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Flood Risk Assessment in Akoko-Edo and Environs South–South Nigeria Using GIS and Landsat Data

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ABSTRACT

This work presents the results of a flood risk assessment in Akoko-Edo and environs using GIS and landsat-TM data. This study is aimed at identifying the causes of the flood and quantifying the hydrological processes leading to this extreme event through a Geographic Information System (GIS) and Landsat approach. It also assesses the situation, through the analysis of the spatial and temporal rainfall variability and the quantification of the discharge at different locations in the study area and compared with other cases that are believed to be the cause for high runoff volume .This study thus tries to identify the causes for the occurrence of floods and future risks to look over options for prevention or reduction of the hazard in the area by concentrating the study in the area through GIS and landsat based analysis. The data was processed and enhanced to give colour composites, geologic maps, drainage pattern, land use and land cover map, flood risk area map, rain fall map. The results showed that Akoko- Edo area has a low risk to flooding in the Northwest area while in Etsako East area there is high risk towards the Northwest, central and the Eastern part of the area, as well as towards the Northern part there is a very high risk of flooding. In the central area, there is a moderate risk while there is a low to very low risk towards the southeastern part of the area. Etsako west has a moderately high risk to flooding in the Southern part to a very high risk in the South while in the central there is a very high risk to flooding for people living around the area but towards the North there is a very low to low risk of flooding.

1.0 Introduction

Natural hazards result from internal processes (processes that operate within the earth's interior (such as movement of magma, mantle convection, etc.) or/and internal stress (such as earth quake, volcanic eruption and tectonic creep). Other hazards like landslide, river flooding and coastal hazards result mainly from external processes (processes operating on earth's surface such as rainfall, wind, etc) [1].

Flood is a general and temporary condition of expanse of normally dry land where properties are inundated by water or mudflow. Flood is described as any relatively high flow that overtops the natural or artificial banks in any reach of a stream and it is the result of runoff from rainfall and/ or melting snow in quantities too great to be confined in the low water channels of streams. Floods are the most common natural disaster and does not need to be experienced around the coast only but can occur any place where depression exist on the surface of the earth among elevated surroundings. The occurrence of flood is associated with risk. The risk is usually negative and brings destruction of vegetations and properties found there. It is not possible to prevent floods but it is possible to prevent or reduce the damage due to floods by controlling the floods. Thus flood control or management is defined as the prevention or reduction of the flood damage [2].

In Africa flooding is the most frequently occurring and destroying one next to drought & hunger like South Africa in 1987, Sudan in 1996 and Somalia in 1997 [3]. Surface water flows can cause extensive damage by eroding soils and stream banks; carrying off valuable agricultural nutrients and pollutants; destroying bridges, utilities and urban development; and causing flooding and sediment deposits in recreational, industrial and residential areas along stream systems. Urbanization of farm land causes more rapid run off, higher peak discharges and larger run. Flood and erosion are influenced from a variety of factors such as rainfall distribution, soil type, land use, etc.

These factors are presented in various types by time and space, and GIS technique has been used as a method to predict the hazard of soil erosion and runoff in watershed (Neumann and Gert, 1989)[4].Vegetation cover is important for the protection of the soil surface from the beating action of raindrops (rain splash) and erosion by surface runoff. Studies in West Africa have shown annual erosion under natural forest cover lower than 500 kg/ha even on slopes up to 65 %,while rates were up to 1000 times higher from bare soil on similar slopes [5].Various measures can be taken to reduce the risk of flooding in the flood plains. The construction of dams has also been a very successful means of controlling floods but structural failure is one of the reasons that prompt the search for other management options.

This implies that flood hazards cannot be controlled in a sustainable way by simply constructing structures (levees).

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One of the most effective methods of reducing damage has been to alter the size of floods themselves. By planting trees, controlling soil erosion, and preserving wetlands, people have helped to reduce the size of floods [6]. Long lasting control & removal of such hazards, watershed based study and management intervention is mandatory [7].

