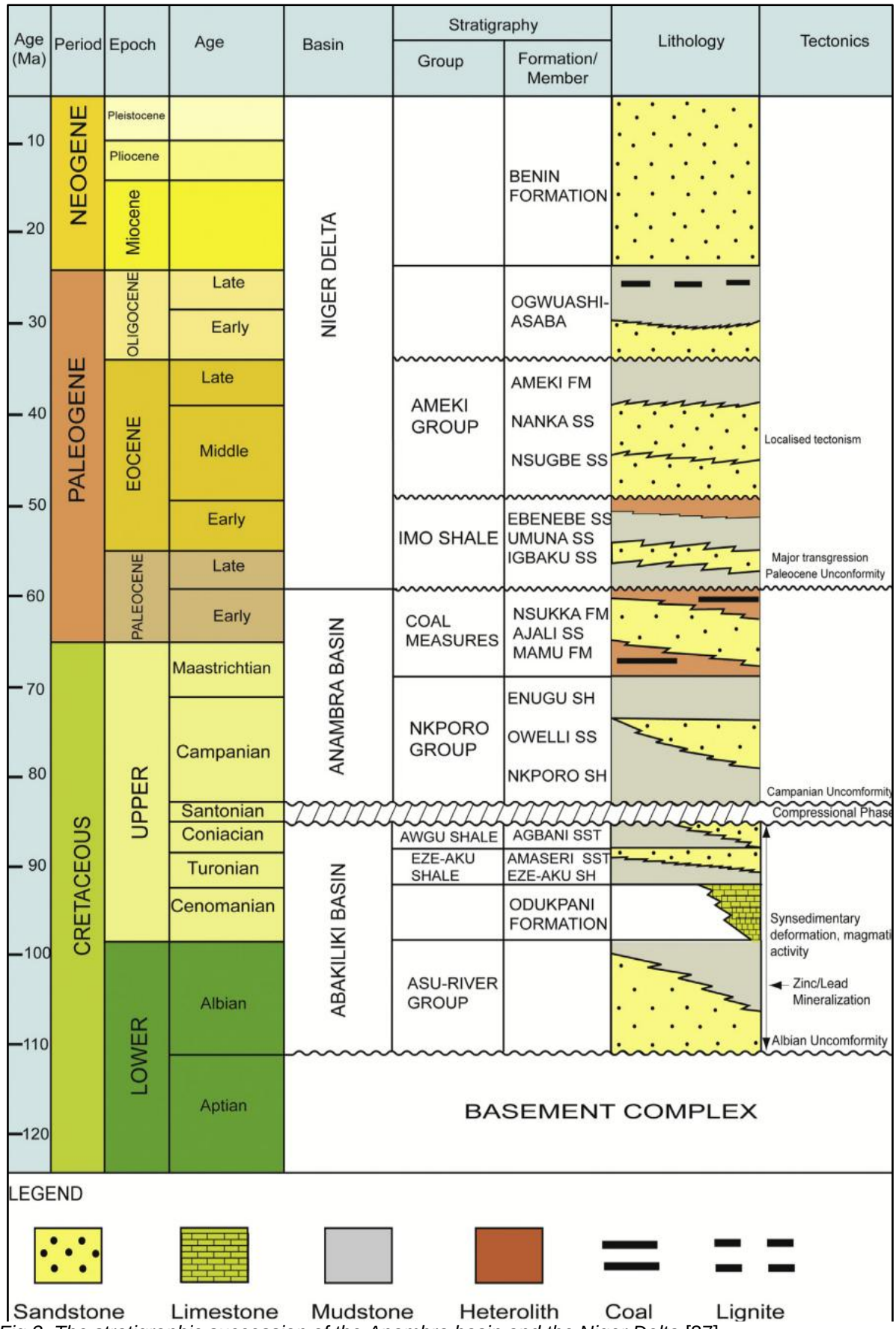

Fig 3. The stratigraphic succession of the Anambra basin and the Niger Delta [37]

