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(RESEARCH ARTICLE)

A geotechnical approach to gully erosion control and management at Inyishi, Ikeduru L.G.A., Imo State, Nigeria

Obi L.E. [1,*] and Uwanugo R.G. Uchejiora [2]

[1] *Civil Engineering Department, Imo State University, Owerri, Nigeria.*

[2] *Civil Engineering Department, ChukwuemekaOdumegwuOjukwu University, Anambra State, Nigeria.*

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Abstract

This research is aimed at appraising the root causes of gully erosion at Inyishi in Ikeduru Local Government Area of Imo State, Nigeria, and the possible geotechnical control and management techniques that could be applied in curbing the menace. In pursuance to these objectives, field and laboratory investigations were undertaken. The field works involved reconnaissance and chain surveys, and contouring of the gully catchments. It was observed that gullies were initiated in the research area by flow concentrations induced by environmental factors related to roads and aligned buildings constructed with inadequate drainage facilities upstream of the gully locations. Laboratory investigations carried out involved engineering analyses of soil samples collected at the gully sites and beds for the determination of the soils grain sizes, Atterberg limits, moisture content, specific gravity, permeability, shear strength and bulk density relations. A summary of the engineering properties of the soil revealed its poorly graded and sandy nature, its inadequate fine materials content, low liquid and plastic limits, which ranged between 35.80 to 42.20 % and 28.35 to 35.00 % respectively, as well as its low permeability index of 1 × 10-2cm/sec. These findings, coupled with the fact that the gully area was underlain with friable and cohesionless soil, with small time of concentration, which renders it easily disaggregated by runoff are pointers to the relative ease of water infiltration and seepage at the gully locations. The erosive power of the slope within the gully area was estimated by chain surveying of the entire catchment. The efficacy of natural local materials such as vetiver grass, wood shavings, palm kernel shells, coconut husk, bread fruit husk, dead plant mulch, etc. for the geotechnical works on gully erosion control and management was explored. General specifications on the geotechnics of managing the installed control works for their sustainable services were proffered.

Keywords: Erosion; Gully; Geotechnical; Reconnaissance; Contouring; Catchments

1. Introduction

Basically speaking, three factors – heavy surface runoff, ground slope of the research area and its soil type combine in the determination of its soil erodibility. This underscores the fact that different soils are detached and eroded at different rates under specific conditions such as organic matter content of the soil, its clay content, porosity, hydraulic conductivity, and the vegetal covering in the area. All these affect the shearing resistance of the soil to runoff and other erosion causing agents. [1]

According to Heeds (1986), whenever short-term engineering measures are employed to reclaim any eroded and gullied area [2]. The site needs to be protected by geotechnical measures as a basis for long term control, and for stabilization and reinforcement of the soil(s) with woody vegetation. This will protect the slopes, intercept rain drops, maintain infiltration, and retard velocity of runoff, as well as provide mechanical reinforcement for the plants' root systems (Gray and Leiser, 1982) [3]. For a given rainfall rate, Chukwueze (1986) showed that soil detachment (erosion) is directly proportional to the shear strengths of soils, which Ogbukagu (1986) observed was high in the soil types of the South-

*Corresponding author: Obi L.E.
Civil Engineering Department, Imo State University, Owerri, Nigeria.

east Nigeria, including those in the research catchment. Soil erosion is a major environmental problem prevalent in the South-east region of Nigeria [4]

The research area – Inyishi is in this region of the country. See Appendices i and ii. The development of gully erosion in the research area is attributed to the fact that the area's soil is almost friable and unconsolidated, mostly sandy without adequate binding matrix; a situation that is often worsened by extremely heavy rainfall, with a recorded mean annual rainfall of 3000 mm of long duration, and intensities of up to 200 mm/hr [5].

