

EFI Index

A New Quantitative Parameter in Planning of Sustainable Land Management in High Risk Erosion Areas

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1. Abstract

For many years erosion and land degradation have posed a serious threat to lives and property in South Eastern Nigeria; and indeed in some areas have reached alarming proportions. Recognizing the severity and magnitude of this problem, the Federal Government of Nigeria, for and on behalf of the states affected, requested assistance from the United Nations Development Program (UNDP) under its 4th Country Program for Environment and Natural Resources Management. Against this background, the UNDP in May, 1995 commissioned five Consultants (including the author) to carry out baseline studies and design a program to combat erosion, landslide, and other forms of land degradation in four of the affected States, namely: Abia, Akwa Ibom, Cross River, and Imo. EFI-Index was developed by the present author, and used for the first time in that baseline study.

The EFI-Index is a numerical parameter to characterize the intensity of erosion and the topographic texture in a given area. The formula for computing the EFI-Index is derived from the basic properties and elements of erosional features, such as length, depth, and width, by combining the methods of Mekel (1977) and Faniran (1969). The EFI-Index gives the "erosion frequency and intensity" within a specific area in numerical terms; however the numerical values can be classed into intervals, and characterized in descriptive terms. Thus an EFI Index of less than five (5) indicates slight erosion intensity; 5-10 moderate, 10-15 high, and above fifteen (15) severe erosion intensity.

The EFI-Index provides a more comprehensive quantitative or semi-quantitative characterization of erosion within a given area than has hitherto been developed. The EFI-Index can be applied to administrative areas (political units) as well as hydrophysical areas on the terrain. Furthermore the EFI-Index is proportional to the total quantity of material removed from the area by erosion. It is therefore very useful for obtaining earthwork volumes in planning rehabilitation or reclamation work particularly in high-risk erosion areas. Finally EFI-Index can be used to obtain quantitative estimates in environmental impact assessment, as regards erosion and land degradation.

2. Introduction

For many years, accelerated erosion, landslide and general land degradation have ravaged many parts of South Eastern Nigeria. Lives and property have been lost; people have been forced to desert their ancestral homes. Schools and colleges have been devastated, and even University campuses are not spared the menace of these hazards. Beautiful landscapes and

fertile agricultural lands have been completely lost; such loss of fertile agricultural land has inevitably led to lower food production.

The Governments of the states most affected (namely: Abia, Akwa Ibom, Cross River, and Imo) recognizing the serious threat erosion posed to human existence in the area sent proposals to the United Nations Development Program (UNDP) for assistance in this area. This request came under the 4th Country Program for Environment and Natural Resources Management, which the Federal Government of Nigeria had requested the UNDP to support activity in these states.

Against this background the UNDP in May 1995 commissioned five consultants (including the author) to carry out baseline studies and design a program to combat erosion, landslide and other forms of land degradation in the affected states. The EFI - Index was developed by the present author and used for the first time in that baseline study. The development and formulation of the EFI-index arose out of the necessity to uniquely characterize the severity of erosion within the different terrain mapping units (in this case the Local Government Areas), so as to enable comprehensive evaluation and design of combat measures.

3. The Study Area

3.1 Location and Extent

The area under study comprising Cross River, Akwa Ibom, Abia and Imo States, and here referred to as South Eastern Nigeria, lies roughly between latitudes 4°25'N and 7°00'N of the equator; and longitudes 6°30'E and 9°30'E of Greenwich meridian (Fig.1). It is therefore situated dominantly within the Tropical Rain Forest belt and covers a total landmass of about 50,000 sqkm.

3.2 Vegetation

South Eastern Nigeria encompasses three broad ecological zones, namely: the Mangrove Swamp Forest, the Tropical Rain Forest, and the Derived Savanna Woodland.

3.2.1 Mangrove Swamp Forest

Mangrove Swamp Forest occurs in an irregular band spanning the Atlantic coast of Nigeria from Lagos and Badagry in the West to Calabar in the East. Mangrove Forest also occurs in the estuaries of the main rivers. Mangrove Swamp Forest comprises 10-15 per cent of the study area, and consists mainly of species from two genera, ie. *Rhizophora* and *Avicennia*.

3.2.2 Tropical Rain Forest

The Tropical Rain Forest is by far the most extensive ecological zone in South Eastern Nigeria. It is characterized by an abundance of plant and animal species, often exceeding 150 species of plants per hectare. This great diversity makes the Tropical Rain Forest in Eastern Nigeria the richest of all terrestrial ecosystems (UNDP, 1995).

There has been extensive human interference in the Tropical Rain Forest. Nigeria's wood product requirements, both for export and local needs, are obtained largely from this ecozone. However there are still some areas of virgin climax Tropical Rain Forest found in the Cross River State of Nigeria; these are the Oban Group of Forests, which are believed to have remained densely forested for over 60 Million years. The Oban Group Forests have been

declared a National Park and protected through the joint efforts of the Cross River State Government, the Federal Government, and the World Wide Fund for Nature (WWF).

