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Investigation into the Causes of Gully Erosion in Parts of Anambra State

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Abstract

Gully erosion is a natural disaster that have affected many parts of south-eastern Nigeria particularly the state of Anambra. The causes of progressive gullies in some parts of Aguata local government area of Anambra state was investigated. The gullies can be found in Ula region of Ekwulobia, Otaalu region of Akpo, Ogbei region of Nkpologwu and Achina town. Some samples were collected from the walls of the gully at depths ranging from 1.5 to 2.5m. Laboratory analysis which include index property tests and compaction tests were carried out on the samples. Questionnaire survey and analysis was also carried out to sample people's opinion. Unified soil classification system classified all the soil samples under clayey sands (SC) which is susceptible to erosion. The empirical values of erodibility factor, K determined show that the soil samples are moderately erodible. Based on the laboratory test results and questionnaire responses, it is evident that soil properties and human activities contribute to the development of gullies. It is recommended that all effort should be made to protect soils from exposure to runoff especially at slopes.

1. Introduction

Soil erosion is the process of detaching and transporting soil by means of surface water or wind as a result of inadequate or improper vegetative cover. This natural hazard from the onset has been a naturally occurring process and remains one of the world's biggest environmental problems, threatening sustainability of both plants and animals in the world [1][2]. It involves the gradual washing away of soil through the agents of denudation such as, wind, water, glacier and man. These denudating agents loose, wear away, dislodge, transport and deposit wear off soil particles and nutrients in another location [3]. There are four types of known soil water erosion processes which include: splash, sheet, rill and gully. The process begins by water falling as raindrops and flowing on the soil surface. Splash erosion results when the force of raindrops falling on bare or sparsely vegetated soil detaches soil particles. Sheet erosion occurs when these soil particles are easily transported in a thin layer, or sheets, by flowing water. If this sheet runoff is allowed to concentrate and gain velocity, it cuts rills and gullies as it detaches more soil particles [4]. Fig. 1 shows the different types of soil water erosion.

This gully erosion is perhaps the terminal phase of the four-stage erosion process. As the erosive force of flowing water increases with slope length and gradient, gullies become deep channels and gorges [6].

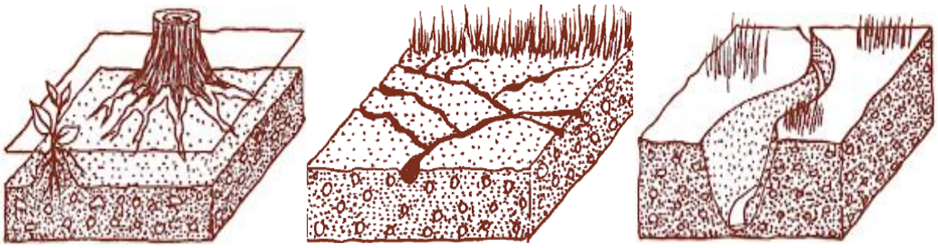

Fig. 1: Types of soil water erosion [5]

The formation of gullies has become one of the greatest environmental disasters facing many towns and villages in south-eastern Nigeria. This region is fast becoming hazardous for human habitation. Many people have been forced to relocate because their houses have been threatened by progressively ravaging gullies. Large areas of agricultural lands have become unsuitable for cultivation as erosion destroys farmlands and lowers agricultural productivity [7]. Of all the states is South-Eastern Nigeria, namely; Abia, Anambra, Ebonyi, Enugu and Imo states that are affected, Anambra state is the most affected, having more than one thousand (1000) active gully erosion sites [4].

Several scholars have worked to find out the causes of these gullies in different parts of south-east of Nigeria, but no scholar has particularly focused attention on the gullies developing around the towns of Akpo, Achina, Ekwulobia and Nkpologwu in Aguata local government area of Anambra state. The identified causes of these gullies includes: topography, land use, soil characteristics, construction activities, deforestation etc. This study intends to discover the causes of gully erosion at the case-study towns and also explore cheap and locally available means by which the effect of gully erosion can be minimised.

1.1 Study area

The study area is Aguata local government area. Aguata is a local government area in Anambra State in Nigeria. Anambra State lies within latitude 5° 45′ N and 6° 46' N and longitude 6° 31' E and 7° 03' E. The estimated landmass of the state is about 7200 km^2. The area is underlain by cretaceous to recent sedimentary formations of the Anambra basin that are of varying aquifer potentials. The Anambra basin is mainly filled with clastic sediments comprising of several distinct lithostratigraphic units ranging from upper camparian to recent in age. The lithostratigraphic units have a thickness of almost 2500m and consist of Nkporo Shale, Manu formation, Ajali sandstone, Nsukka formation, Imo shale, Ameki formation, Nanka sands, Ogwashi-Asaba formation, Benin formation and the Alluvial plain sands [8].