2.1 Imo Shale

The Imo Shale (Palaeocene –Lower Eocene) is the olderst stratigraphic unit in Niger Delta Basin. It is a trangressive sequence of (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, this 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 infiltration into the ground. This reduces the volume and velocity of water runoff, mitigating the erosive force that typically lead 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 elatively resistant to weathering compare to sandstone formation (Ameki Group). Imo shale exerts a major of control on gully development by dereasing 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 [39], [21], [40]. The Ameki Formation consists of alternating sandy shale, clayey sandstone, fossiliferous shale (consisting of mollusks, 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-colored clays. The Ameki Formation (Middle–Upper Eocene) is a regressive sequence. Active gullies of enormous magnitude are found in this unit [36], [1]. 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.

3.0 CAUSES OF GULLY EROSION IN ANAMBRA STATE

Because of more prevalence of gully erosion in the Anambra State as earlier noted by [18], the region has attracted more attention of a number of researchers to unravel the causes of gully erosion. Therefore, the works from this area are overwhelming in the literature.

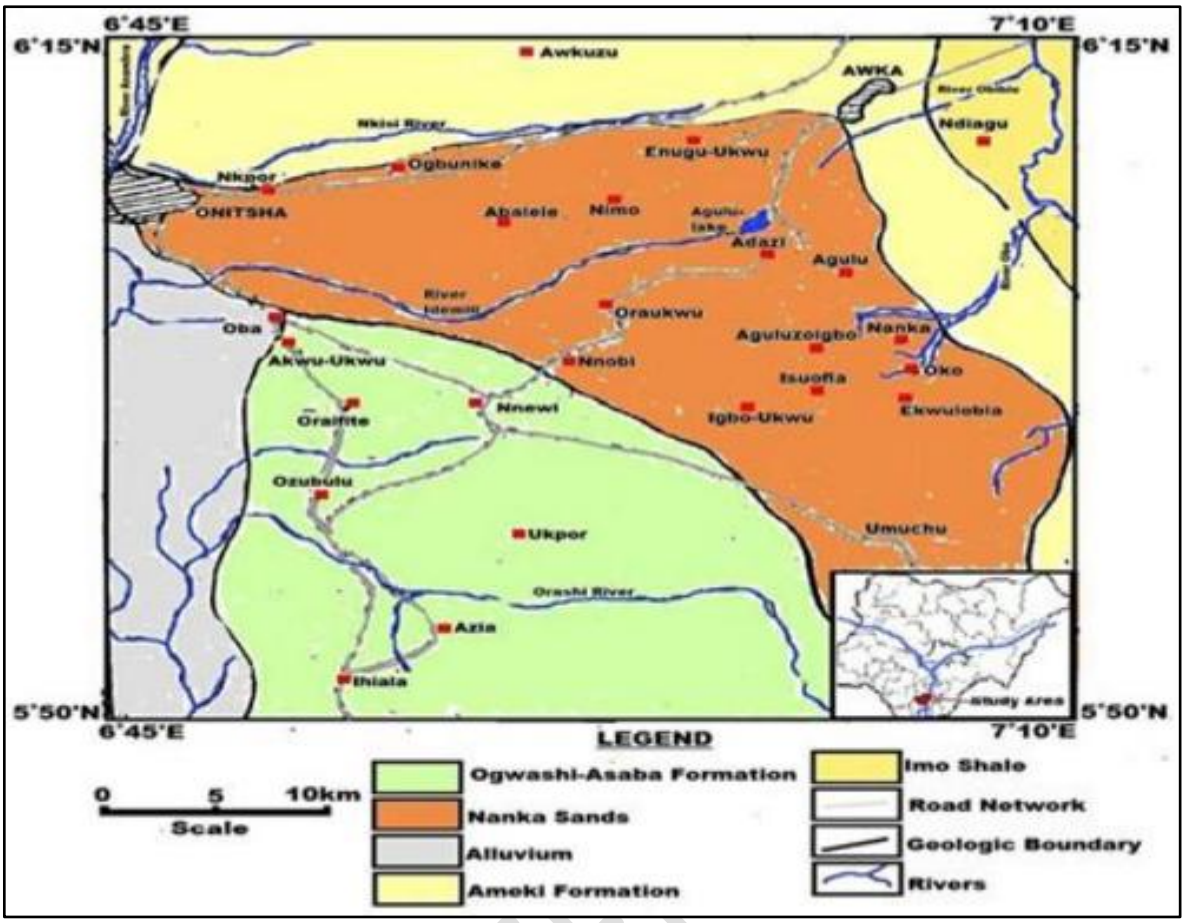

Fig 4: *Geologic map showing the geology of the study area [41].*

Gully erosion in Anambra state occurs because of the type of lithology in the area, topography, pH of soil/water, heavy rainfall, and other anthropogenic factors. [42], [14], [4], [1], [7] [6]; [8].

3.1 Type of lithology/Hydrogeological condition of the area

Gully erosion is triggered as result of the geological setting of the study area (Anambra state) [6]. Hydrogeology of some part of Anambra state affect the rate and pattern of surface water runoff. Predominantly sandy geologic formations, members or units (Amaki Group) are more easily eroded than shaley ones, that is Imo shale [7]. Strength of soils and groundwater/soil interactions leads to gully erosion in some part of Anambra state such as the Nnaka and Ekwulobia axis. This is because the top unit which is the Ameki group is porous and very permeable that during rainfall infiltration increases [1]. As the water flow vertical to percolate to the groundwater on reaching the Imo shale which is impermeable infiltration and percolation reduces making the topsoil to be saturated with water and increasing runoff. This makes the soil to be easily eroded along the drainage