Chapter 8

# Gully Erosion in Southeastern Nigeria: Role of Soil Properties and Environmental Factors

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Additional information is available at the end of the chapter

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## 1. Introduction

The countries of sub-Saharan Africa are besieged by serious environmental degradation resulting in desert encroachment, draught and soil erosion due to either wind impact or very high intensive rainfall resulting in heavy runoff and soil loss. The problems have adversely affected agricultural productivity and thus casting doubt of food security in the zone. The ecological and social settings in the zone are often distorted some times leading to losses in human and material capitals. In Nigeria desertification and aridity are the major environmental problems of the Northern part of the country while the high torrential rainfall of the southern Nigeria creates enabling environment for catastrophic soil erosion in the region.

The greatest threat to the environmental settings of southeastern Nigeria is the gradual but constant dissection of the landscape by soil erosion by water. Although the incipient stages of soil erosion through rill and interrill are common and easily managed by the people through recommended soil conservation practices, the gully forms have assumed a different dimension such that settlements and scarce arable land are threatened. Therefore, gully erosion problems have become a subject of discussion among soil scientists, geographers, geologists, engineers and social scientists. Ofomata [1] indicated that gully erosion types are the most visible forms of erosion in Nigeria mainly because of the remarkable impression they leave on the surface of the earth. Again Ofomata [2] remarked that more than 1.6% of the entire land area of eastern Nigeria is occupied by gullies. This is very significant for an area that has the highest population density 500 persons per km$^2$ in Nigeria. Before the 1980’s the classical gully sites in the region were the Agulu, Nanka, Ozuitem, Oko in Aguata area, Isuikwuato and Orlu. With the increased development activities the number and magnitude escalated thus making many government administrations within the region to set up soil erosion control with different names in different states. At the last count the Federal Government of Nigeria has started showing interest in ecological problems in the country including the control of the gullies which has reached more than 600 active sites in the region. The gullies are also a visible manifestation of the physical loss of the land due to erosion. Long before now a lot of attention has been focused on the control measurers. As early as the 1930s, the colonial government in Nigeria has undertaken a campaign of tree planting with the main objectives of controlling erosion especially on the steep slopes of upland landscapes in the region. Ever since then there has been a constant enquiry as to the causes of these catastrophic erosion. Most researchers [2, 3, 4] have shown that the environmental factors of vegetation, geology, geomorphology, climate in the form of rainfall which is very aggressive in the region and the soil factor all contribute in the erosion problem and their development. The consequence of the soil erosion is loss of land for agriculture and for habitation. During some slides caused by gully formation, lives have been lost while some communities have been separated because of deep and very wide gullies that may reach in some cases 12 m deep and more than 1.5 km long like the Nanka/Agulu gully complexes or in Oko in Aguata, Anambra State. Crop yields have been reduced, thus creating problem in the "green revolution" campaign.

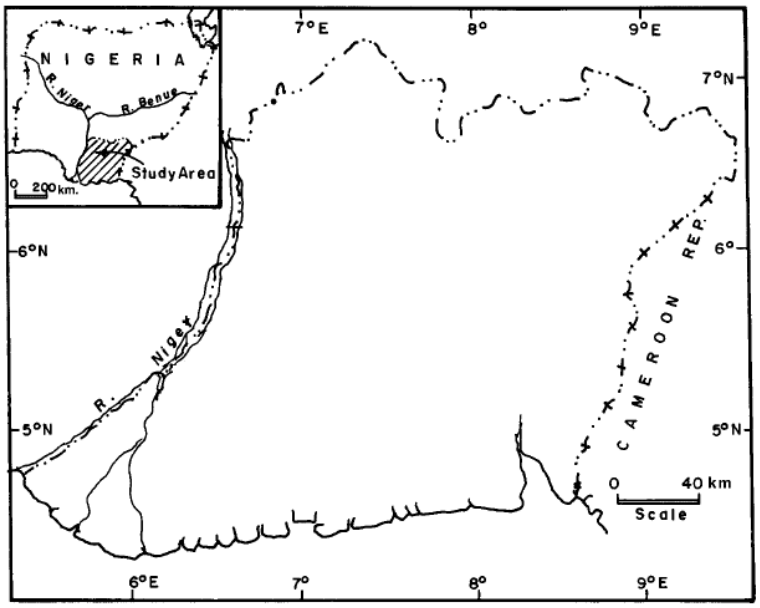


Figure 1. Location map.