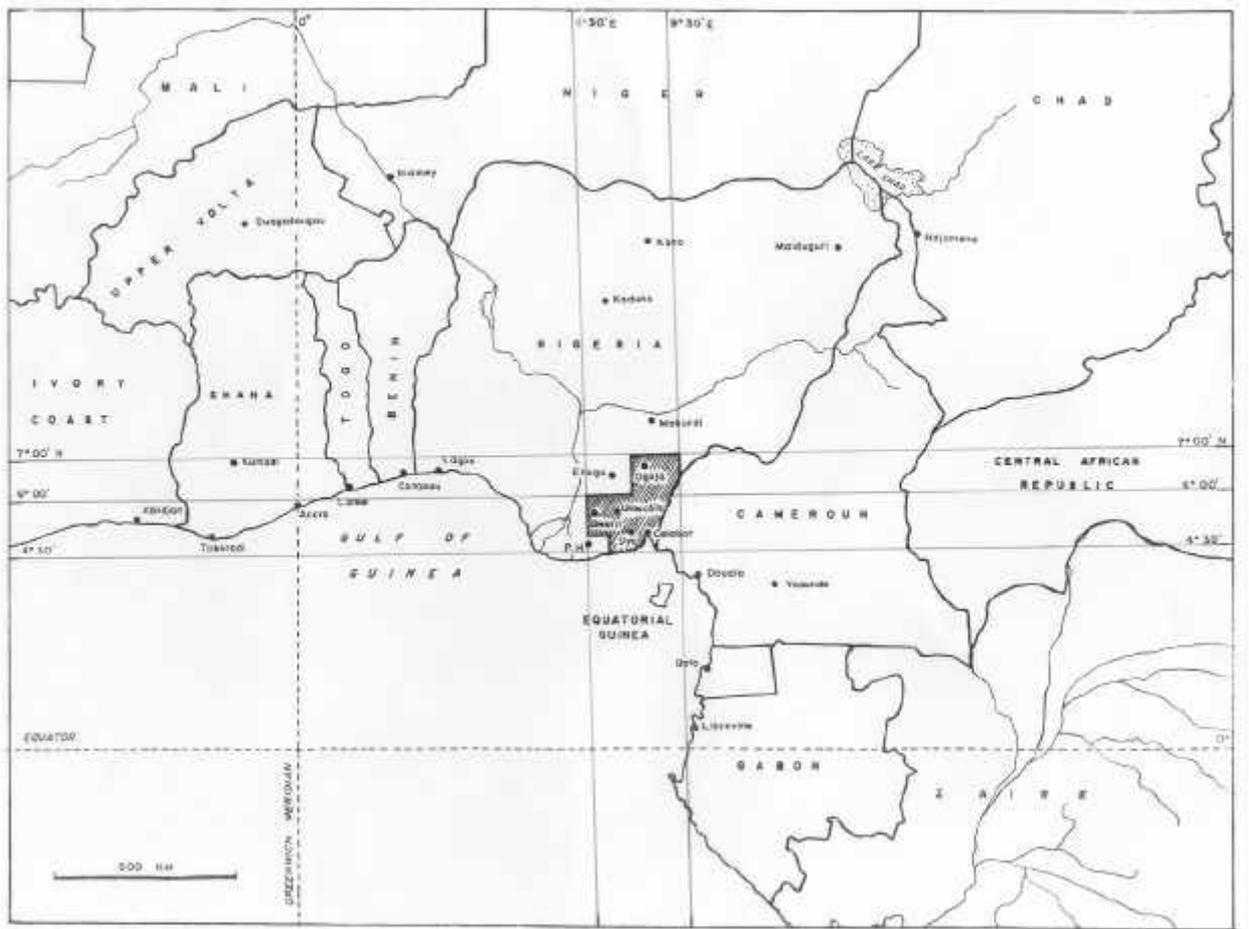


Figure1. Location of South East Nigeria.

3.2.3 Derived Savanna Woodland

Due to persistent human interference, by way of cultivation and grazing, several parts of the study area have been transformed into what is generally termed “Derived Savanna Woodland”. The Derived Savanna Woodland is characterized by the presence of tropical rainforest tree species in association with grassland species typical of the Savanna of Northern Nigeria. In some places up to 60% of the vegetation cover is grass. On the Obudu Plateau in Cross River State is a type of semi-tropical grassland caused by the moderating effect of the height of the land.

3.3 Geology

South Eastern Nigeria presents an interesting geology dating from the Precambrian period. One of the most spectacular events in geologic history started in the Middle Jurassic (about 160 million years ago) and by early Cretaceous times culminated in the break-up of the super-continent of Gondwanaland; this is the Continental Drift. Due to continental drift the South American Plate separated from the African Plate resulting in the opening of the South Atlantic

Ocean. The opening of the South Atlantic Ocean initiated tectonism in the region of Southern Nigeria and led to the development of the Benue Trough (Wright, 1966; Nyong, 1995,14). The development of the Benue Trough provided the main structural control and framework for subsequent geologic evolution of South Eastern Nigeria.

