Gully erosion in the Agulu-Nanka region of Anambra State, Nigeria

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ABSTRACT In the Agulu-Nanka area gully erosion covers an area of about 1100 km². The gullying started around 1850 and the rate of gully growth is estimated at 20-50 m year⁻¹. The British Colonial Office and the local inhabitants attempted to control the gullying by constructing small dams and planting trees, but the measures failed. The area lies in the humid tropical rainforest belt of Nigeria. The landscape is a cuesta within the Awka-Orlu uplands formed by the Nanka formation (early Eocene) and the Imo Shale formation (Palaeocene). Both the geological, hydrogeological, geotechnical and hydrogeochemical characteristics of the area and human activity have contributed to gully development and growth. Major aquifers and aquitards form multiaquifer systems and heavy rainfall causes a rise in the water table. The increase in hydraulic head produces rapid flow rates that enhance the gullying process. Expansion and contraction of the clays and shales in the rainy and dry seasons respectively lead to slumping and landslides. Slightly acidic waters produced by redox reactions decompose cementing materials, thereby disaggregating the sand grains and facilitating gullying. An integrated approach is suggested for controlling erosion and gullying. It includes detailed mapping of the affected areas and other areas of potential gullying, and evaluating the adverse effects of rainfall, groundwater flows and seepage, water geochemistry, and anthropogenic activities such as agriculture.

Erosion en ravines dans la région d'Agulu-Nanka de l'Etat d'Anambra, Nigeria

RESUME Dans la région d'Agulu-Nanka l'érosion en ravines couvre une superficie d'environ 11 km². Ce ravinement a commencé vers 1850 et l'allure de la croissance de ces ravines est estimée à 20-50 m par an. Le British Colonial Office et les habitants de cette région ont essayé de contrôler ce type d'érosion en construisant de petits barrages et en plantant des arbres mais ces mesures n'ont pas eu le succès escompté. Cette région est située dans la bande de fôret tropicale humide du Nigeria. Le paysage est constitué par une "cuesta" dans les hautes terres d'Awka-Orlu constituées par la formation Nanka (Eocène
ancien), et la formation de schistes d'Imo (Paléocène). Les caractéristiques géologiques, hydrogéologiques, géotechniques et hydrogéochimiques de la région et les activités de l’homme ont contribué à la fois à la formation de ravines et à leur développement. Les grands aquifères et les aquitards constituent des systèmes de multi-aquifères et la pluie intense provoque une montée du niveau de la nappe. L'augmentation de la charge hydraulique produit une vitesse d’écoulement rapide qui favorise le processus de ravinement. Le gouflement et le retrait des argiles et des schistes respectivement pendant la saison des pluies et la saison sèche conduisent aux effondrements et aux glissements de terrains. Les eaux légèrement acides produites par réactions redox décomposent les matériaux cimentant entre eux les grains et aussi désagrègent les couches sableuses ce qui facilite encore le ravinement. On suggère une approche intégrée pour contrôler l’érosion et la formation de ravines. Elle comprend une cartographie détaillée des régions affectées et d'autres régions susceptibles de l'être et l'évaluation des effets néfastes de la pluie, des écoulements souterrains, de l'infiltration, de la géochimie de l'eau et des activités de l'homme telles que l'agriculture.

INTRODUCTION

In the middle of the nineteenth century important changes in the physical landscape of the Agulu-Nanka-Oraukwu study area (Figs 1 and 2) occurred. They started with the initiation of narrow channels which rapidly widened by erosion into major gullies that have now approached canyon proportions. The gully system that was initiated about 135 years ago within the area bounded by Agulu, Nanka and Oko, has now expanded to cover an area of about 1100 km$^2$ (Nwajide & Hoque, 1979). The gullying attracted considerable concern and extensive control programmes were established by the British Colonial Office (Grove, 1951).

The development of the gullies has caused extensive damage to the environment and has driven many people away from their homes and farmlands. Earlier studies have attributed their genesis and growth to the influence of human activities on geomorphological processes and qualitative and semi-quantitative methods were employed to produce suggestions for solving the problem. However, investigations carried out by Egboka & Nwankwor (1982) have shown that the primary causes of gully genesis and growth lie in the hydrogeological and geotechnical properties of the complex aquifer system underlying the affected areas. The high hydrostatic pressure in the aquifers produces a reduction in the effective strength of the unconsolidated coarse sands in the walls of the gullies leading to intense erosion. The erosion is followed by mass movements and sediment removal by flood flows. This is most pronounced during the rainy season.