**Figure 1.** Location map of the reviewed area

## 2. Causes of Soil erosion

Soil erosion generally is caused by several factors working simultaneously or individually to detach, transport and deposit soil particles in a different place other than where they were formed. The resultant effects of this phenomenon are deep cuttings and ravine which dis-

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sects the entire land surface. These are very common site all over the geographical region of southeastern Nigeria. It is well established fact among earth scientists that a number of environment factors as well as pedological parameter influence the extent of soil erosion where ever it occurs globally. These factors are perhaps guided by human factors known as anthropogenic factors. Although man has helped in reshaping and preserving the earth surface yet man has also helped in causing instability of equilibrium in the natural ecology and hence the rapid spread of environmental problem such as soil erosion. Igwe [5] noted that the anthropogenic factors are mainly technical factors comprising mainly of land use and tillage methods, the choice and distribution of cultures and the nature of agro-technology. In Northern hemisphere including many countries of Europe, Giordano et al. [6] showed that among the factors that encourage soil erosion are vegetation clearance, intensive harvesting and over-grazing leaving the soil bare. Other factors are soil compaction caused by heavy machinery which reduces the infiltration capacity of the soil and thus promoting excessive water runoff and soil erosion. In classical modelling works on soil erosion prediction and estimation, works by Renard et al. [7], Igwe et al. [8] among others recognised topography/ relief, rainfall and soil factors as being the main agents that determine the extent of soil erosion hazard. The soil factor represents the soil erodibility which is also a product of geology and soil characteristics. In showing how these factors influence the extent of soil erosion and gullying in southeastern Nigeria, there is going to be an attempt into discussing how these parameters contribute to gully erosion in other geographical zones.

## 3. The role of topography

Hudson [9] observed that in simplest terms steep land is more vulnerable to water erosion than flat land for reasons that erosive forces, splash, scour and transport, all have greater effect on steep slopes. Soil erosion generally is a function of slope attributes. The slope length and the amount of soil erosion have always been proportional to the steepness of the slope. Also the slope geometry of hill sides (i.e. whether convex or concave) often contribute significantly to soil loss and gully development. In southeastern Nigeria, Ofomata [3] found that there is a positive relationship between relief and soil erosion while in southwestern Nigeria, Lal [10] observed an increased severity of soil erosion as the slope changed from 5 to 15%. On a 15% slope he recorded a total soil loss of 230 t/ha/yr from bare plots as against soil loss of 11.2 t/ha/yr on 1% slope.

The topography of southeastern Nigeria according to Ofomata [2] can be classified into three relief units. These units are the plains and lowlands including all the river valleys, the cuesta landscapes and the highlands. It is observed that the uplands which are made up of highly friable sandstones yield easily to erosion and induce gullying even on slopes of about 5%. The cuestas and other highlands with somewhat stable lithology resist gullying but provide aggressive runoff which moves down to devastate the lowland areas especially at the toe slopes and river head-waters. The popular or infamous Agulu-Nanka gully erosion sites started from the head waters of streams and slopes of Awka-Orlu Upland region. The genesis and location of this particular gully site on the landscape is similar to numerous other gully sites in the region.