South Eastern Nigeria consists of the following tectonic and structural elements: the Calabar Flank, Oban Massif, Obudu massif, Southern Benue Trough, and part of the Niger Delta Miogeosyncline. The Southern Benue Trough further consists of the Abakaliki Anticlinorium, Afikpo Syncline, Ikom-Mamfe Embayment and Ogoja Sub-Basin (Fig. 2). These structural elements control and dominate the geologic evolution, and litho-stratigraphic succession of South Eastern Nigeria.

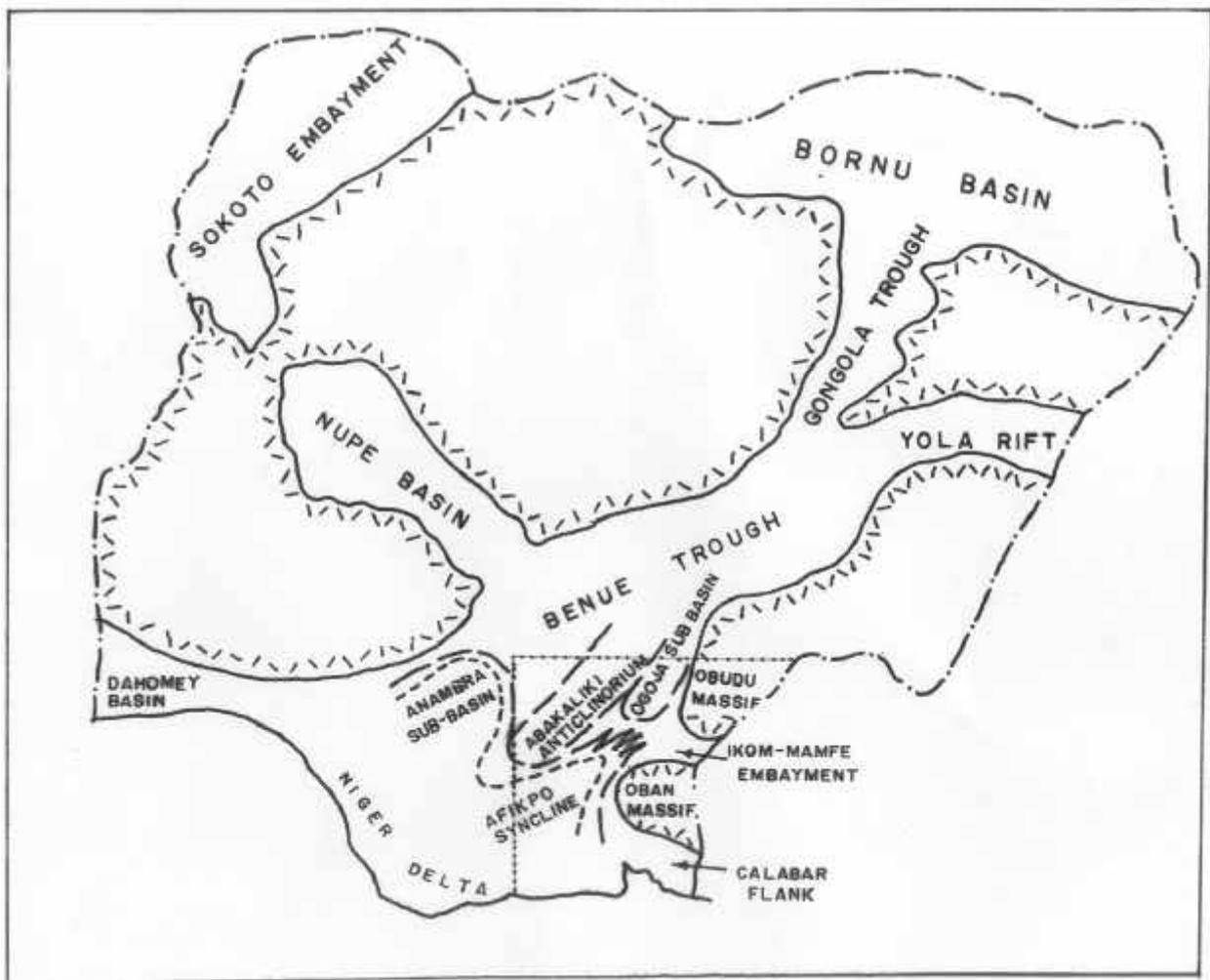


Figure 2. Structural setting of South Eastern Nigeria.

Three major tectonic cycles could be identified in South Eastern Nigeria (Murat, 1972, 260). The first major tectonic phase (Aptian-early Santonian) directly followed, and was related to, the initial rifting of the Southern Nigeria continental margin and the opening of the Benue Trough. This phase produced two principal sets of faults, trending NE-SW and NW-SE. The NE-SW set of faults bound the Benue Trough; while the NW-SE sets defined the Calabar Flank. The second tectonic phase (Turonian-Santonian) was characterized by compressional movements

The soils formed on Coastal Plains Sands range from Dystric Nitosol and Dystric Cambisol, to Dystric Acrisol. Texturally these include sands, loamy sands and sandy loam topsoils with sandy clay loam to sandy clay subsoils. The soils are generally very deep and well drained.