lines [7]; [8]. The unconsolidated, friable, and loose nature of the rocks enhances erodibility. This implies that the bond holding the sand grains is very weak, which increases the erodibility of the soil. The presence and movement of groundwater can weaken the stability of soil and rock formation. In some part of Anambra state, excessive groundwater flow erode the surface materials making them more susceptible to surface erosion.

3.2 Topography of the area

Hilly or mountainous terrains with steep slopes and sandy areas are easily eroded [7]. Hence, escarpments are products of a continuous geomorphic evolution of the landscape that produce surfaces highly amenable to erosion as presently found in Agulu, Nanka and Alor-Oraukwu areas of the state. The vegetation in the area is controlled by geologic factors of topography [7]. The landform

reveals that the area is roughly divided into two equal parts. The southern part are relatively high with an elevation that ranges from 240–390 m, whereas the northern part and the southeastern part are low lying at an elevation of about 40–140 m [1], [7]. [8] stated that most areas with high to severe susceptibility are along steeps slopes which also coincides with the boundary of the two major soil types (shale and sand). The gully activities in some part of Anambra state occur as a result of active and gradual process of cutting the sandstone Formation (Ameki group) down to the water base level at the underlying shale Formation the Imo shale [43], [8].

3.3 The pH of the soil/water

Chemical weathering is one of the important factors that leads to the development and growth of gullies in Anambra State [42], [1]. The slightly acidity of the surface and groundwater facilitate the decomposition of the cements binding the rock particles together and making them to be easily eroded by mass wasting and excess runoff [14], [1]. This acidic water attack leads to the destruction of dams and other engineering structures/works put in place to control gullies. [1] stated that most of the erosion sites are around small towns and villages that are well populated. Some places in Anambra state like the Nnaka area, the water contained in the pore spaces of the soil is slightly acidic, the acidity of the water attacks the cement binding the particles together making the soil to be loose. This makes the soil to be very reactive that during rainfall, the ions like Ca^{+}. Na^{+} and Mg^{+} ions that acts as cementing material binding the particles together will be leached out and taken to the ocean where they form salt with chlorine and the rest of them.