**Figure 2.** Typical gully site

## 4. Influence of climate

The rainfall of southern Nigeria generally is heavy and aggressive. Rainfall amount ranges from over 2500 mm in the southernmost region towards the Atlantic Ocean to about 1500 mm annually around River Benue in the northern borders. Rainfall intensities are high and often above 50 mm/h with short interval intensities in excess of 100 mm/h. Rainfall often come between the month of March and last till October. In some years the rainy period is unduly prolonged while in other years their onset may be delayed for more than 5 weeks. The present global climate change resulting from El-Niño and has not helped issues in this regard.

The nature of the rainfall regime contributes significantly to the erosivity of rainfall. Rainfall erosivity is the potential ability of rain to cause erosion. It is also a function of the physical characteristics of rainfall. Obi and Salako [11] reported that the raindrop sizes obtained generally in the Guinea savannah ecological zone of West Africa ranged from 0.6 to 3.4 mm. The mean drop sizes ($D_{50}$) of 28 rainfall events ranged from 1-1 to 2.9 mm. There are experimental evidence to suggest that intensity and energy are likely to be closely linked with erosivity. A number of statistical relations have been established in the past between the erosive power and amount of rainfall in other parts of the tropical region [12, 13, 10, 14]. The best estimator of soil loss was found to be a compound parameter, the product of the kinetic energy of the storm and intensity. In Nigeria, the total kinetic energy load of 1091 mm rainfall

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at Samaru in Northern Nigeria was about 3600 $Jm^{-2}$. This was twice the amount recorded in southern Africa by Stocking [15]. However, the product of the kinetic energy of the storm and the maximum intensity of the rainfall during the first 30 mins of a storm ($EI_{30}$) was most significantly correlated with soil loss determined on standard field plots [16]. Erosivity values therefore have been used successfully to produce iso-erodent map of West Africa [14].

In southeastern Nigeria, Obi and Ngwu [17] characterised the rainfall regime and recommended Lal's index of Aim as having advantage over other indices of erosivity such as KE> 1 and $EI_{30}$. However, Salako et al. [18] compared all the available indices of erosivity adopted in southeastern Nigeria and came up with some modifications of existing ones. Two indices $E_kI_{30}$ and $E_kI_m$ were recommended

Where;

$E_k$ is in $MJha^{-1}$ (kinetic energy)

$I_{30}$ is 30 minutes rainfall intensity and

$I_m$ being maximum intensity computed over a 6 minutes duration

Rainfall therefore plays very significant roles in the erosion hazard of southeastern Nigeria. The rainfall distribution, amount and intensity in combination of other environmental factors contribute in accelerating the rate of interrill rill and gully erosion in southeastern Nigeria. This is evidenced in the sense that as rainfall amount decrease northwards, the rate of all types of soil erosion by water decreases.

## 5. The influence of vegetation

The constant deforestation of the former rainforest due to population explosion and increased agricultural activities in the region expose the bare soils to the vagaries of weather thus escalating the soil erosion problems. The implication is that the soils are frequently subject to different degrees of erosion including accelerated erosion. Vegetation and land use are one of the most important factors in soil erosion process in southeastern Nigeria. Stocking [15] noted that vegetation acts in a variety of ways by intercepting raindrops through encouraging greater infiltration of water and through increasing surface soil organic matter and thereby reducing soil erodibility. According to Lal [19], choosing an appropriate land use can drastically curtail soil erosion.

In southeastern Nigeria soil erosion especially gullies are most intensive on soil on which the former growth has been disturbed, that is mostly on agricultural soils stripped of growth for reasons of infrastructural developments such as road and housing construction. Ofomata [3] showed that in the region soil erosion is connected mainly with agricultural activities and other related land use activities such as mining, road building, urbanization, industrialization and general infrastructural development. These land use activities deprive the soil surface of its vegetation and also contribute directly to sliding, slumping, interrill and rill erosion including gullying.