Table 1. Lithostratigraphic Units in South Eastern Nigeria

Geologic Age	Geologic Formation	Lithologic Description
Pleistocene – Holocene	Alluvium and Quaternary Deposits	Unconsolidated Freshwater sands and gravels with silt and clay admixtures
	Beach Ridges	Fine grained greyish white sands
Oligocene – Pliocene	Coastal Plains sands	Coarse to medium grained unconsolidated sands, with gravels ferruginous sandstones and clays.
Oligocene Miocene	Ogwasi-Asaba Formation	Gritty clays and pebbly sandstones with lignite layer.
Eocene	Bende-Ameke Formation	Sandstone and shale sequence with bouldery and shelly limestone.
Paleocene	Imo Shale Group	Grey Calcareous shales and siltstones with bands of sandstone and ironstone.
Maastrichtian	Nsukka Formation	Alternating sequence of shales and sandstones with coal seams (the Coal Measures).
	Ajali Sandstones	
	Mamu Formation	
Campano Maastrichtian	Nkporo Formation	Dark grey shales and soft mudstones with occasional thin beds of sandstones and limestones
Coniacian	Awgu-Ndeaboh Shale Group	Shales with thin limestone bands and lenticular sand bodies.
	New Netim Marl Formation	Thick Marl unit with intercallations of thin bands of dark shales
Turonian	Amaseri Sandstone Formation	Highly bioturbated fine to medium grained calcareous sandstones with fossiliferous shales at the base.
	Ezillo Formation	Dark grey shales with fine sandstone and siltstone intercalations.
	Eze-Aku Formation	Alternating Shales, siltstones and limestones with lateral facies changes to sandstones
Cenomanian	Ekenkpon Shale Formation	Thick black highly fissile shales with intercalations of marls calcareous mudstones and shell beds.
Albian	Asu River Group	Poorly bedded sandy shales with fine to medium grained sandstones lenses.
	Mamfe Formation	Cross bedded coarse to medium grained immature sandstones with basal conglomerates and arkoses.
	Mfamosing Formation	Massive bedded, grey chalky limestones with fossils
Aptian- Neocomian	Awi Sandstone Formation	Fluvio-deltaic clastics consisting of grits, sandstones mudstones and shales.

On the Basement complex Gleyic Luvisols and Ferric Acrisols are developed. These are deep fairly well drained soils, with loam to sandy clay loam topsoil and gravelly sandy clay or gravelly clay loam subsoils.