1.1 Location of Study Area

The study area is located within longitudes 6^o 00¹ to 6^o 40¹E and latitudes 7^o 00¹ to 7^o 30¹N. The major communities include Akoko-Edo, Etsako west, Etsako East and Etsako central, south-south, Nigeria, Fig. 1. It forms part of the western massive.

1.2 Geology of the Study Area.

The geology of the area comprises namely, the *Basement Complex* and *Sedimentary Basins.* The Basement Complex, which is Precambrian in age, is made up of the *Migmatite-Gneiss Complex*, the *Schist Belts* and the *Older Granites.* They are structurally and petrologically distinct from the Older Granites. The Sedimentary Basins, containing sediment fill of Cretaceous to Tertiary ages, comprise the Niger Delta, the Anambra Basin, the Lower and Middle Benue Trough,

The Nigerian basement was affected by the 600 Ma, Pan-African orogeny and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin, [8], [9]. The basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African cycles (600 Ma). The first three cycles were characterized by intense deformation and isoclinal folding accompanied by regional metamorphism, which was further followed by extensive migmatization. The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses [10]. Late tectonic emplacement of granites and granodiorites and associated contact metamorphism accompanied the end stages of this last deformation. The end of the orogeny was marked by faulting and fracturing (Gandu et al., 1986[11]; Olayinka, 1992[12]).Within the basement complex of Nigeria, Fig. 1, four major petro-lithological units are distinguishable, namely:The Migmatite – Gneiss Complex (MGC),The Schist Belt (Metasedimentary and Metavolcanic rocks), The Older Granites (Pan African granitoids) and Undeformed Acid and Basic Dykes. The sedimentary basins comprises of several geological Formations such as; Mamu, Ajalli, Nsukka, Imo shale group, Ameki, Ogwashi-Asaba, Benin and Alluvium. These Formations are mainly found within Anambra and Niger Delta basins. They were deposited during either the transgressions or regressions. The Mamu and Nsukka are characterized by shale,sandstone and sometimes mudstones while Imo shale, Ameki and Ogwashi-Asaba are made up of shale, clay and sandstones except Ogwashi-Asaba that has lignite series within it.

The Benin and Alluvium consists mainly alternating layers of sands, clays and mud (Reyment, 1965[13] and Kogbe et al, 1989[14]).

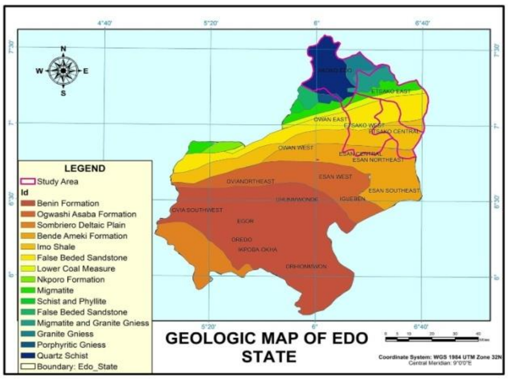

Fig 1. Source- Nigerian geological survey agency 2006.

2.0 Theoretical Background

The design of land observation satellite evolved from earlier system that although not tailored for earth observation purpose, provides successful operation of today's satellites. The first earth observation satellites (TIROS) were launched in April, 1960 which was designed to monitor cloud patterns. Land satellite (Land sat) was designed and launched in the 1960s and 1972 respectively as the first satellite specifically for broad scale observation of the earth's land area.

Geographic Information System therefore is the acquisition of data and derivative information about an object, classes or materials located at some distance from the sensors by sampling radiation from selected region of the electromagnetic (EM) spectrum for sensors mounted on moving platform (e.g. Aircrafts and satellites) operating in or above the earth's atmosphere.

In 1960 when the name remote sensing was first coined, it simply referred to the observation of and measurement of an object without touching it. The use of remote sensing is applied in many disciplines, from the environmental scenes of geography, geology, botany, zoology, civil engineering, forestry, meteorology, agriculture to oceanography. It usually refers to the use of electromagnetic radiation sensors to record images of the environment which could not be reached physically. In general, Remote Sensing makes it very easy to collect data on inaccessible or dangerous areas thereby making it replace costly and slow data collection, ensuring that areas or objects are not disturbed in the process.