## 6. The influence of geology

The general influence of lithology on soil erosion processes is manifest directly by the resistance of the denuded bed rocks exposed to the flow of water and affected by the character of parent materials whose properties are given by the bed rock. The direct effect of bedrock is also manifest in the properties of the soil forming parent materials which conditions the principal properties. Some geological materials are vulnerable than others to aggressive energy of the rainfall and runoff. High erosion risks match with units of weak unconsolidated geological formations. This is more pronounced when such geological units coincide with medium to long and even very long slopes with marked gradients.

In Nigeria, Ofomata [1] classified the potential erosion susceptible areas based on underlying geology. He indicated that areas of high susceptibility correspond to geological regions of weak unconsolidated sandy formations while least susceptible areas are within the consolidated tertiary to recent sediments. Also in southeastern Nigeria, the classical gully sites are located in the False-bedded sandstone, Coastal Plain sands, Nanka Sands and the Bende-Ameki Formations. These are all sandy formations which have more gullies than their Shale formation counterparts. In these formations, there exist the sites of worst catastrophic soil erosion in the whole of sub-Saharan Africa. The geology therefore plays direct and indirect influence on the gully formation. The indirect effect is on the soil formation and the nature of soil which contribute significantly to erosion processes. The influence of soil process on soil erosion often referred to as erodibility is the subject of discussion in the next section.

## 7. The influence of soil factor (erodibility)

The erodibility of the soil is defined as the vulnerability or susceptibility of the soil to erosion. It is a measure of a soil's susceptibility to particle detachment and transport by agents of erosion. Igwe [20] remarked that a number of factors such as the physical and the chemical properties of the soil influence erodibility. In southeastern Nigeria, the nature and the long weathering history of the soils parent material evident in the dominance of the clay mineralogy by non-expanding minerals and low soil organic matter concentration due to high mineralization rates and excessive leaching of nutrients could be linked to the worsening situation. The highly weathered soils contain high concentrations of Fe and Al oxides. Inappropriate land use and soil management options are also a common feature of agriculture in the region. Anthropogenic factors often combine to weakened soils to produce severe gullies. The soils are hence loose and slumps under high intensive rainfall that renders them easily detachable. Some of the soils have the tendency to slake and form seals under such intense rainstorms thereby resulting in considerable runoff and soil erosion. The soil erodibility factor has since been recognized as a contributing factor to soil erosion hazard. The erodibility of the soils in terms of soil indices that predict or promote soil erosion will be elaborated on. The contributions of soil factors to soil erosion in Nigeria have variously been discussed [21, 20, 22]. Igwe et al. [21] found that the soil

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clay content, level of soil organic matter (SOM) and sesquioxides such as Al and Fe oxides, clay dispersion ratio (CDR), mean-weight diameter (MWD) and geometric-mean weight diameter (GMD) of soil aggregates all influence soil erosion hazards in southeastern Nigeria. SOM, Al and Fe oxides control dispersion and flocculation of the soils. In the event of very aggressive rainfall, the soil inherent properties often combine with the physical forces of rainfall to produce soil erosion in the soils.

**Figure 3.** Gully cutting

Erodibility varies with soil texture, aggregate stability, SOM contents and hydraulic properties of the soil. Igwe [22] claimed that the soil dispersion ratio (DR) and the clay dispersion ratio were good indices of erodibility. The soils with high water-dispersible clay (WDC) in southeastern Nigeria often create problem in that in tilled land use, mud flow and soil loss from runoff cause major alteration in the stream flow within watersheds causing severe environmental challenges. Soil crusting, sealing resulting from aggregate breakdown are secondary problems arising from deposited sediments. The large particle sizes are resistant to transport because of the greater forces required to entrain these large particles while the fine particles are resistant to detachment because of their cohesiveness. Aggregate stability and associated indices have been shown to be most efficient soil properties that predict the extent of soil erosion.