In the research area, gully erosion problems worsen every year with each rainy season, as the devastation increases, creating erosive landforms with sharp edges, especially along hills and slopes which are generally referred to as gullies or the gully erosion phenomenon [6]. The objective is to research on gully erosion control in Inyishi using geotechnical approach by determining the nature and extent of the damage already done by erosion, carrying out geotechnical studies which would facilitate selection of adequate soil materials to be used for reclamation of the gully erosion sites, carrying out basic engineering studies and tests, and recommending from the tests results the appropriate geotechnical options for the control of gully erosion [7].

1.1. Erosion Mechanics

Erosion Mechanics demonstrate that as runoff descends steep slopes, it gathers considerable force (momentum) with which it tends to cut the ground. Under such a situation, loose soils such as sand and silt offer very little resistance to the scouring effects of running water. Consequently, when a large quantity of water flows rapidly over a poorly graded soil, gully begins to develop, giving rise to gully erosion [8].

Ofomata (1978), noted that of the 75, 488 km^2 of the entire Southeastern Nigeria land area, about 16,688 km^2 or 22 % was affected by severe erosion, 465 km^2 by active gully erosion and 753 km2 or 10 % by incipient gully erosion [9]. In Imo State, the home state of the research area (Inyishi), Abarikwu (1988), identified about 1970 erosion sites, with gully erosion occurring in about 40 % of the land mass [10]. The integrated opinion of these researchers as to the wide-spread incidence of erosion in the Southeastern Nigeria was ascribed mostly to the fact that the sands in the region were almost friable, with restricted clay contents, and unconsolidated to great depths, a situation that was exacerbated by the high rainfall and rainfall intensities of the area [11].

In 1998 for example, the annual rainfall for Owerri, a town close to the research area (Inyishi) was 2555 mm, Enugu - 1860 mm, Okigwe - 8250 mm, and Agulu - 2032 mm [11]. Rainfall intensities of about 145 mm/hr have been recorded in most parts of the areas geographically situated in proximity to the research area [12]. Associated to erosion is the phenomenon of flooding which favourably crystalize it. In 2012, Nigeria was rudely jolted by flood devastation in several parts of the country. The excess runoff generated by the unprecedented heavy rains of that year wrecked havoc across the country, leading to the authorities opening the dams in neighbouring Cameroon and Niger republic to relieve the pressure [13].

The destructive influence of flood and erosion to the environment has led man to explore into ways of combating them through proactive measures, either to prevent their occurrence or harness the inherent challenges already posed by them for solving other problems confronting him. In Nigeria the National Environmental Standards and Regulatory Enforcement Agency (NESREA) is the government agency charged with the responsibility of protecting and developing the environment's biodiversity and conserving same for sustainable development [14].

2. Material and methods

2.1. Materials

The materials and equipment employed for the fieldwork include: Cutlass for clearing of grasses and hedges, soil samples for physical examinations on site, and analyses of the engineering properties of the soil, station pegs for marking out points on the field during the chain survey, a 30 m measuring tape for taking offset distances during the chain survey, 2 m long ranging poles, automatic leveling instrument, compass on a tripod stand, palm kernel shells, vetiver grass for testing their efficacy in erosion control, water which was used as raindrops/rainfall.

2.2. Methods

The method adopted in the research was the geotechnical approach for the control of gully erosion in the research area, since the resources for such control could be sourced from within the locality with limited capital input. Also, oral interviews of relevant resource persons in the research area, site surveys for topographic mapping and height determination and laboratory soil tests for the determination of the engineering properties of the research area's soil. In this research the study area was visited to identify the location of the gullies, the topographic survey was initiated for possible reclamation works, the geotechnical data were analyzed, the hydraulic design parameters such as rainfall intensity and quantity of runoff were evaluated and the appropriate geotechnical measures, including soil conservation techniques for gully erosion control in the research area were recommended.

2.3. The Research Area's Local Setting

The Inyishi Local Setting as represented in appendix iii depicts the physical local setting of the Inyishi town. The area's geotechnical features such as farm lands, plantations, water bodies, built-up areas, etc. are shown, while appendix iv depicts a pictorial plan representation of the area. It shows a graphic view of the critical infrastructure along the gully axis. Appendices iii and iv served as handy tools and working drawings during the research.