The fundamental principles of remote sensing are derived from the characteristics and interactions of electromagnetic radiation (EMR) as it propagates from source to sensor. The principles are related to the following:

1)The absorption of the scattering effect of the atmosphere on EMR

2)The source, type, and amount of energy it provides

3)The mechanisms of EMR interaction with earth surface features

4)The source of sensors response as determined by the type of sensor, etc, interpreted to yield useful information.

3.0 Materials and Data Acquisition

The data used are acquired in the form of images of the following: Landsat ETM 2001 Image, Map of Akoko Edo, Etsako West, Etsako East, Etsako central and its environs, Geology map of the study area, SRTM DEM of the study area, Slope/Aspect map, Erosion/topographic map, Drainage map and Land use map.

3.1 Instrumentation

The instruments used to carry out this research are classified into field instrument and office instrument. These include; GPS receiver, digital camera (active component of the satellite), compass, and software applications used for processing the data and analysis.

Procedure Adopted

- The image window of the study area was processed using standard image processing techniques.
- Gully sites in the area was identified and characterized.
- The pattern of spread of gullies was mapped using image classification.
- Accuracy was assessed using overlay technique.

3.2 Mathematical Formula for NDVI Calculation on Per-Pixel Basis

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \text{-------------- (1) 3.1}$$

- Where NIR is the near infrared band value for a cell
- RED is the red band value for the cell.

NDVI is the normal difference vegetation index. The Normalized Difference Vegetation Index (NDVI) is an index of plant “greenness” or photosynthetic activity, and is one of the most commonly used vegetation indices. It can be calculated for any image that has a red and a near infrared band.

3.3 Application of Normalized Difference Vegetation Index (NDVI)

The ecosystem comprises of varied organic and inorganic materials which are related. This relationship between many ecosystem parameters has made NDVI a veritable tool in solving ecological problems. The uses include assessing or monitoring:

- vegetation dynamics or plant phenological changes over time
- biomass production
- carbon sequestration or CO_2 flux
- changes in rangeland condition and soil moisture
- vegetation or land cover classification

4.0 Results and Discussions

4.1 Results from Terrain Analyses

The Digital Terrain Model or Digital Elevation model of the study area as shown in the figure below was created in ILWIS by first digitizing the contour map on screen using the mouse. This was followed by converting the resulting vector layer to a raster layer (contour interpolation). The DEM is employed for structural, geologic and tectonic interpretations such as locating faults, drainage pattern, geomorphology, plate position, slope, lineaments and the boundary between geologic units. The figure below has a slope ranging from 11.83335108 – 1.024935921 in the area.

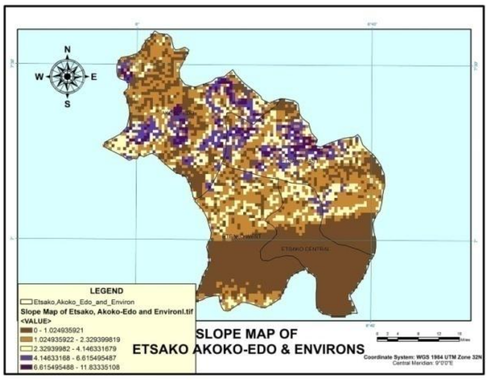

Fig 2. Slope Map Of Akoko-Edo, Etsako & Environs.

4.2 Results from Color Composites

The composites were generated for the purpose of enhancing spectral signatures of the image for the study area thus, enhancing the observation of the different patterns which can be attributed to the different stratigraphic units existing in the study area thus, aiding the interpretation of their features.