In other parts of the world the use of aggregate stability indices in predicting soil erodibility have shown reliable information on the extent and degree of soil erosion [23, 24]. In Western Europe, Le Bissonnais [25] indicated that the mean-weight diameter (MWD) of soil aggregates was a very reliable soil property that could show the erosion potential of the soil in the sense that MWD predicts soil erodibility. Therefore aggregate stability and MWD are very reliable properties in explaining, quantifying or predicting soil erosion and other soil problems such as crusting and sealing.

Again other soil properties encourage structural failure, sliding and mass movement of soils. These soil factors are the mineralogy of the clay and even the soil chemical properties. The stability of the soil mass is therefore depended on the clay minerals present. Illite and smectite more readily form aggregates but the more open lattice structure of these minerals and the greater swelling and shrinkage which occur on wetting and drying render the aggregates less stable than those formed from kaolinite. Soils in which either kaolinite or illite clay predominates but contains small amounts of smectite are easily dispersive. Smectitic soils are more erodible than the soils that contain only small amount of smectite. Conversely, soils that do not contain smectite are more stable, less erodible and less susceptible to seal formation.

**Figure 4.** Gully site in association with interill and rill erosion

The sodium dithionite extractable Fe oxide is a soil chemical property which relates significantly with erodibility of the soil. This particular property affects the soil structure and the soil fabric, often being responsible for the formation of soil aggregates and cementation with other major soil components [26, 27]. The mechanism of aggregation of soils in southeastern Nigeria in the presence of Fe (Hydr) oxide has been demonstrated [8, 26, 27]. The presence of OH-Al polymers may lead to a reduction in the swelling and expansion of clay particles by bonding adjacent silica sheets together and by displacing interlayer cations of high hydration power and thus promoting aggregation. Well crystallized aluminium hydroxide may also be able to act as cementing agent in acid soils such as in southeastern Nigeria but its magnitude may be negligible as compared with non-crystalline materials. Iron oxides

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therefore are more effective than aluminium hydroxide in cement effectiveness except for soils undergoing frequent oxidation-reduction processes.

## 8. Anthropogenic influence

An important factor which contributes significantly to soil erosion problem in southern Nigeria is anthopogenic influence arising from misuse of land. Poor farming systems have contributed to collapse of soil structure and thus encouraging accelerated runoff and soil loss due to erosion. In the event of uncontrollable grazing caused by the nomads has resulted in deforestation of the landscape while indiscriminate foot paths created on the landscape has helped the incipient channels on the landscape to form. These channels eventually metamorphose to gullies especially when they are not checked at inception. Road constructions including uncontrolled infrastructural developments have contributed significantly in gully developments. Some road networks under construction have been abandoned in the region due to gully formation.

**Figure 5.** Gully about cutting an asphalt surfaced road

## 9. Identification of gullies and erosion sites

Soil erosion sites in southeastern Nigeria have been identified through various methods. In the 1960s and 1970s gullies were enumerated through natural resource surveys but this method proved to be very cumbersome and often do not actually represent the actual situation on ground. This led to the use of aerial photo interpretation (API) in the generation of information for soil erosion studies. Niger Techno & Technital Spa [28] employed API in the documentation and publication of soil erosion problems in eastern Nigeria. The other methods in this category is remotely acquired data from satellites, radar imageries and from geographic information systems GIS. The advantages of API and other remotely acquired information is that the information they show are real and exact and sometimes in real time. However, acquiring information through this source is very expensive and most often unaffordable by some governments and establishments in Nigeria.