3.4 Deforestation/Heavy Rainfall

Deforestation exposes the soil directly to the atmosphere and direct rainfall. During rainfall the soil will be compacted, thereby causing erosion along the drainage lines [1], [7]. The erodibility of soil increases with increased compaction because it reduces water infiltration by closing pore spaces thereby increasing surface runoff [1]; [7]. This shows that Anambra state soils are following Federal Government specifications for non-weak soils. High compaction values for Anambra State soils depict high susceptibility to erosion. Erodibility of soil increases as compaction increases resulting in an increase in bulk density [8].

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

3.5 Other Anthropogenic Factors

One of the most common factors in man-made causes of gully erosion is the improper or poor termination of urban drill terminal or non-provision of adequate outlet structure at the end of drains [6]; [8]. The concentration of run-off through a culvert or drain outlet into a lower ground basin constitutes a waterfall, hence creates a gully-head [6]; [8]. This gully-head recedes and increases, swallowing up the drainage channel. Putting stresses on the environment may trigger off soil gully erosion and landslides [7].

4. Effect Of Gully Erosion

Gully erosion in Anambra state has enormous negative impact on both man and the environment. It leads to water pollution, loss of arable land use for farming, coloration of water, sedimentation of water ways, dissection of the property causing access and management difficulties and destruction of lives and properties [6]. A vast area of farmlands has been lost due to the menace of gully erosion while others are at their various stages of destruction leading to drastic decrease in agricultural productivity and ultimately food shortage that can lead to faming. If an unconfined aquifer is located close to the gully floor, dirty water from the gully will recharge the aquifer leading to contamination of the aquifer [1], [6].

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

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

5.1 CONTROL

To be effective, gully control needs to be tackled in two ways: fixing the problems in the catchment, and stabilizing the gully itself. Gully walls can be stabilized through civil engineering works such as the construction of concrete embankment and grouting [1]. [15] suggested that enacting and enforcing all necessary legislations that will prevent developers from erecting structures along natural drains when appropriate channeling and/or alternative drains have not been provided should be put in place.
[10]suggested that Organizing workshops, seminar, symposium, educating the communities in Anambra state, Environmental campaign awareness, Construction of storm water sock away, Good farming practices, and Construction of control Dams, ditches up valley, earth dams of adequate capacity should be should be encouraged to control the gullies.
[1] stated that Simple grouting and stabilization stop the increase of gullies especially when applied at a very early stage of development (fixing the problem in the catchment). Excess runoff can be controlled using pipeline structures this will help to channel the water to a nearby surface water. Materials to be used for the construction work should be acid resistant especially areas that are slightly acidic. Extensive afforestation program can be very effective in the control of gully erosion especially when well applied. This helps to protect the soil from the direct impact of raindrops and runoff as well as maintain the moisture content of the soil at responsible level during the dry season. [1] stated that stability in moisture content i svery important to avoid the formation of tension crack which triggers erosion). Hydrogeology of the area influences the development and growth of gully, therefore controlling groundwater level by installation of well and dewatering facilities at strategic locations is necessary to check gully erosion. [1] opine that gully prone areas should be delineated and human activities such as agriculture and civil works controlled as these acts as gully triggers and catalyst.

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

5.2 Challenges Of Controlling These Gullies

Both the state and federal governments tried in so many ways to control these gullies, but they are still facing some challenges in controlling the menace such as lack of funds, failure of engineering structures, Geology setting of the area, Lack of public awareness and increase in rainfall, inadequate application of the recommended control measures due to insufficient funding, lack of strict adherence to the proposed drainage design, and improper land-use practices [44], [18], [8] Controlling these gullies requires lots of money, huge amounts of money running into hundreds of millions of naira are required in controlling these gullies. Numerous gully sites which have been controlled by both the State and Federal Governments with the use of concrete structures include, among others, Awka, Mbaukwu, Agulu, Nanka, Ekwulobia, Nnewi, Nnewichi, AdaziNnukwu and Nsugbe Erosion Sites [18]. A close observation reveals that the majority of the concrete structures have distorted thereby increasing their magnitudes and leading to the incessant widening of the sites said to have been controlled [18]. Examples of such sites with failed structures include St. Theresa's Catholic Church Gully Erosion Control Project at Agulu, Umuchu Gully Erosion Control Project, Nnewichi Gully Erosion Control Projects [18]. Concrete structures tend to fail when used for deep gullies that are greatly affected by groundwater especially when such gully floors are in very permeable and friable sands [18]. This is because of the geological setting of the area (the Ameki group and the Imo shale).