2.4. Contouring

Perimeter leveling was employed during contouring. The automatic leveling instrument and leveling staff were used to determine the heights of the station pegs, using a temporary bench mark (T.B.M.) of 100 m. The levels were reduced using the height of instrument method. The contour map and its cross sections are represented in appendices v and vi.

2.5. Determination of Axis of Alignment for the Control Structures

The drainage from the axis of the inactive gully area was decided to be located at km 0+000 m. This would transport runoff from the axis into an existing drainage along the Amaugo road at km 0 + 150 m, which would further be piped through a culvert at km 0 + 171.8 m across the Oziri – Inyishi road, down to the proposed drainage of the active gully area at km 0 + 183.6 m, and finally to discharge into an existing natural depression at km 0 + 300 m, which has been draining the area for years (see appendix vii).

The choice of this axis was made after adequate appraisal of the site's slope, the profile of the existing gully along the axis, the aesthetics of the choice on the environment and the engineering economy of dispensing with already existing critical infrastructure within the area.

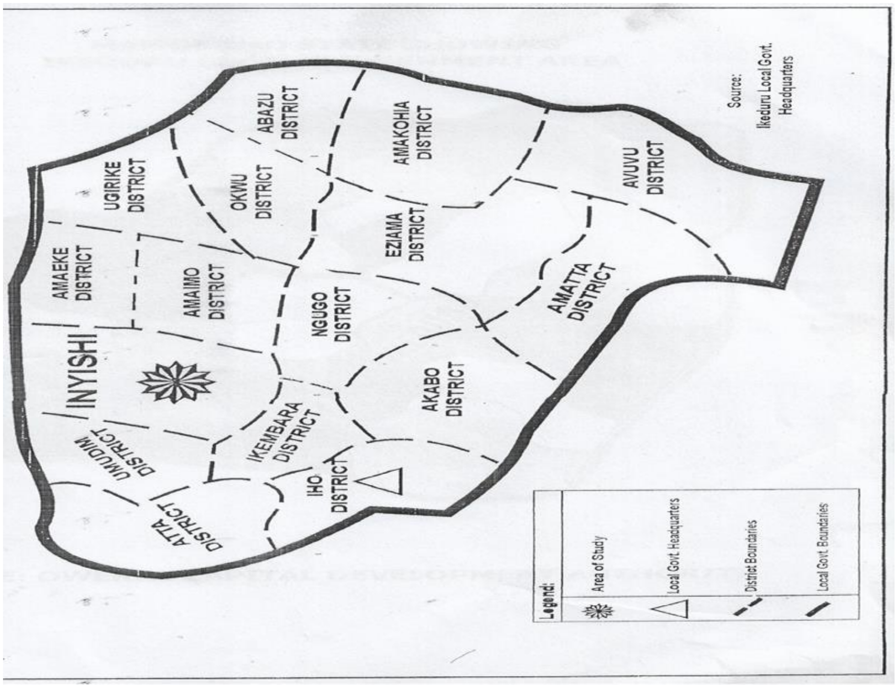

Figure 1 Map of Ikeduru Local Government Area showing the Research Area –Inyishi

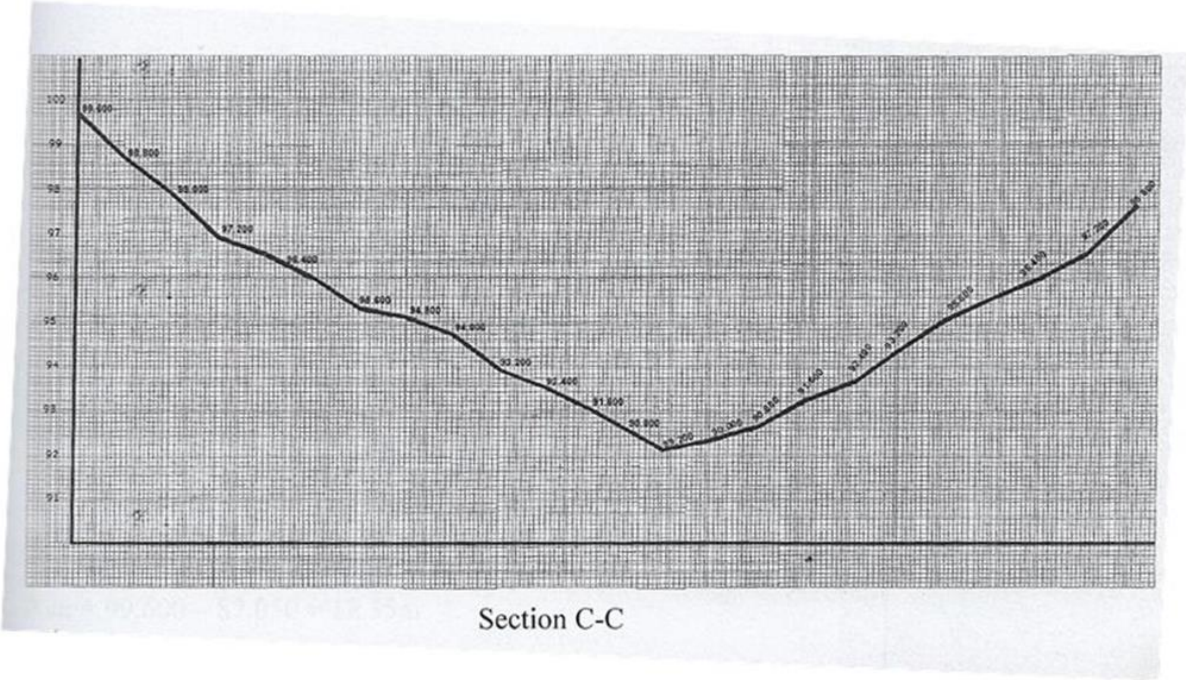

Figure 2 Cross Section of the Surveyed Area in the Study Area

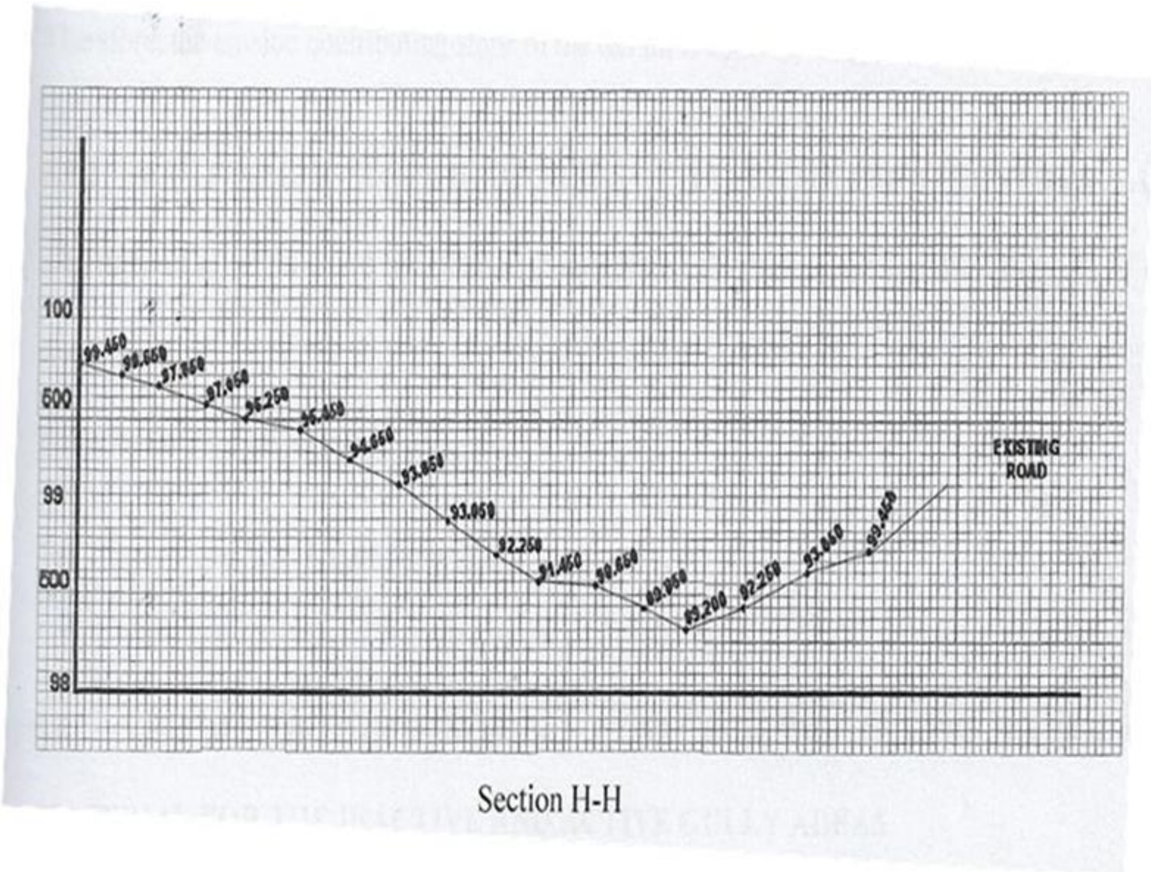

Figure 3 Reduced level of the Sections of the Gully Erosion area

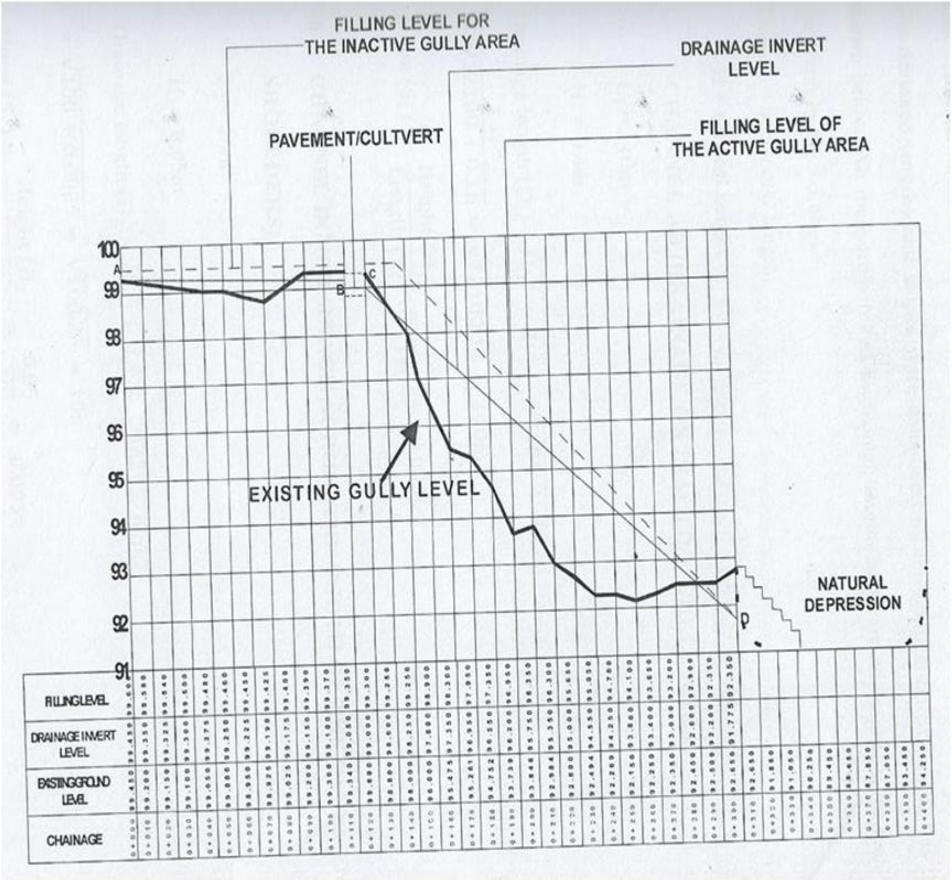

Figure 4 Longitudinal Section of the Mid-offsets for the existing Ground Levels, Final Filling Levels, the Culvert and Pavement to Drainage Area