Of late modelling soil erosion hazard in southeastern Nigeria has been very useful not only for erosion hazard prediction but for conservation purposes. Ofomata [3] used multiple regression equation with the environmental factors of climate, vegetation, soil and anthropogenic factors being the variables to predict the soil erosion hazard in southern Nigeria. Again, Igwe et al. [21, 8] employed two different models in predicting soil erosion hazard in some parts of southeastern Nigeria. The predictive abilities of these models with some modifications were satisfactory and approximated data obtained from the field. Table 1 presents the predictive ability of some soil parameters in 25 selected soils in the region.

| Soils | Soil Classification | DR | CDI | RUSLE K | CFI | MWD | GMD | Overall* Ranking |
|---|---|---|---|---|---|---|---|---|
| Oseakwa | Gleysols | 5 | 10 | 24 | 10 | 10 | 13 | 11 |
| Akili ozizor | Fluvisols | 21 | 22 | 22 | 22 | 18 | 16 | 24 |
| Osamala | Cambisols | 17 | 13 | 22 | 13 | 1 | 4 | 10 |
| Oroma etiti | Gleysols | 15 | 25 | 21 | 25 | 2 | 5 | 20 |
| Umuewelu | Cambisols | 21 | 20 | 19 | 20 | 3 | 6 | 18 |
| Ezillo | Acrisols | 16 | 12 | 13 | 12 | 17 | 12 | 17 |
| Abakaliki | Acrisols | 10 | 16 | 13 | 16 | 7 | 2 | 8 |
| Okija | Ferralsols | 9 | 8 | 8 | 8 | 4 | 9 | 4 |
| Ogurugu | Fluvisols | 11 | 17 | 11 | 17 | 15 | 8 | 13 |
| Nenwe | Cambisols | 14 | 19 | 25 | 19 | 5 | 9 | 19 |
| Ifite ogwari | Cambisols | 18 | 18 | 16 | 18 | 21 | 25 | 21 |
| Umueje | Cambisols | 18 | 7 | 16 | 7 | 23 | 7 | 12 |
| Umumbo | Cambisols | 24 | 15 | 16 | 15 | 8 | 3 | 14 |
| Omasi | Acrisols | 25 | 21 | 8 | 21 | 22 | 19 | 22 |
| Adani | Acrisols | 23 | 23 | 15 | 23 | 24 | 23 | 25 |
| Nsukka | Acrisols | 12 | 8 | 12 | 8 | 20 | 21 | 14 |
| Obollo afor | Acrisols | 12 | 2 | 5 | 2 | 12 | 15 | 5 |
| Nteje | Ferralsols | 3 | 6 | 5 | 6 | 15 | 20 | 7 |

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| Soils | Soil Classification | DR | CDI | RUSLE K | CFI | MWD | GMD | Overall* Ranking |
|---|---|---|---|---|---|---|---|---|
| Awka | Acrisols | 2 | 1 | 5 | 1 | 13 | 16 | 2 |
| Idodo | Acrisols | 20 | 24 | 20 | 24 | 14 | 14 | 22 |
| Ukehe | Acrisols | 7 | 4 | 8 | 4 | 19 | 22 | 8 |
| Abor | Acrisols | 4 | 4 | 2 | 4 | 9 | 18 | 3 |
| Nachi | Acrisols | 6 | 11 | 4 | 11 | 25 | 24 | 14 |
| Nanka | Acrisols | 7 | 14 | 2 | 14 | 11 | 1 | 6 |
| Nawfija | Acrisols | 1 | 3 | 1 | 3 | 5 | 11 | 1 |

*1- most erodible; 25- least erodible; DR- Dispersion ratio; CDI- clay dispersion index; RUSLE K- Wischmeier erodibility factor (K); CFI- clay flocculation index; MWD- mean-weight diameter of soil aggregates; GMD- geometric mean-weight diameter of soil aggregates (Source: Igwe et al [21]).