Recent findings have shown that sulphur and iron geochemistry were significant influences on the genesis and growth of the Hadesian gully (Egboka et al., 1983). Water from the effluent seepages that feed streams at the bottom of the gully is slightly
acidic. Precipitates of iron sulphide, gypsum and sulphur are widespread. The concrete dams built at several locations to check the erosion by the Colonial Office in 1945 could not withstand the weathering effects of the slightly acidic groundwater and were weakened and destroyed.

The objectives of the current investigation are to describe the geology, hydrogeology, geotechnical characteristics and hydrogeochemistry of the study area, to relate these factors to the erosion and gullying; to explain their significance as causative factors; to relate the environmental hazards to human activity in the area; and to make suggestions for controlling the gullying.

METHODS OF INVESTIGATION

The methods of investigation have included a review of earlier work, geological investigations, soil and water sampling, and laboratory analysis. The roles of agricultural and human activities in gully formation were described by Grove (1951) and Carter (1958). The role of geological processes was discussed by Simpson (1954), Floyd (1965), Ofomata (1965), Ogbukagu (1976), Nwajide & Hoque (1979) and Egboka & Nwankwor (1982).

The geological field investigations covered both the rainy and dry seasons. As a result of the instability of the gully slopes and margins, investigations were limited to the gully floors and the lower reaches of the walls during the rainy season. More widespread and detailed studies were conducted during the dry season when slope failures were at a minimum. Detailed stratigraphic, lithological and geochemical studies were carried out. Groundwater flow patterns, effluent seepage and channel flow were observed and described.

Water samples from Agulu Lake, Uchu Lake and the Idemili River, and from effluent groundwater seepages at the bottom of the gully were collected and analysed at the geochemistry laboratory of the Anambra State Water Corporation, Enugu.

PHYSIOGRAPHY, CLIMATE AND GEOLOGY

The gullied area lies within the humid tropical rainforest belt of Nigeria and evidences savanna-type vegetation (Fig.1). The dominant vegetation is the cashew trees plated by the former Colonial Office in an unsuccessful attempt to contain the gully expansion. Many of these trees have been uprooted and consequently buried by the gullies. The surviving trees and remnants of the original rainforest are found as small patches in the unaffected areas, in the stabilized gully areas and in the river valleys. The landscape forms part of the Awka-Orlu uplands and is a cuesta. According to Nwajide (1977), the crest of the cuesta stands at over 350 m a.m.s.l, and at Isuofia attains a height of 378 m a.m.s.l. The area is drained by many rivers such as the Idemili, Nkisi, Mamu, Crashi, Uchu and Aghomili (Figs 2 and 3). Some of these rivers have their source areas on both flanks of a major groundwater divide (Figs 3 and 4). Also lakes such as the Agulu, Ulasi, Otiba and Uchu occur.

Two main seasons exist in Nigeria, namely, the dry season (the
FIG. 1 The location of the study area.

FIG. 2 The geology of the study area (based on Nwajide, 1977).
Harmattan) that runs through the months of October to March, and the rainy season that begins in March and ends in October. The southward moving Sahara desert air mass causes the dry season which is associated with extreme aridity, a dusty atmosphere, lowering of water levels and intense leaf fall. The rainy season follows the northward advance of the maritime air from the Atlantic Ocean. July and August are usually the wettest periods of the rainy season. The convectional nature of the heavy rainfall results in alternating periods of sunny and rainy conditions. According to Ofomata (1965), the annual rainfall (1950-1959) for Enugu, about 70 km north of

FIG. 3 The Agulu-Nanka-Oraukwu gully complex.

FIG. 4 Idealized flow net in a two-dimensional cross section through the Nanka escarpment (based on Egboka & Nwankwor, 1982).
Agulu (Figs 1 and 2), was 1646 mm while Agulu (1959-1962) received 1569 mm. Ofomata (1965) further showed that 89% of the rain for Enugu fell in the months of April-October, and 80% for Agulu fell from May to October. Floyd (1965) gave an annual rainfall of 2032 mm for the Agulu-Nanka area and Grove (1951) suggested that as much as 508 mm may sometimes fall in a month. Ogbukagu (1976) suggested that local violent storms are most predominant in the months of July, September and October. Some of the rainfall occur as violent downpours accompanied by thunderstorms, heavy flooding, soil leaching, extensive sheetwash, groundwater infiltration and percolation.