4.3 Normalized Difference Vegetation Index

From equation (1) 3.1 the expression of vegetation indices are based on the observation that different surfaces reflect different types of light differently. Photosynthetically active vegetation, in particular, absorbs most of the red light that hits it while reflecting much of the near infrared light. Vegetation that is dead or stressed reflects more red light and less near infrared light. Likewise, non-vegetated surfaces have a much more even reflectance across the light spectrum. By taking the ratio of red and near infrared bands from a remotely-sensed image, an index of vegetation “greenness” can be defined. The Normalized Difference Vegetation Index (NDVI) is probably the most common of these ratio indices for vegetation. NDVI is calculated on a per-pixel basis as the normalized difference between the red and near infrared bands from an image.

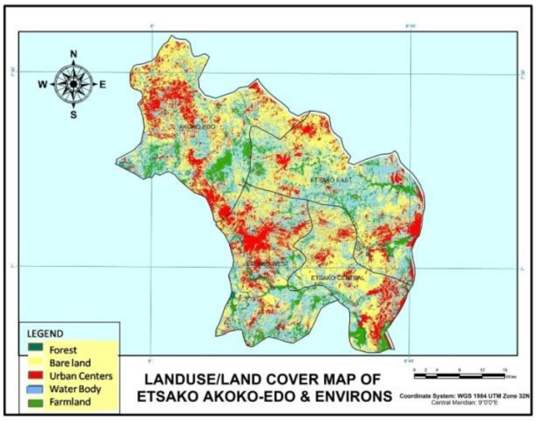

Fig 3. Landuse/Land cover Map of Akoko-Edo, Etsako & Environs.

Looking at Fig. 3, blue areas correspond to water bodies, red areas correspond to urban centers, yellow correspond to bare land areas, green represents farm lands and dark green represents forest,[15]. With this image, zones of vegetation and bare lands, water bodies and urban centers can be delineated.

4.4 False Colour Composite Map

Color and color tone are the brightness levels in digital images. The reflection of color tones of different materials on the earth helps in distinguishing surface materials and their boundaries, [16]. The composite image provides a naturalistic and earth view of the landscape of the study area

4.5 Drainage Patterns

The drainage linears were derived from the drainage pattern of existing topographic map and the satellite image.

Geomorphologists dealing with remote sensing applications have studied stream drainage patterns and their relationships to terrain conditions. Many have deduced different rock properties and structures using topographic relief interpretation from the imagery. They have illustrated and quantified relationships among selected rock properties, topographic relief, and stream drainage patterns [17];[18].

Stream drainage density in eroding rock landscapes can be explained by a function of rock resistance to weathering, topography and climate. Rock resistance to both chemical and mechanical weathering is an important factor in explaining drainage patterns.

In terms of topography, higher relief creates a finer-textured drainage as in our study image. But the relationship with climate is more complicated. It is the amount of

protective vegetation cover, which can be correlated to temperature and precipitation that significantly controls erosion and drainage density. Thus softer rocks, such as shale areas, have higher drainage densities in drier climates than wetter climates. The protection of the rock and soil surface by vegetation compensates for the increase in precipitation [18].
Stream drainage density usually indicates the porosity and permeability of the underlying materials. Materials with good permeability generally have a medium to coarse drainage density. Such materials include sandstones, terrace gravels, limestone, volcanic ashes, and sand dunes.

Stream drainage density also shows that fine-grained or impermeable materials have little moisture on the surface. This moisture does not infiltrate and must run off on the surface.

Stream drainage patterns can reveal larger-scale coarse structure of underlying rocks, e.g., stream drainage patterns with numerous straight parallel or sub-parallel segments can indicate extensive jointing on dipping bedded or foliated rocks. Consistent angular relationships between stream elements indicate fractures. Co-centric drainage shows doming of layered sequence of rock related to intrusion or folding [19].