**Table 1.** Ranking of soils in order of significant erosion predictability

In other parts of the world the use of some soil parameters such as the water-dispersible clay (WDC) has been adopted as a major parameter in soil erosion models as in the Water Erosion Prediction Project (WEPP) [29]. This method has been widely used in the development of soil erosion models for some parts of eastern Nigeria [22]. Soils with high WDC have high soil erosion potential and therefore WDC constitutes a great problem to the soil and the entire environment. The negative influence of high clay dispersion on soil erosion results in detachment, transportation and deposition of sediments with essential plant nutrient elements down stream. This clay associated sediments constitute high environmental menace to man, livestock and agricultural fields. The streams and rivers are silted, while the aquatic life suffers serious problems due to high concentration of nitrates, organic matter and phosphorus in clay suspension down stream. These information have served as basic information for soil conservation processes

## 10. Control and Remediation

The state of soil erosion problem in southeastern Nigeria calls for a comprehensive soil conservation programme so as to check catastrophic erosion hazard. The soil conservation measures should be those farming system practises which ensure sustainable soil productivity while maintaining equilibrium between the ecosystem and regular anthropogenic influence. In the design of soil conservation strategies, the permissible soil loss tolerance so as to avoid catastrophe in the event of failures of such strategies. In the United States of America, the permissible soil erosion loss is between 2.5 and 12.5 t $ha^{-1}$ $y^{-1}$ [7], while in Czech Republic, Holy [30] noted that the permissible soil loss was between 1.0 to 16 t $ha^{-1}$ $y^{-1}$ in very deep soil of 120 cm thickness. Obi [31] observed that for a highly weathered, porous and deep ultisol in southeastern Nigeria, the tolerable soil loss was about 10 t $ha^{-1}$ $y^{-1}$ under maize production, with appreciable loss in the production capacity of the soils.

Therefore, the suggested soil conservation measures based on the agricultural land use is recommended for the entire agro-ecological system. The land use option suitable to the area should be that based on integrated watershed management with arable farming, agroforestry and intensive afforestation. These practises are considered cheap option which can be afforded by the rural poor farmer. The methods are also very sustainable and not destructive to the agricultural land. This is aimed at reducing the annual soil loss rate and prevents the development of fresh gullies in the area. Agricultural land use should be based on topographic variations, major soil distribution, soil potential erosion hazard, hydrology and other geomorphological variables. Igwe [4] recommended that the entire region should be partitioned into 4 broad sections based on their location on the landscape. The lowlands and valley floors which also contain sediments should be put to rainfed and irrigated farming of arable crops. The main soil conservation strategies should be those that improve plant nutrient availability, land levelling in case of irrigation and drainage. On the land areas that are on 5% slope and below, the regular recommended cultural practises of organic matter application to the soil is suggested while mulching, crop rotation and well managed agro-forestry are some of the ways of keeping the soil uneroded. Crop residues in association with tillage systems contribute immensely in the conservation of the soil or other wise. The other remaining 2 land units are those that vary between 5-30 % slope and mostly the sites of catastrophic gullies in the area. They should be permanently forested and may be used for wildlife conservation. The kind of forestation should be that which produces intimate multistoreyed association of woody species, grasses and creeping legumes. This will ensure steady cover for the bare soil and offer some kind of protection to the soil against the high intensive and aggressive rainfall. The major soil conservation strategies are broad-based terraces and cover cropping of bare soils. A more comprehensive soil conservation method will involve the application of certain hydrological or bioenvironmental processes so as to control the overland flow and excessive runoff.

## 11. Conclusion

Soil erosion in the form of gullies is very common in southeastern Nigeria. This review has shown the influence of geology, climate, geomorphology (slope), vegetation, man and soil itself on gully development and soil erosion in general. Typical empirical examples are cited from previous works from other researchers in other parts of the world and locally. Past works on estimation of potential soil erosion hazard in the region indicate that more than 1.6% of the entire land area has been devastated by gullies. The inherent characteristics of the local soils to a large extent promote the spread of soil erosion especially the gully type in the region. The roles of anthropogenic factors with regards to land use and its influence on the vegetation are considered. The serious deforestation of the vegetation and poor revegetation or afforestation programmes have all contributed to the catastrophic erosion hazards. General strategies for

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soil conservation with respect to soil erosion should include a more comprehensive soil conservation method which will involve the application of certain hydrological or bioenvironmental processes so as to control the overland flow and excessive runoff.

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