The dominant geological formation is the Eocene Nanka Sands (Fig.2). It is a sequence of unconsolidated or poorly consolidated sand, 305 m thick, underlain by the thick Imo Shale formation of Palaeocene age, and overlain by the lignite-clay seams of the Oligocene Ogwashi-Asaba formation. The Nanka Sands are predominantly sandy with thin claystone and siltstone bands, lenses and laminations. The sand is poorly-sorted, cross-bedded and medium to coarse grained. These units, separated by shale-siltstone-fine sand layers, may be as thick as 30 m in some places. The deposits also exhibit well developed patterns of alternating cross-bedded sands and layers of dark-grey shales. The shale units generally occur in beds 40-50 cm thick alternating with fine sand and siltstone. The component beds and laminae exhibit a wide variety of colours often arranged in bands. The units generally have a low angle of dip ranging between 7° and 9°W.

HYDROGEOLOGICAL AND GEOTECHNICAL PROPERTIES

The hydrogeological and geotechnical characteristics of the area have greatly influenced the growth of the gullies. The unconsolidated sands are loose, friable and poorly cemented with thin shaley layers. The sands are very permeable while the shales are not. Below the water table, these sands and shales are saturated with water which affects their strength. The area receives torrential downpours of rain during the rainy season when the water table rises and high groundwater flow rates occur. During the dry season, the water table falls as a result of hydraulic head decay. This produces decreased flow rates, and an increase in the depth of the unsaturated zone. During the dry season, erosion and gullying activities are therefore at a minimum.

The depth to the water table varies spatially. In areas that remain unaffected by gullying, the water table may be as deep as 60 m. In areas where the overlying lateritized soils have been eroded, the water table is shallower and may outcrop as effluent seepages, springs, ponds or streams. A considerable rise in the water table occurs during the rainy season, despite the thick unsaturated zone. This is due to the high vertical hydraulic conductivity of the freely draining medium- to coarse-grained soil overlying the multi-aquifer system. Some aquifer parameters for assessing the hydraulic properties have been calculated. Characteristic values of hydraulic conductivity, groundwater velocity, groundwater discharge and transmissivity are
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8.17 x 10^{-3} \text{ cm s}^{-1}, 42 \text{ m year}^{-1}, 2.96 \times 10^{6} \text{ m}^{3}\text{year}^{-1}, \text{ and } 5.92 \times 10^{5} \text{ m}^{2}\text{year}^{-1} \text{ respectively (Egboka & Nwankwor, 1982).}

Hydrogeologically, the Agulu-Nanka gully complex comprises a series of aquifers separated by aquitards. The aquifer-aquitard units form a multi-aquifer system. Above the water table, a deep unsaturated zone, which may be up to 60 m deep during the dry season, occurs. The water table becomes shallower towards the surface courses and the edges of the numerous lakes. The area is part of the drainage system of several rivers and lakes. The rivers include the Idemili, Akponkwu, Mamu, Obibia, Odo, Otalu, Uchu, Aghomili and Orashi; the lakes include Agulu, Ulasl, Otiba and Uchu (Fig. 3). The rivers either originate from these lakes or from the groundwater reservoirs beneath the gully complex through effluent seepage. A regional surface water divide running north-south occurs, with streams and rivers flowing away from it on both flanks (Figs 3 and 4). This indicates that a regional groundwater divide occurs at some depth below the surface water divide. The water from Agulu and Ulasl lakes and the Idemili River flows west of the divide while the water from the Nanka gully, and the Odo and Uchu Rivers, flows eastwards, suggesting the existence of a major surface water and groundwater divide between the two areas. It seems that erosion on both sides is now approaching the divide.