CONCLUSION

Anambra state suffers most from the havoc of gully erosion. Both natural and anthropogenic factors trigger gully erosion in the state. About 70% of the land in Anambra state is at risk of gully erosion, but only about 3% of the erosion menace is under control. The effectiveness of use of only concrete drainage structures in controlling gully erosion is not 100% effective in deep gullies that are greatly affected by high water currents. Some of the solutions that are proffered include improved concrete embankment, channelization, and afforestation. Concrete drainage channels should not be used only in controlling these gullies, it should be integrated with other measures to yield a positive result. Addressing the challenges of gully erosion in Anambra State requires a multi-faceted approach involving collaboration between government agencies, local communities, researchers, and other relevant stakeholders. It necessitates increased investment in erosion control measures, capacity-building programs, and the development of sustainable land use policies. Furthermore, integrating

climate change adaptation strategies into erosion control efforts is crucial to enhance resilience and minimize future erosion risk. Anambra state can work towards preserving its natural resources, protecting communities, and ensuring a sustainable future by implementing sustainable erosion control measures and promoting responsible land use practices.

REFERENCES

1. Obiadi II, Nwosu CM, Ajaegwu NE, Anakwuba EK, Onuigbo NE, Akpunonu EO, et al. Gully Erosion in Anambra State, South East Nigeria: Issues and Solution. International journal of environmental sciences. 2011; 796-806
2. Nwaezeapu VC, Tom IU, David ETA, Vivian OO. Hydrocarbon Reservoir Evaluation: a case study of Tymot field at southwestern offshore Niger Delta Oil Province, Nigeria. Nanosci Nanotechnol. 2018;2(2). doi:10.18063/nn.v0i0.618
3. Ibekwe KN, Oguadinma VO, Okoro VK, Aniwetalu E, Lanisa A, Ahaneku CV. Reservoir characterization review in sedimentary basins. Journal of Energy Research and Reviews. 2023;13(2):20-28.
4.Onyeka JO, Obi LE,Uwanugo RGU. Erosion Control in the Erosion-Ravaged Area of Nanka – Adazi-Nnukwu – Agulu Axis of Anambra State, Nigeria, International Journal of Constructive Research in Civil Engineering. 2019; 9-19.
5. Okagbue CO, Ezechi JC. Geotechnical characteristics of soils susceptible to severe gullying in eastern Nigeria. Bul. Of International Asso. Of Engineering Geology, 1988; 38: 111-119.
6. Abdulfatai IA, Okunlola IA, Akande WG, Momoh LO, Ibrahim KO. Review of Gully Erosion in Nigeria: Causes, Impacts and Possible Solutions. Journal of Geosciences and Geomatics. 2014; 2: 125-129. doi: 10.12691/jgg-2-3-8
7. Okoye CO, Emengini EJ, Onwuzuligbo C. Environmental Sensitivity Index Mapping and Assessment of Gully Erosion Sites in Anambra State-Nigeria. Journal of Environment and Earth Science. 2014.
8. Emeh C, Igwe O, Ugwuke TAS. Geospatial analysis of Gully Erosion Causative Factors: A case study of Anambra State Prone Site, Southeastern Nigeria. 2022; https://doi.org/10.21203/rs.3.rs-1606049/v1
9. Aniwetalu, et al. Spectral analysis of Rayleigh waves in the Southeastern part of Niger Delta, Nigeria. Int J Adv Geosci. 2018;6:51-6. http://dx.doi.org/10.14419/ijag.v6i1.8776
10. Nwabineli EO and Ezeh CC. Gully and flooding in Anambra State: The way forward. Journal of Environmental and Earth Science. 2013.
11. Ezezika OC, Olorunfemi A. Resolving the gully erosion problem in southeastern Nigeria: innovation through public awareness and community-based approaches. Journal of soil science and environmental management. 2011; 2:286-291.
12. Igbokwe JI, Akinyede JO. Dang BA, Ono MN, Nnodu VC, Anike L. Mapping and Monitoring of the Impact of Gully Erosion in Southeastern Nigeria with Satellite Remote Sensing and Geographic Information System, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 2008
13. Igwe CA. Gully erosion in southeastern Nigeria: Role of soil properties and environmental factors. Research on Soil Erosion, G. Danilo, Ed., InTech. 2012. doi:10.5772/51020
14. Egboka BCE, Okpoko EI. Gully erosion in the Agulu-Nanka region of Anambra State, Nigeria. Challenges in African Hydrology and Water Resources: Proceedings of the Harare Symposium, IAHS Publ. 1984;144: 335–347.
15. Okeyeh EI, Akpan AE, Egboka BC, Okeke HI. An Assessment of the influence of surface and subsurface water level dynamics in the development of gullies in Anambra state, southeastern Nigerian. Earth science interaction. 2013; 8:1-4.
16. Okagbue CO, Uma KO. Performance of gully erosion control measures in south eastern Nigeria. Proceeding of the International Symposium on Forest Hydrology and Watershed Management, Vancouver, Canada. IAHS Publication. 1987;167:163-172
17. Egboka BCE, Nwankwor GI. The hydrogeological and geotechnical parameters as causative agents in the generation of erosion in rain forest belt of Nigeria. Journal of African Earth Sciences. 1986;3: 417-425.
18. Onwuka SU, Okoye CO. Assessment of the effectiveness of use of concrete structures in managing gully erosion in anambra state, nigeria.World Journal of Environmental Sciences & Engineering. 2014;1-10.
19. Reyment RA. Aspects of the Geology of Nigeria. University of Ibadan Press. 1965; 145.