2. Methodology

The materials used for this study are four soil samples collected from the walls of the gully and questionnaire

The methods adopted in the study include:

(1) Field observation

(2) Laboratory analysis of soils from the gullies

(3) Use of questionnaire to obtain information from the residents of the towns

2.1 Field observation

Pictures were taken at the gully sites visited in the towns of Ekwulobia (Ula region), Akpo (Otaalu), Nkpologwu (Ogbei) and Achina. The pictures show the various features of the gully including its level of development. All the gullies are surrounded by farmlands most of which have been lost to the gullies.

2.2 Sample collection and laboratory analysis

A total of four (4) samples were collected, one sample from each town. The samples were packaged in polythene bags (to avoid moisture loss) and transferred to Nnamdi Azikiwe University Civil Engineering (geotechnics) laboratory for analysis. Table 1 below shows the towns, sample labels, sampling depths, and description.

Table 1: Sampling depths and sample description

Town	Sample label	Depth (m)	Visual Description
Achina	A	1.5	Reddish
Akpo	B	2.0	Light brown
Ekwulobia	C	1.5	Reddish
Nkpologwu	D	2.5	Light brown

Geotechnical tests carried out on the soil samples include natural moisture content, particle-size analysis, Atterberg/consistency limit, compaction, and specific gravity tests in accordance with procedures specified by the British Standard Methods for testing soils for civil engineering purposes [9]. The laboratory tests were conducted to determine soil index properties.

2.3 Questionnaire

Questionnaires were distributed randomly to peoples from the four towns of study to ascertain their views to the current situation of erosion menace in their communities. Table 2 shows the number of questionnaires distributed to the residents of the four (4) towns.

Table 2: Number of questionnaires distributed to the four towns

Towns	Number of copies of questionnaire distributed
Achina	100
Akpo	100
Ekwulobia	100
Nkpologwu	100
TOTAL	**400**

3. Results and Discussion

During the field observations, pictures were taken to show the level of deterioration of the gullies. Six (6) pictures were taken in all as shown in Plates 1-6.

Plate 1; Gully site at Ekwulobia

(Ula region)

Plate 2; Gully site at Achina

Plate 3; Gully site at Akpo (Otaalu)

Plate 4; Still part of Otaalu gully

Plate 5; Gully site at Nkpologwu (Ogbei)

Plate 6; Still part of Ogbei gully

Plate 1 shows an active gully. The roots of the vegetation present do not hold the soil particles together to restrain them from sliding down to the bottom of the gully and transported to the nearby river. Plate 2 shows a gully developed due to bad termination of road drainage. Plate 3 shows another active gully which has no restraining feature. This is in line with the thoughts of [10] who attributed the causes of gullies in South Eastern Nigeria to the combination of physical, biotic and anthropogenic factors. Plate 4 shows a gully which has been restrained from further expansion using bamboo tress. The same is applicable to plates 5 and 6. Bamboo has been effectively used to control gully expansion but it also has disadvantage that it tends to take over all the land around where it is planted and it is difficult to destroy except through burning which affects the properties of the soil.

3.1 Discussion on laboratory test results

Table 3 shows the summary of the results from the laboratory tests carried out. The laboratory tests include natural moisture content which is often seen as a possible indicator of the soil liquid limit. Particle size tests show the gravel content, sand content and fines content. According to [11], particle size affects the movement and retention of water, solutes, heat and air and thus affects soil properties. The fines content range from 27.58% to 43.32% which in each case was lower than gravel and sand content combined and may not effectively hold the soil particles together against the erosive power of runoff. The specific gravity values range from 2.50 to 2.70 which is typical of soils with high sand content or organic matter [12]. Atterberg limit test results and particle size distribution results are basically used for soil classification.

Based on USCS, the soil samples are predominantly sand because the fines content (silt + clay) fraction are less than 50% but the characteristics of fines present based on the plasticity chart show that they are predominantly clay because their Atterberg limits fall above A-line and plasticity index are all greater than 7. They can be classified as inorganic clay of low to medium plasticity (CL). Based on AASHTO system, samples A and D can be called fine-grained soils because more than 35% pass No. 200 (0.075 mm) sieve. Samples B and C have fines content of 34.99% and 27.58% respectively which are not far away from the 35% mark thus the fines content would not also have significant impact on the engineering properties of such soils. Soils that belong to classes SC and CL are usually impervious, have low to medium compressibility and fair shear strength. These properties favour erosion when the soils are indiscriminately exposed by human activities.