Radial drainage shows doming, volcanic activity, or small resistant cylindrical intrusions in less resistant rocks. Well-developed dendritic drainage patterns without well-developed parallel elements suggest a uniform stratum without abundant discontinuities. This can consist of sedimentary, igneous, or metamorphic rocks, or sheets of relatively uniform glacial or alluvial materials. Distributed channel patterns indicate alluvial fans, pediments, or deltas, and they are usually associated with an abrupt decrease in stream velocity [20][21].
Extensive drainage channels indicate strong foliation, dipping sequences of resistant and nonresistant rocks, or strong unidirectional fracturing.

The shapes of the main channels in the stream drainage area also provide clues about the geological structures {21}. For instance, braided channels indicate easily erodible coarse-grained materials, while meandering channels indicate medium to fine grained materials. Relatively narrow and straight channels indicate resistant materials, but abrupt changes in channels indicate changes in geological structures. Extreme changes in channel types indicate changes in the materials that make up the bank. The main channel in the drainage area having discontinuities indicates cracks (breaks and fractures) and/or faults, as well as unconformities, Fig 4.

Fig 4. Lineament on Drainage map of Etsako, Akoko-Edo and Environs.

From Fig 4. above is a map to correlate the trends of drainage and structural orientation in the whole area and from statistical analysis and visual obsevation, it reveals that the drainage pattern in Akoko Edo and Etsako has a dendritical partern.

4.6 Flood Risk Assessment

The factors that are necessary for the incidence of the flood catastrophe were reviewed and the local dwellers were interviewed. Accordingly drainage density, slope, elevation, land use type and road density are listed in order of importance.

To assess flood risk of the town using GIS, Multi-Criteria Evaluation was used. MCE is a procedure which needs several criteria to be evaluated to meet a specific objective. It is most commonly achieved by one of two procedures. The first involves Boolean overlay whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as intersection (AND) and union (OR). It was observed that Akoko Edo area has a low venerability to flooding in the Northwest area and has a moderately high risk towards the Northeastern and Southwestern part, in Etsako East area there is high risk towards the Northwest, central and the Eastern part of the area, towards the Northern part there is a very high risk of flooding, towards the central there is a moderate risk while there is a low to very low risk towards the southeastern part of the area. Etsako west has a moderately high risk to flooding in the Southern part to a very high risk in the South while in the central there is a very high risk to flooding for people living around the area but towards the North there is a very low to low risk of flooding. In Etsako central there is a very low to moderately high degree of risk in the Northern and Southern part of the area while towards the central part there is a very high risk of flooding in the area.

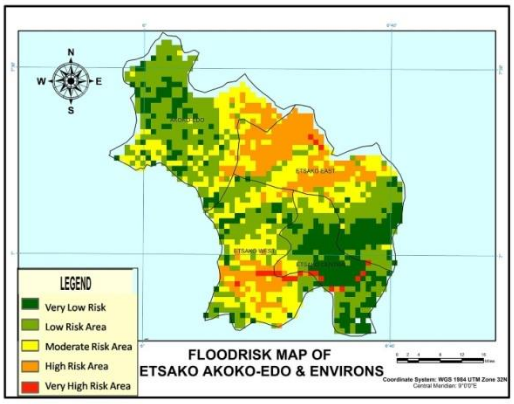

Fig 5. Floodrisk Map of Akoko-Edo, Etsako & Environs.

5.0 Conclusion

Since the primary objective of this study is to identify the flood risk assessment of Akoko Edo, Etsako West, Etsako East and Etsako central all in Edo state, it was necessary to process the GIS and Landsat -TM data in a manner that would both enhance trends and facilitate the computation of locations and areas prone to flooding. Drainage pattern, land use, land cover, sloop map, geology map, were the basic hypothetical models used in this study.

The GIS analysis and interpretation as well as digitally processed satellite remotely sensed data have revealed that the area of study has a high risk to flooding.

In conclusion, this study has shown beyond doubt that landsat TM imageries are essential in determining possible flood plains and has a lot of research potentials for geologic applications especially in identifying the flood risk assessment of places such as Akoko Edo, Etsako West, Etsako East, and Etsako central. The recommendation is that government is advised to construct dams in the affected areas and grow plants that are resistant to erosion as well as water loving plants or crops.

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