20. Murat RC. Stratigraphy and Paleogeography of Cretaceous and Lower Tertiary in the Southern Nigeria. In: Dessauvagie, T.F.G and Whiteman, A.J., Eds., African Geology, University of Ibadan Press, Ibadan. 1970;251-266.
21. Oguadinma et al. Lithofacies and Textural Attributes of the Nanka Sandstone (Eocene): proxies for evaluating the Depositional Environment and Reservoir Quality. J Earth Sci Geotech Eng. 2014;9660:4(4)2014:1-16ISSN: 1792-9040 (print). http://www.scienpress.com/Upload/GEO/Vol%204_4_1.pdf
22. Oguadinma, Okoli N, Ezenwaka K . An integrated approach to hydrocarbon prospect evaluation of the Vin field, Nova Scotia Basin. S.E.G. technical program expanded Abstracts. International Exposition and Annual Meeting, Dallas, Texas. 2016; 99-110. Doi: 10.1190/segam2016-13843545.1.
23. Oguadinma VO, Aniwetalu EU, Ezenwaka KC, Ilechukwu JN, Amaechi PO, Ejezie EO. Advanced study of seismic and well logs in the hydrocarbon prospectivity of Siram Field, Niger delta basin. Geol Soc Am Admin Programs. 2017;49. DOI: 10.1130/abs/2017AM-296312
24. Oguadinma V, Okoro A, Reynaud J, Evangeline O, Ahaneku C, Emmanuel A et al. The art of integration: A basic tool in effective hydrocarbon field appraisal. Mediterranean Geosciences Union Annual Meeting; 2021.
25. Oguadinma VO, Kelechi IN, Ademola L, Arukwe MC. Ahaneku VC. Reservoir and sequence stratigraphic analysis using subsurface data. ESS Open Arch. February 09; 2023. https://doi.org/10.22541/essoar.167591074.46965817/v1
26. Frank, EJ, Cordry EA. The Niger Delta Oil Province. Recent Developments Onshore and Offshore, Proceedings of the Seventh World Petroleum Congress, Mexico City. 1967; 1B: 195-209.
27. Short KC, Stauble AJ. Outline of Geology of Niger Delta. AAPG Bulletin. 1967; 51: 761-779.
28. Adeleye DR. Nigerian Late Cretaceous Stratigraphy and Paleogeography. AAPG Bulletin. 1975; 59 (12): 2302-2313.
29. Weber, KJ, Daukoru EM. Petroleum geology of the Niger Delta. In Proceedings of the 9th World Petroleum Congress, Geolog. 1975;2: 210–221. London: Applied Science.
30. Avbovbo AA. Tertiary Lithostratigraphy of Niger Delta. American Association of Petroleum Geologists Bulletin. 1978; 62: 295-300.
31.Jan Du Chêne RE, Salami MB. Palynology and Micropaleontology of the Upper Eocene of the well Nsukwa 1 (Niger Delta, Nigeria). Archives des Sciences. 1978; 13(1): 5–9.