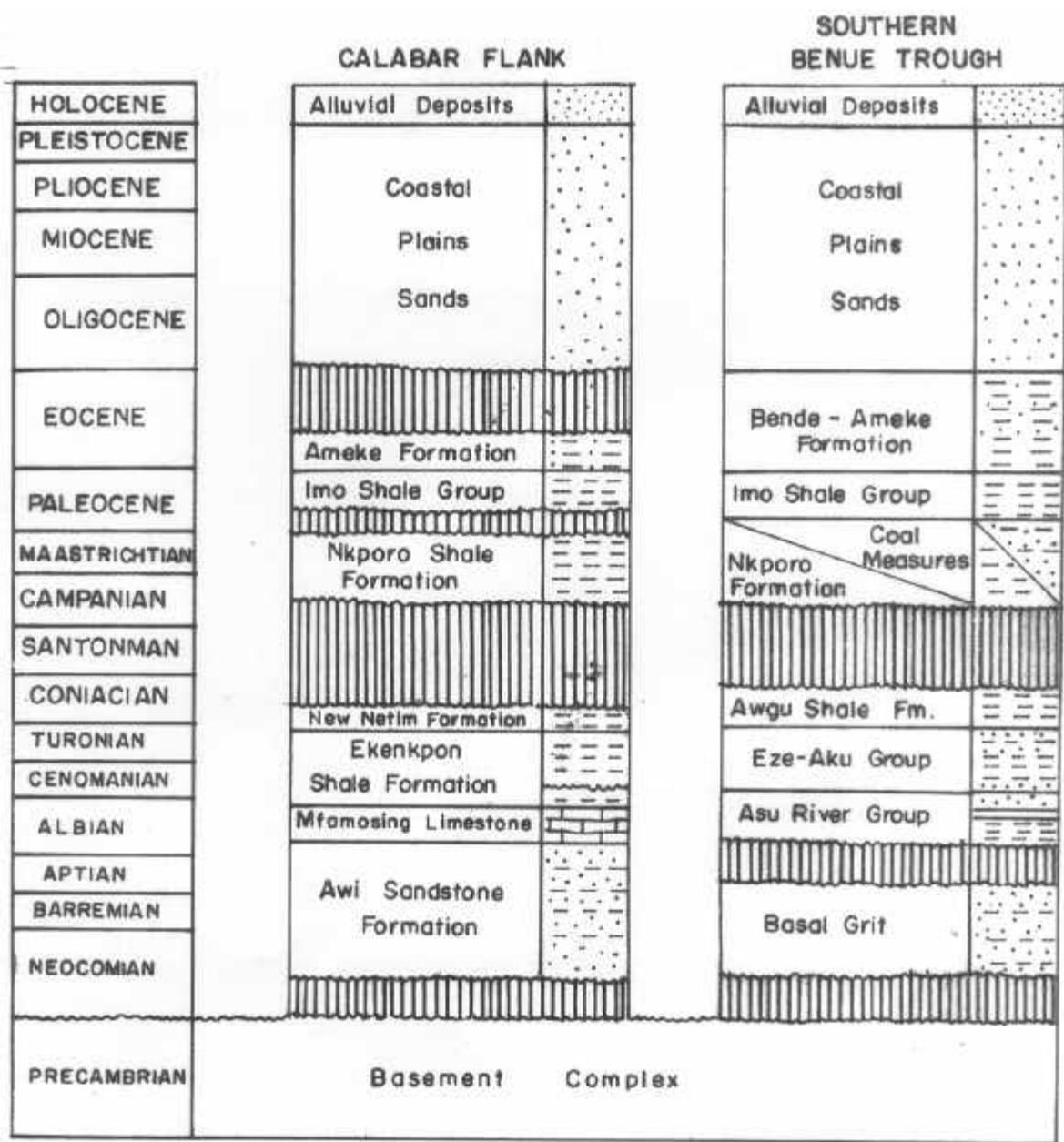


Figure 4. Lithographic correlation within South Eastern Nigeria.

On shales and marls Ferric Luvisols, Eutric Gleysols, Orthic Luvisols and Ferric Acrisols occur. The soils are moderately deep, moderately well drained to poorly drained, with loam to sandy clay loam topsoils and sandy clay to sandy clay loam subsoils. In some locations the subsoil is remarkably gravelly, ferruginized or mottled. Fig. 5 shows a triangular plot of 200 soil samples from the study area.

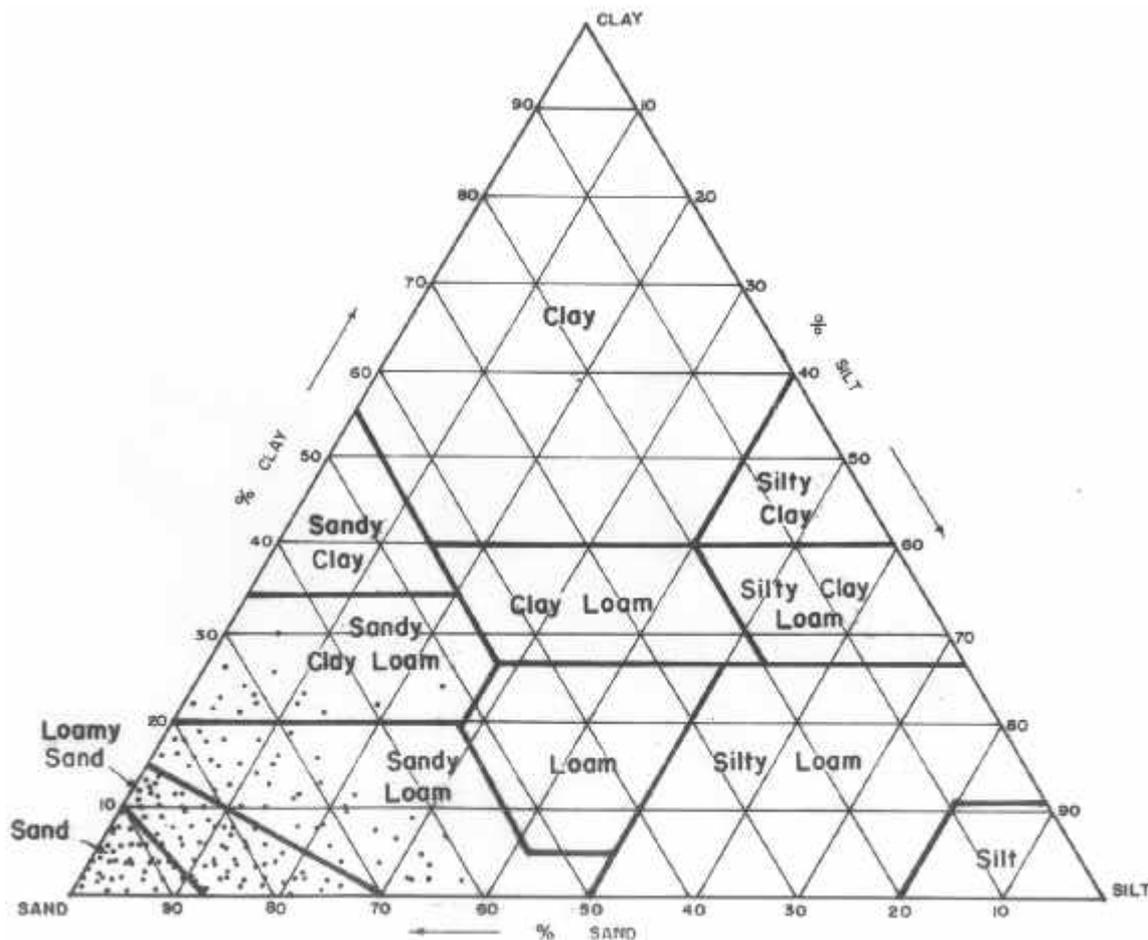


Figure 5. Textural classification of soils from South Eastern Nigeria (200 samples).