3. Results

The field and laboratory experiments carried out formed the basis of information upon which the research revolved. The conceptual and empirical frameworks postulated the use of earth materials such as vetiver grass, wood shavings, coconut husk, palm kernel shell, breadfruit husk and dead plant mulch as potentially good enough materials for erosion control in the research area, since their usage enhanced soil infiltration after the velocity of overland flow would have been reduced through their interception of the impact energy of raindrops. From the physical identification of the soil tests carried out, the soil samples obtained from the gully and borrow site were virtually similar and exhibited similar pre induced soil properties prior to testing. They were gritty in nature when rubbed between the fingers. The absence of the characteristics dark colour and odour indicated that organic matter was not present in the soil. The soil samples were nearly uniform in size, with little fine contents. This suggested that the soil is a coarse-grained soil, predominantly sandy in nature. Less than 50 % by weight of the coarse-grained soil were larger than the BS No.4 sieve. This further classified the soil as sand because according to Ogbukagu (1986), and Babalola (1986), loose sand bands are coarse and poorly graded, with the little fines. Analysis from the soil classification showed that the moisture contents varied between 28 % to 36 %, and the average moisture content was 33.07 %, which indicates high moisture content, likely to reduce during the dry seasons. The cohesion and angle of internal friction (ϕ) for the gully site averaged 22.0 KN and 34.70 respectively. Such low values make the soil susceptible to erosion. The average values for the liquid and plastic limits are approximately 22.275 and 21.583 respectively. These suggest that the liquid and plastics limits of the gully area have low values. The values are underlain by a friable and cohesionless soil which can be disaggregated with relative ease. This is confirmed by the Unified Soil Classification System because the soil falls within the field designated CL and ML, which are soils of low to very low strength. The plasticity index of the soil indicated that the soil samples exhibited medium compressibility, since the LL<35.0<50.0, and can be altered by increase or decrease in the moisture content of the soil. The density of the soil was 1836 kg\m^3, with its unit weight as 18.01KN/m^3. This indicates an averagely compact soil.

From the grain size analyses, the uniformity coefficient (Cu) was less than 5 in the cases of the soil tests, which indicated a very uniform soil. The soil samples were coarse-grained since more than half of the materials of about a range between 98.10 % and 99.0 % for the gully and reclamation sites respectively were larger than the 75 mm sieve size (sieve no. 200). Also, more than half of the fraction was smaller than the 4 mm sieve size. These, further classify the soil as sand. Less than 5% of the coarse-grained soil of about a range between 1.0 % and 1.92 % were smaller than 75 mm sieve size, which classify the soil as poorly graded sand (SP), with little fines (clay and silt contents). It is, therefore, inorganic and medium compressible.

According to Lambe (1979), pp. 37, it was observed that when this type of soil is compacted and saturated, the compressibility becomes very low and the shearing strength becomes good, although it still remains pervious when further compacted. However, the overall workability of the soil as construction material remains fair, which suggests that the soil at the site is not entirely bad, rather the volume of runoff passing through it is the chief cause of its erodibility.

The high velocity flow concentration at the erosion sites of Inyishi also causes scouring because of the area's high slope. This is also as a result of reduced infiltration caused by the removal of vegetation, erection of structural infrastructure, and improper construction of civil engineering works.

Below is the empirical tests results of the experiment on the application of geotechnical measures (vegetative/ground cover) in the control of soil and gully erosion in the research area.

Table 1 Results of the Runoff Data Obtainedat the Site.