The expansion of the gully complex results from the high pore water pressures in the aquifer complex, particularly during the peak recharge times of the rainy season. These high pore water pressures reduce the effective strength of the unconsolidated coarse sands along the seepage faces on the gully walls. The sands are gradually loosened and eroded. The less permeable clay layers are lubricated and saturated with water. The clays subsequently expand and lose their shear strength. Caving-in, piping, slumping and landslides are common. These erosional activities occur in a cyclic manner and result in step-like features that are displayed all over the affected areas (Fig. 5).

The behaviour of the interbedded shales, which undergo large changes in volume as a result of alternate wetting and drying, enhance the gullying. The shales increase in volume when wet and become sticky and plastic during the rains. They form a caked dry mass during the dry season. Drying causes contraction of the clay and shale, resulting in the formation of extensive tension cracks or pressure release fractures. The cracks are also transferred to the sandstone units. They are observed horizontally at the ground surface and vertically and transversely on gully walls, extending for a distance or height of many metres. The tension cracks at the ground surface occur about 1.5 m from the edge of the gully, and they maintain this almost uniformly for a distance of about 50-100 m, until they terminate at angles of about 45° to the edge of the gully. The cracks widen with time. During the rains, they serve as channels for vertical flow of water to the underlying sand/shale boundaries.

As a result of the shales being thoroughly saturated after many days of rainfall, the clay minerals swell and develop a tendency to slide. Large masses of sand underlain by the plastic shale slide down dip into the gully, with the shale acting as a lubricant. Cashew trees, bamboos and abandoned homes are carried by the sliding
mass into the gully. Quicksands also occur in some places. After heavy rains, the water table rises and the pore water pressure increases. This creates conditions that are unable to withstand any imposed stress. This may explain the washing away of some small dams built by the former Colonial Office in 1945 in an attempt to check the erosion. Many people in the area have lost their lives in the quicksand.

HYDROGEOCHEMICAL PROPERTIES

The hydrogeochemical characteristics of the area are important factors in the generation and growth of the gullies through chemical weathering (Egboka et al., 1983). The surface water and groundwater are slightly acidic, thereby facilitating the decomposition of the cements binding particles together and loosening them for erosion.
The deposits of amorphous sulphur indicate highly reducing conditions and consequently an anaerobic environment. Oxidation-reduction (redox) reactions are possibly occurring along the water flow system through complex geochemical activity (Fig.6). All these processes contribute to soil disaggregation and erosion, and to the destruction of engineering structures built to control the gullying. The cementing materials include limonite, ilmenite, calcite and a clay matrix (Nwajide, 1977).

Extensive deposits of amorphous sulphur occur along the channels at the bottom of the gully. Gysiferous deposits and iron pyrites are observed. During the rainy season, any vegetation affected by the flood water of the Odo River gradually dies, probably as a result of its slightly acidic nature. Attempts by the local inhabitants to use the coarse sand from the Odo River plain for block-moulding have been abandoned because the mixture of sand and cement does not set, even at high cement concentrations.

Investigations by Egboka et al. (1983) have indicated that acids are produced during oxidation and reduction in the physico-chemical weathering environment. Iron-sulphur bacteria *Thiobacillus Thiooxidans* oxidize ferrous sulphide such as pyrite producing sulphuric acid and soluble iron as exemplified by the equation:

\[
4\text{FeS}_2 + 15\text{O}_2 + 2\text{H}_2\text{O} \rightarrow 2\text{Fe}_2(\text{SO}_4)_3 + 2\text{H}_2\text{SO}_4
\]

During the rainy season, large quantities of free acid are produced and dissolved in effluent groundwater that flows into the Odo River. This acidified water becomes toxic to vegetation.

**ANTHROPOGENIC FACTORS**

In 1945, a Soil Conservation Centre which attempted to monitor the erosion problem was established at Agulu, but the scheme was terminated in 1950. The affected areas are in the heartland of the Igbo ethnic group where the human population is dense. Any space not inhabited is cultivated, primarily for yams, cassava, maize and vegetables. Since the inception of the gully, the population has increased in a geometrical progression and the settlements such as Agulu, Nanka, Oko and Ekwulawbia have assumed suburban status. Urbanization has been associated with deforestation, construction of new roads, changes in the flood channels and increased runoff.