Table 3: Summary of all Laboratory Test Results

Towns	**Achina**	**Akpo (Otaalu)**	**Ekwulobia (Ula)**	**Nkpologwu (Ogbei)**
Sample Labels	**A**	**B**	**C**	**D**
Natural Moisture Content (%)	6.78	7.58	10.32	5.95
Liquid Limit, LL (%)	27.50	37.80	35.00	31.80
Plastic Limit, PL (%)	19.90	18.60	24.20	20.40
Plasticity Index, PI (%)	7.60	19.20	10.80	11.40
Maximum Dry Unit Weight (kN/m^3)	19.13	20.40	19.72	19.62
Optimum Moisture Content (%)	10.50	9.40	10.70	11.00
Specific Gravity	2.50	2.55	2.70	2.52
Gravel Content (%)	1.67	7.14	0.00	1.54
Sand Content (%)	55.01	57.87	72.42	62.23
Fines Content (silt + clay) %	43.32	34.99	27.58	36.23
Soil Plasticity	Medium	High	Medium	Medium
USC plasticity chart	CL	CL	CL	CL
Unified Soil Classification System (USCS)	Clayey sands (SC)	Clayey sands (SC)	Clayey sands (SC)	Clayey sands (SC)

3.1.1 Soil erodibility index

Soil erodibility and erosivity are two common parameters used to analyse gully erosion development. Erosivity is related more to rainfall while erodibility is related more to soil properties [7]. In this study soil properties were examined, therefore the erodibilty index can properly be related to the soil's susceptibility to erosion. According to [13], soil erodibility is a factor that can be used to evaluate the soil's vulnerability to erosion. It usually measures the soils resistance to erosion. According to [14], soil erodibility which is usually defined by the factor, k depends on five major soil properties which include texture, structure, permeability, organic matter content and water content. Some researchers have worked hard to examine the relationship between soil erodibility and soil properties. This probably began with the work of [15].

[16] reported a high negative correlation between clay content and soil erodibility (R = 0.77). This means that soils with low clay content is highly erodible. All the soils samples used in this study have (silt + clay) content less than 50% which is quite low. [17] also discovered a relationship between (silt + clay) content and soil loss due to erosion. [18] discovered similar trend in organic matter content. There is 2 % rise in erodibility index for every 10% decrease in soil permeability [19]. Universal Soil Loss Erodibility (USLE) models developed by [20] and [15] and Water Erosion Prediction Project (WEPP) model as outlined by [13] are shown in Table 4.

Table 4: Models for estimating soil erodibility [13]

Author	Model
USLE	
El-Swaify and Dangler (1977)	$K = -0.03970 + 0.00311 X_2 + 0.00043 M + 0.00185 X_3 + 0.00258 X_4 - 0.00823 X_5$
Wischeimer and Mannering (1969)	$K = (0.043 R + \frac{0.62}{M} + 0.0082 S - 0.0062 C)$ % silt
WEPP soil erodibility coefficient	$K_{ib} = 2.728 \times 10^6 + 1.921 \times 10^7 fs$ $K_{rb} = 0.00197 + 0.030 fs + 0.03863 e^{-1840M}$

Where;

X_2 = proportion of unstable aggregates greater than 0.25 mm (%)

X_3 = soil water content

X_4 = redefined silt (%) = % silt + % fine sand

X_5 = redefined sand fraction (0.01 – 2 mm)

R = soil reaction (directly proportional to soil pH)

OM = organic matter content

S = % sand

C = clay ratio = $\frac{\%sand + \%silt}{\%clay}$

f_s = % fine sand

M = % organic matter

K_{ib} and K_{rb} means inter-rill erodibility and rill erodibility respectively and are used for soils having more than 30% sand.

According to [21] these methods are more suited for temperate soils and may not be suitable for tropical soils as soils are heterogenic. They however developed similar model for tropical soils. The model may not be applicable in this situation because of limitation on the required tests done but based on the high negative correlation between clay content and soil erodibility established by [16] it is proven that the soils in this study would be highly erodible as they are coarse-grained soils. Their coarse-grained nature is due to the fact that they possess low fines content (clay + silt %) less than 50% according to USCS soil classification. This is slightly different from AASHTO standard that pecked coarse-grained soils as having (clay + silt %) less than 35%. However, the value of (clay + silt %) for sample 1 and 4 are not far from 35%.