Sample No.	Sample Name	Quantity of Runoff in ml.	Time (s) characteristic of runoff
1.	Vetiver grass	255	126
2.	Wood shavings	285	116
3.	Coconut husk	310	112
4.	Palm kernel shell	350	110
5.	Breadfruit husk	375	104
6.	Dead plant mulch	455	101
7.	Bare soil	506	98

As the splash energy of the water sprinkler was made uniform by the constant application of equal volume of regular tap water across the entire runoff plots, it is concluded that the sample sediment collected at the catchment basin is a good index of the erosion across the different runoff plots. The quantity of sediment collected and the colour clarity of the discharge in the catchment basin is in effect a measure of this index. The minimized runoff from the soil samples covered by the different earth materials may be attributed to soil infiltration, which became enhanced as a result of slowed overland flow velocity (Okorie and Adeola, 1986). See appendix vii.

4. Conclusion and Recommendations

Different approaches are often considered in the evaluation and resolution of flood and erosion problems in any given situation. However, the method applicable often times is dictated by the nature, scope or magnitude of the challenge posed by the erosion menace, and, by the available resources for the control of the problem.

Thorough evaluation of the hydrologic, geologic and physiographic factors of the research catchment, including the geotechnical characteristics of the gully site was done with the aim of determining the root causes of the gully formations and their dimensions.

Although the findings from this research revealed that the geotechnical approach to gully erosion control is very effective; especially in local village settings like in the Inyishi research area, the adoption of any single measure for gully erosion control and reclamation of gully sites may not be a self-sufficient option, unless the complex task of general involvement of the human population in the gully control process and effort are also willfully engaged. In doing so, the host communities should be involved to promptly pinpoint early developments of any gully in their localities for prompt attention before the damages become extensive and more capital intensive to manage, since erosion is a dynamic process.

Recommendations

- Despite government recognition of the menace of gully erosion across the country, particularly in the south-east region, her general commitment to fighting the scourge appears ad-hoc and grossly inadequate. It is, therefore, recommended that government should appreciably increase her control efforts, and diversify it to include the institution of a national erosion research centre to coordinate the activities of similar satellite offices in each state of the federation so as to appropriately formulate and coordinate erosion research policies across the country. This approach will involve more people since people are a good predictive tool for early detection of erosion gully development, which could be stemmed by their early preemptive management, such as application of earth materials on small flood plains, water puddles or basins within homesteads and local environments. In addition to the above policy recommendation.
- Adequate rectangular drainage channels or open surface diversion drains should be provided in the community to collect runoff waters and overland flows before they are transported into the natural depressions downstream. The filling of the gullies should be done with soil that can be well compacted, and which has high resistance to flowing water so that it would be able to retain the designed channels' walls. This will be useful in reducing the backwater effect and further erosion devastation in the area.
- The designed engineering structures should be maintained at regular intervals to avoid siltation, and all farming activities near the installed control structures should be discouraged.
- Effort should be made to transmit runoff flows in the research area of Inyishi at non-erosive velocities by implanting engineering structures such as interceptor drains, drop structures, and controlling the overfalls at their gully heads so as to drop the discharges at various points in the channels, etc., as well as reducing the high percentage slope of 6.4 % which was determined during the fieldworks to 3 % by filling.
- Earth materials (creeping plants/trees, carpet grasses, stones, etc.) such as vetiver grass, palm kernel shells, wood shavings, coconut husk, bread fruit husk and dead plants, etc. should be used in providing vegetal cover for the soil.
- Public awareness campaigns through the print and electronic media on the best practice for proper utilization of the installed control structures is advocated.
- Government bodies should endeavour to plan awareness campaigns on education of the inhabitants of the research area on the consequences of indiscriminate bush burning, refuse disposal, and farming activities near gully sites.
- Erosion research institutes and auxiliary laboratory soil testing centres should be established by the governments and corporate bodies.

Compliance with ethical standards

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Disclosure of conflict of interest

There was no serious clash between the authors as they worked harmonious without any visible altercation and conflict

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