4. Erosion Survey and Mapping

4.1 An Overview

Erosion survey necessarily involves a number of interrelated operations, the overall aim of which is to identify, investigate, and present information on erosion within a given portion of the earth's surface. The practical procedure in erosion survey may be complex, but invariably involves the following operations amongst others:

- The erosional features and landforms must be identified, defined and/or delimited on the terrain.
- The geodynamic processes involved must be investigated and the impact of each assessed.
- The delimited erosional features and landforms must then be described, measured, and presented in the appropriate format, which necessarily always includes maps.

The resulting maps can be geomorphological maps, geomorphometric maps, or even specialized engineering geological maps depending on the purpose and scope of the survey; or

they may simply be called “Erosion Maps”. An important problem in erosion survey is how to characterize the severity or intensity of erosion in various parts of the mapped area. From such characterization it would be possible to assess the impact on the landscape and hence the total environment. This forms the thrust of the present paper.

4.2 Characterizing Erosion

Erosion (Latin, *erred*, to gnaw away) is a comprehensive term applied to the wearing away and removal of the earth’s surface material by geomorphic agents. A geomorphic agent is any natural medium capable of securing and transporting earth material; thus running water, including both unconcentrated and concentrated runoff, is a geomorphic agent.

Both geological erosion and accelerated erosion could be distinguished. Geological erosion involves the gradual removal of the surface soil and rock material; and constitutes the normal geologic process of landmass denudation. Accelerated erosion or induced erosion is the type that has been speeded up by man’s activities or rare natural factors, so that the soil material is removed much faster than it can be formed. Accelerated erosion has been responsible for the gapping erosion gullies, otherwise known as ravines, in the landscape of South Eastern Nigeria. The ravines deviate sharply from the general landscape of the area and pose immense environmental problems.

Erosion can be divided into as potential erosion and actual erosion. Potential erosion gives an indication of the likelihood and possible intensity of erosion that could occur under given physical and climatic conditions in an area. It also expresses the susceptibility of an area to erosion. Potential erosion could therefore be regarded as “that which is likely to be”. Actual erosion gives the existing forms and intensity of erosion in an area under the prevailing physical factors and climatic conditions. Actual erosion therefore is “that which is in existence”.

The most fundamental way of characterizing erosion is in terms of the basic properties and elements of the erosional features, such as length, depth, width, side slopes etc; these could be determined by precise survey measurements. Erosion can also be characterized by the rates of the erosional processes, and the various factors influencing them in time and space. This leads to the concepts of erodibility and erosivity. A new method of characterizing erosion by the EFI index is proposed in this paper.

4.2.1 Erodibility

Erodibility of the soil or rock material is a measure of its susceptibility to erosion; it is therefore a property or characteristic of the material being eroded. Knowledge of erodibility is important in the preparation of erodibility maps, soil loss predictions in erosion control, and in planning land conservation practices. Erodibility may be determined by direct measurements in the field, or calculated using the erodibility equation, which is also referred to as the “nomograph method”. Direct measurement of erodibility is very costly and time consuming, and has been feasible only in a few locations in Nigeria (Usono et al, 1989, 333); in fact there is no such location within the study area. Nevertheless it should be noted that erodibility represents the combined effects of all properties of the soil or rock that significantly influence the ease with which it can be eroded by rain drops and runoff if not protected.

4.2.2 Erosivity

Erosivity is the potential ability of rainwater or rainstorm to cause erosion. Erosivity is a function of the storm type, raindrop size distribution, terminal velocity of raindrops, and rainfall intensity; it is therefore a property or characteristic of the agent causing erosion. Many indices have been

developed for the determination of rainfall erosivity, but the EI_{30} developed by Wischmeier and Smith (1978) is the most commonly used (Usoro et al., 1989, 333). By definition the value of EI_{30} for a given storm equals the product of the total storm energy (E) and the maximum 30 minute intensity (I_{30}). Technically EI_{30} indicates how particle detachment is combined with the transport capacity of runoff to cause soil erosion. Computation of erosivity values requires painstaking processing of long-term records of rainfall from individual synoptic stations.

EI_{30} erosivity values have been computed for 16 locations in Akwa Ibom State (within the study area) by Usoro et al (1989, 342) who remarked as follows:

“The general trend is such that erosivity values decreased with decrease in rainfall from the South to the North. But in contrast the extent and severity of erosion decreased from the North to the South. This might be interpreted to mean that areas of lower erosivity are more vulnerable to soil erosion than those with higher erosivity. This contradiction is related to the topography, pressure on the land, and unwise land use”.

From the foregoing it is clear that while erosivity values might provide adequate characterization of potential erosion in an area, the actual erosion can seriously be misrepresented.

4.3 The EFI Index

The EFI Index provides a more comprehensive quantitative or semi-quantitative characterization of erosion within a given area than has hitherto been developed and is based on the characteristic parameters of the erosional features. The EFI Index therefore relates to the actual erosion as exists on the ground.