3.1.2 Estimation of K based on empirical relationships

[22] in an extensive work carried out on soil erodibility for a wide range of soils discovered that the plastic limit of soil depends strongly on both clay content and organic matter. Thus clay and organic matter are needed for prediction of plastic limit. They developed empirical equations that have significant R-squared values to predict plastic limit, liquid limit and plasticity index of soils within ranges of 11 – 74% clay content and 0.2 – 6.9% organic matter content.

Two important empirical relationships developed by [22] were used to determine the soil's organic matter (OM) content and clay (C) fraction

$$\mathbf{PL} = 10.55 + 4.63OM \ (R^2 = 0.96;\ P < 0.0001) \quad (1)$$

$$\mathbf{LL} = 6.65 + 0.626\,C + 0.007\,C^2 + 7.4\,OM - 0.128\,COM \ (R^2 = 0.931;\ P < 0.0001;$$

$$\text{RMSE} = 4.43) \quad (2)$$

Where, C = clay content; S = sand content; OM = organic matter content;

PL = plastic limit; LL = liquid limit

[23] discovered that there is a significant negative correlation between soil erodibility (K) and activity index (A) ($R^2 = 0.939$). They developed equation where

$$\mathbf{K} = -0.56\,A + 0.52777 \quad (3)$$

$$\mathbf{A} = \frac{PI\ (\%)}{C\ (\%)} \quad (4)$$

PI = plasticity index, C = clay fraction, A = activity index, and K = erodibility factor

Table 5 summarizes the values of clay content, organic matter content and activity index determined using the empirical relationships above.

Table 5: Clay content, organic matter content, activity index and K-values of the samples

Samples	Clay (C) content (%)	Organic matter (OM) content (%)	Activity Index (A)	K
A	13.10	2.00	0.58	0.20
B	29.85	1.74	0.64	0.17
C	17.57	2.95	0.61	0.19
D	19.24	2.13	0.59	0.20

From Table 5, it can be seen that the clay content and organic matter content are not significant in the soil. Thus, the erodibility values are quite significant. This further explains why the soils are highly erodible based on soil properties.

3.2 Questionnaire analysis

The questionnaire was analysed using cluster and stacked barchart in MS Excel. Figs. 2 – 6 presents the reaction of the respondents based on the structured questions. The challenge with the questionnaire was that most of the people around the places sampled have little or no education and most were not knowledgeable in this aspect of study. However, the researcher did his best to explain to most of them what was meant and those who could understand filled properly.