The pressure on farmland for agriculture is excessive. The forest and bush are regularly cleared for farming and exposed to erosion and gullying. Between 1945 and 1949, extensive planting of acacia, bamboo and cashew trees was undertaken. Ditches, sumps and diversion channels were dug. Small dams were also constructed. Instead of checking the gullying, the ditches and sumps increased groundwater percolation and flow rates, and hence the gullying. Numerous tracks and pathways have been created by farmers and these form rills and channels for surface runoff that is discharged into the gullies.

The erosion in the Agulu-Nanka area has become a great tourist attraction and tourist pressure causes further stress to the weak soils and may contribute to gullying. The local inhabitants of the
FIG. 6  Cycles of oxidation-reduction along the flow system: a model (based on Egboka et al., 1983).
affected areas also make paths into the gullies to fetch water for domestic use and these further enhance the gullying.

THE HUMAN IMPACT

The Agulu-Nanka gully represents a great national disaster which has caused considerable fear and panic in the people. It was even suggested in the 1940s that the population of Agulu-Nanka-Oko areas should be moved to a safer and stable zone around Anaje in the neighbouring Cross River State. However, the people reacted against this suggestion by the British Administration, and the plan was abandoned. Most of those areas have nevertheless now been lost to erosion as predicted. Families may have been forced to abandon their homes for safer ground on more than one occasion. Lives, domestic animals and buildings, institutions and property worth millions of naira have been swallowed up by the gullies.

SUGGESTED CONTROL MEASURES

The Sediment Off-loading Model (SOM) as opposed to the Tectonic Origin Model (TOM) has been used to explain the genesis and growth of the Agulu-Nanka gully (Egboka, 1984). Proper control measures can only be based on a complete understanding of the mode of origin. TOM relates to tectonically generated ancient gullies, some of which are of geologic age. SOM describes contemporary gullies, most of which are less than 300 years in age, resulting from sediment erosion, transport and deposition elsewhere. All the control measures initiated since 1935 have failed. At present, channelization structures are being constructed. These will probably also fail since their design did not take into account most of the findings discussed above.

Detailed investigations

It is suggested the following proposals should be implemented as a matter of urgency before any further control measures are embarked upon:

(a) The areas affected and threatened by erosion and gullying should be declared a disaster area. Human movement and agricultural activities should be restricted and controlled and the present construction of control structures should be stopped.

(b) A detailed investigation of the pedological, geological, hydrogeological, geotechnical, and hydrogeochemical characteristics of the region and of the socio-psychological conditions of the people should be undertaken to provide relevant data on which efficient control measures can be based. Affected and potential areas of gullying should be delineated, the soil and geology mapped, and the groundwater geology, the hydrology and the geochemistry investigated.

(c) Detailed isotope studies should be carried out to establish the age relationships of the lakes, streams, rivers and groundwaters in relation to the geology of both sides of the water divide (Figs 2, 3 and 4). This would provide information on the precise relationship
between the lakes and other water bodies and the gullying.

(d) The data collected should be subjected to statistical analysis. The resulting information should be made available to a team of scientists and engineers, including hydrogeologists, civil engineers, and geotechnical engineers, to produce a master plan and designs for erosion and gullying control.

Control measures

Based on a literature review and the preliminary investigations described earlier, the following control measures are suggested. They should only be initiated after executing the detailed investigations outlined above that will provide more detailed information.

(a) Surface and subsurface flows and drainage should be controlled by directing water through concrete channels into lined artificial reservoirs or straight into the lakes or river plains.

(b) The gully walls and bottom should be stabilized through engineered structures, grouting and bolting.

(c) Human activity and agricultural practices should be controlled and their effects reduced to a minimum.

(d) Since the groundwater is slightly acidic, acid resistant construction materials should be used.

(e) Major dewatering schemes at strategic locations where water level mounds develop should be carried out. The pumped water could be treated for use. The dewatering should be on a continuous basis.

(f) After execution of the above projects, the affected areas should be reclaimed by extensive afforestation and other agricultural programmes.

(g) The control measures must be applied to the entire area.

Post-control measures

(a) An Environmental Monitoring Centre should be set up at Agulu or Nanka to monitor the control measures and collect relevant information for future analysis.

(b) An International Workshop on Erosion and Gullying in the Tropics should be sponsored at the Anambra State University of Technology at Awka to focus more international attention on the environmental disaster that is now devastating the area. The workshop would provide more ideas for long-term control of the problem.

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