4.3.1 Theoretical Considerations

From the hydrological perspective, it is known that a considerable proportion of all water reaching the land part of the earth's surface as rain is returned to the seas and oceans through a multitude of surface channels, which include rivers, streams and gullies. This network of surface channels constitutes the drainage of an area. Rainwater first prevails on the ground surface moving bodily in a form of “sheet flow”, thereby causing sheet wash or sheet erosion. Due to irregularities on the ground surface sheetflow cannot occur over a long distance, and the water thus becomes concentrated in tiny preferred channels called “rills”, thereby resulting in rill erosion. The rills integrate to form larger channels called gullies, in which the bulk of erosive activity is concentrated; this is gully erosion.

Field evidence has shown that erosion gullies are intricately related to stream channels; and that gullies are in fact located at valley heads or stream source points (Usoro et al, 1989, 310). Besides, the mechanisms involved in gully erosion are similar to those in stream channels; the hydrodynamics in both cases can be analyzed in terms of the theory of “flow in erodible open channels” (Dake, 1983, 213). In fact streams can be regarded as large “gullies” that perennially contain water, whereas gullies contain water only during and immediately after rains. Gullies can therefore be analyzed using the same mathematical laws as for stream channels.

Furthermore, there is a mathematical relationship between cumulative channel length and the drainage basin area. The ground area necessary on the average to maintain a unit length of drainage channel is called the “constant of channel maintenance” (Haggett and Chorley; 1969, 76). For any erosion gully therefore a definite ground area is necessary for its maintenance; and this invariably encompasses the zones of sheet wash and rill erosion. Thus the erosional activity

in an area can be comprehensively analyzed and quantified by considering only the gullies. The EFI Index has been derived by analyzing only the gullies accordingly.

4.3.2 Derivation and Formulation of The EFI Index

The characteristic parameters of erosional gullies include length, width, depth, and side-slope; the total ground area affected is also useful. These parameters influence the topographic texture of the landscape. One of the earliest definitions of topographic texture is by Johnson (Johnson, 1933; Ajaegbu and Faniran, 1973, 24). Horton (1945) expressed it by the stream frequency and drainage density. Strahler (1952) modified Horton's original system but maintained the same basic concept; however Faniran (1969) combined the stream frequency and drainage density to obtain the index of drainage intensity (Ajaegbu and Faniran, 1973, 24). Mekel (1977) obtained a dimensionless "ruggedness number" as the product of the drainage density and relief (Rengers, 1981, 65). The ruggedness number is a convenient way to express the overall terrain configuration in a semi-quantitative manner. By combining the methods of Mekel (1977) and Faniran (1969) the present author has formulated the "EFI-Index" to characterize the topographic texture and intensity of erosion in a given area. The EFI Index is computed from the following formula consisting of three terms, namely: Erosion Frequency, Erosion Channel Density, and Average Depth.

$$\text{EFI Index} = \sqrt{\frac{N}{A} \cdot \frac{\sum L}{A} \cdot \bar{D}}$$

Erosion Channel Frequency (F)

The first term in the formula is the Erosion Channel Frequency, which is a measure of the number of erosion channels per unit ground area. The erosion channel frequency is analogous to the stream frequency as used by Horton (1945) and Faniran (1969). It is expressed as number per sqkm, and has the dimension L^{-2}

$$F = \frac{N}{A}$$

Where N = Total number of erosion channels
 A = Total ground area (L^2)

Erosion Channel Density (C_d)

The second term in the formula is the Erosion Channel Density. This is defined as the average length of erosion channel per unit ground area. It is an analogous term with the drainage density as used by Horton (1945), Faniran (1969), and Mekel (1977). Erosion channel density could be expressed in km per sq.km or meters per square meter or even meters per sq.km; dimensionally it is L^{-1} .

$$C_d = \frac{\sum L}{A}$$

Where $\sum L$ = Total (cumulative) length of all erosion channels
 A = Total ground area (L^2)

Average Depth (\bar{D})

The third term in the formula is the average depth of erosion in the area. It is obtained by dividing the cumulative of all erosion channels depth by the total number of erosion channels

within the area. This term is analogous to the relief as used by Mekel (1977), and it expressed in meters; it has dimension L¹.

$$\bar{D} = \frac{\sum D}{N}$$

Where $\sum D$ = Cumulative depth of all erosion channels
N = Total number of erosion channels

5. Discussion and Conclusion

The EFI Index provides a more comprehensive quantitative or semi-quantitative characterization of erosion within a given area than has hitherto been developed, and can be applied to administrative areas (political units) as well as hydrophysical areas on the terrain. EFI Index gives the "erosion frequency and intensity" within a specific area on the terrain in numerical terms; however the numerical values can be aggregated to classes and characterized in descriptive terms. Thus EFI Index of less than five (5) indicates slight erosion intensity; 5-10 moderate, 10-15 high, and above fifteen (15) severe erosion intensity. These intensity classes have been colour coded and used to prepare an erosion map of South Eastern Nigeria (Fig.6).

The erosion map has been constructed on a modified form of the Universal Transverse Mercator Projection (UTM) known as the Nigerian Transverse Mercator Projection (NTM). This is a special purpose version of the UTM with three belts, each 4° wide in longitude, covering the whole country (the UTM is 6° wide in longitude). The study area falls within the middle Belt of the projection with the Central Meridian (CM) at 8°30'E. The geomorphological symbols used in the map have been designed in accordance with the International Institute for Aerospace Surveys and Earth Sciences (ITC) system of Geomorphological Symbols and the UNESCO system for Engineering geological maps. All other symbols and annotations are in accordance with established cartographic conventions.