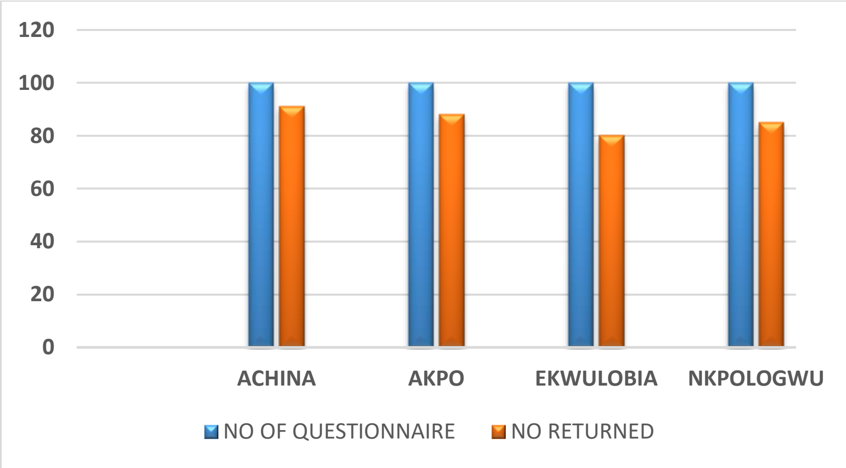

Fig. 2: No of questionnaire issued and no returned

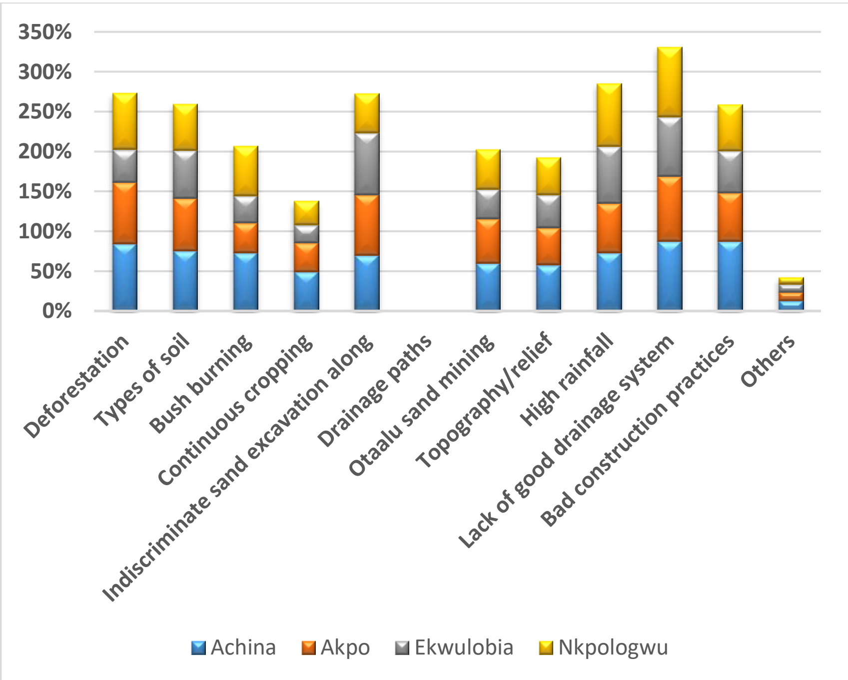

Fig. 3: Causes of gully erosion

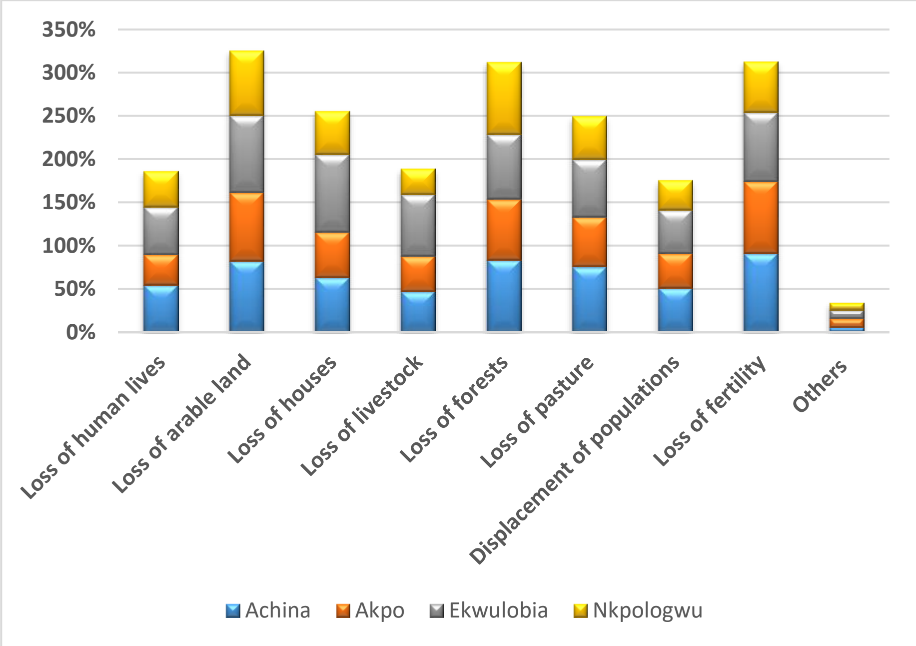

Fig. 4: Adverse effects of gully erosion

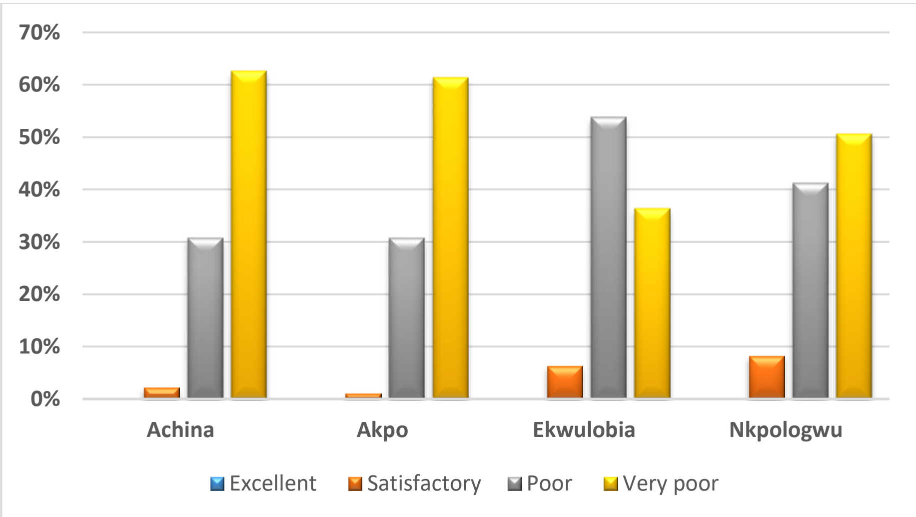

Fig. 5: Public view of government input

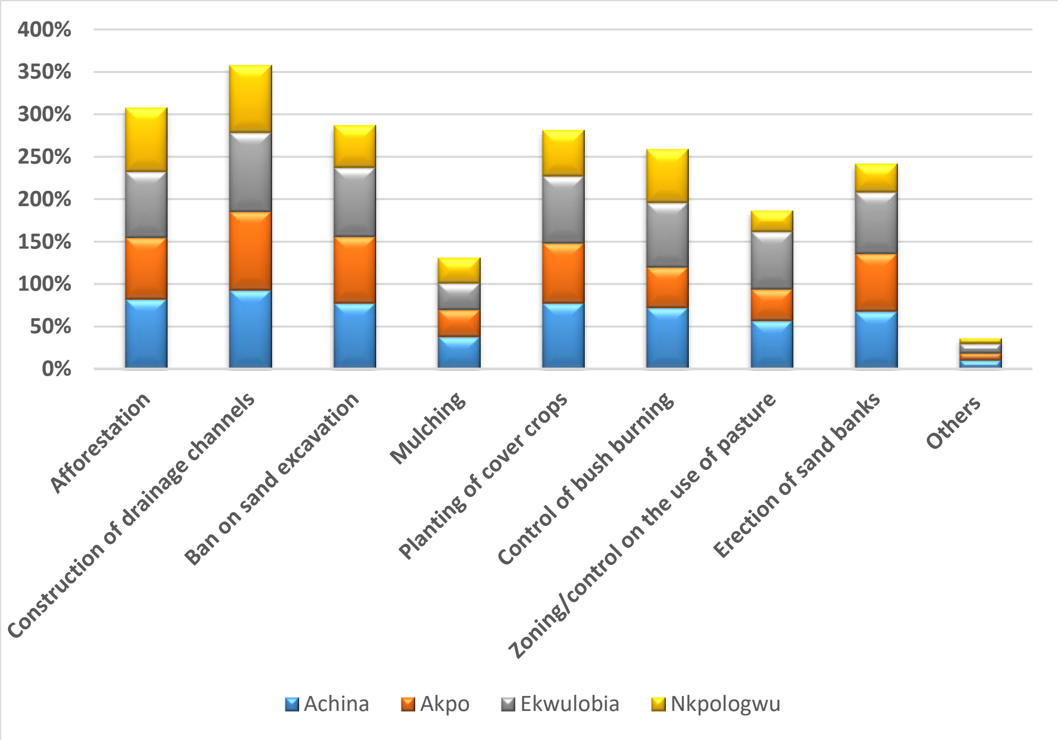

Fig. 6: Suggested remedial measures

From the Fig. 3, one can see at glance, the causes of gully erosion. Deforestation, lack of good drainage system and bad construction practices which have remained unchecked by relevant authorities are among the prime causes. In Fig. 4, gully erosion have brought about much loss of arable lands, forests and fertility. In certain cases, houses and human lives have been lost. In Fig. 5, the respondents rate government very poor to poor. This is because government have very serious duty to control these problems. Strong laws are needed to stop certain activities that bring about development of gullies and it is in the power of government to enact and enforce these laws.
Despite the much needed government intervention, the masses have roles to play such as construction of local drainage channels, controlling of bush burning and punishing those caught doing so, erection of sand banks and control of the use of pasture for grazing (Fig. 6).

4. Conclusion

Based on the results of this study, it can be shown that the soils in the study areas are made up of sand with intercalations of clay. Thus when water moistens the clay, it acts as lubricant aiding the sliding of the soil down the steep topography. Secondly, the topography of the region and other factors such as deforestation, lack of good drainage system, and high rainfall has major contribution to gully erosion in the region. Indiscriminate sand mining operations also has major contribution to gully erosion in the region.

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