32 Nwajide CS. Eocene tidal sedimentation in the anambra Basin, southern Nigeria. Sediment. Geol. 1980; 25:189-207.
33. Arua I. Paleoenvironment of Eocene deposits in the Afkpo syncline, southern Nigeria. J Afr Earth Sci . 1986;5:279–284
34. Ogunleye PO, Oyebanji OJ, Awonusi FO. Seismic stratigraphy and depositional environment of Oligocene-Miocene sediments, western offshore, Niger Delta Basin. Journal of African Earth Sciences. 2020; 163: 103699.
35. Petters SW. Regional geology of Africa: Berlin, Springer-Verlag, Lect. Notes Earth Sci. 1991
36 Ezechi JI and Okagbue CO. A genetic classification of gullies in eastern Nigeria and its implications on control measures. Journal of African Earth Science. 1989 9; 711-718.
37. Ekwenye OC, Nichols GJ, Collinson M, Nwajide CS, Obi GC . A paleogeographic model for the sandstone members of the Imo Shale, south-eastern Nigeria O.C. Journal of African Earth Sciences. 2014;96:190–211. http://dx.doi.org/10.1016/j.jafrearsci.2014.01.007
38. Nwajide CS., Reijers TJA. A geological field excursion to parts of the Anambra Basin Nigeria, In: NAPE mini conference held at Federal University of Technology, Owerri 7-8 May 2004,1-28.
39. Nwajide CS, Hoque H. Gullying processes in south eastern Nigeria. The Nigerian Fields. 1979; 44:64-74.
40. Olajubaje TA, Akande SO, Adeoye JA, Adekeye OA., Friedrich C. Depositional Environments and Geochemical Assessments of the Bende Ameki Formation Potential as Petroleum Source Rocks in the Ogbunike Quarry, South-Eastern Nigeria. European Scientific Journal. 2018;14:1857–7881. http://dx.doi.org/10.19044/esj.2018.v14n27p157
41. Okeke CH , Ubaoji KI , Uzodinma FC. Interaction of Chemical, Physicochemical, and Geotechnical Soil Properties of Anambra State Gully Erosion Sites, Saudi Journal of Civil Engineering. 2021; 379-390. 10.36348/sjce.2021.v05i10.001.
42.Ofomata GEK. Geographical Perspective, on Environmental Problems and Management in Nigeria", Jamoe Publishers Nigeria. 2007
43. Egboka BCE, Nwankwor GI, Orajaka IP. Implications of paleo-and neotectonics in gully Erosion prone area of southeastern Nigeria. Natural Hazards Journal. 1990; 3: 219-23

44. Akpokodje EG, Tse AC, Ekeocha N. Gully erosion geohazards in south-eastern Nigeria and management implications. Scientia Africana. 2010; 9(1): 20-36