From the erosion map of South Eastern Nigeria the area of high to severe erosion intensities appear to be aligned in two directions NW-SE and NE-SW; the NW-SE direction is the more prominent while that of NE-SW is just perceptible. It is interesting to note that the initial rifting of the Southern Nigeria Continental Margin in the Mesozoic Era produced two principal sets of faults trending NE-SW and NW-SE. The NE-SW fault bound the Benue Trough, while the NW-SE faults define the Calabar Flank. Whether the observed trend in erosion intensity has tectono-structural relationships might be debatable, and require further geological and geophysical investigations to confirm.

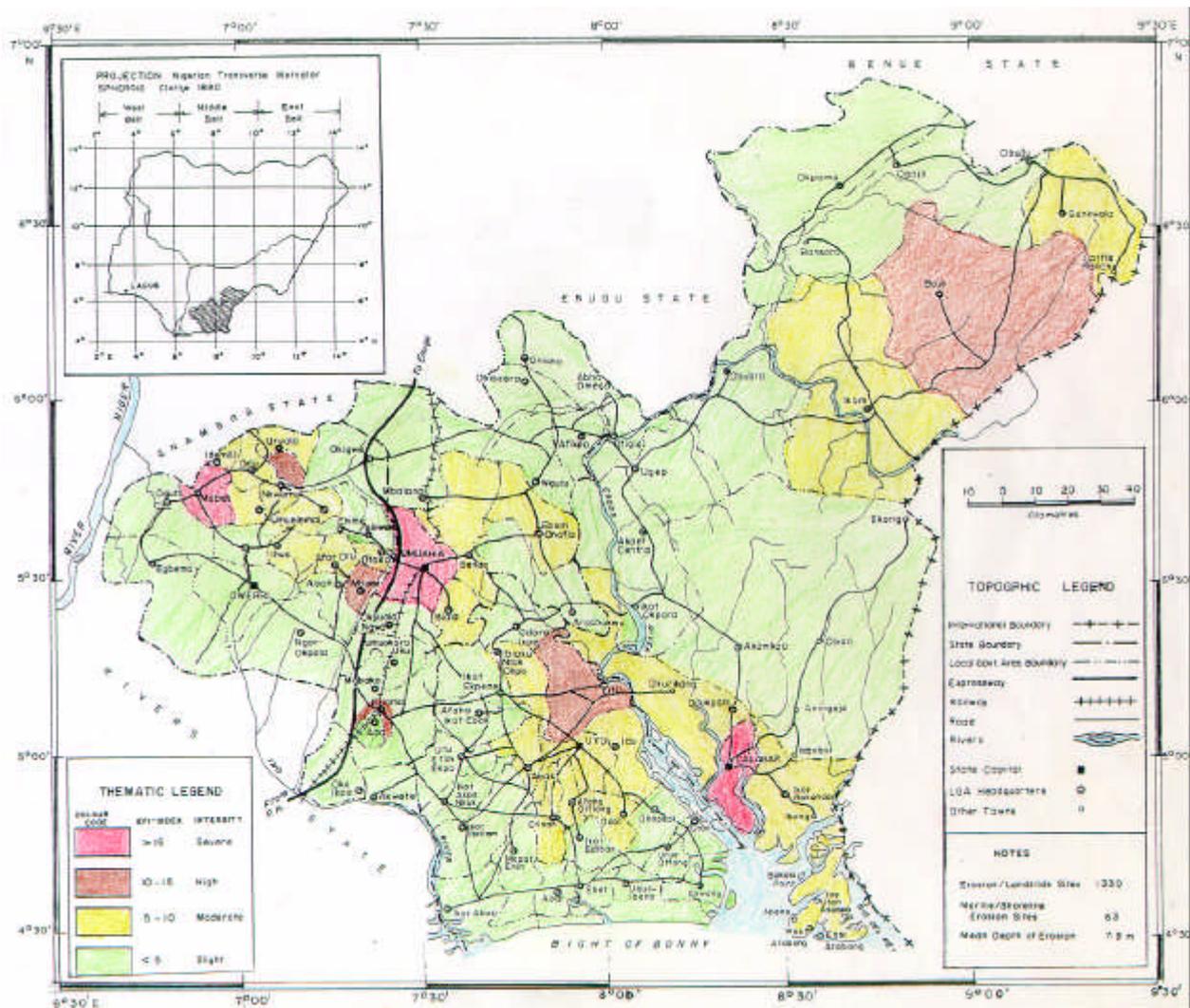


Figure 6 Erosion Map of Southeastern Nigeria.

Nevertheless, the EFI Index is proportional to the total quantity of material removed from an area by erosion, and could therefore be very useful for obtaining earthwork volumes in planning rehabilitation or reclamation work particularly in high risk erosion areas. Finally the EFI Index can be used to obtain quantitative estimates of actual erosion in environmental impact assessment.

6. References

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