Original Research Paper

APPLICATION OF GEOSPATIAL TECHNOLOGIES IN ASSESSING GULLY EROSION IN THE HUMID TROPICS OF ENIONG OFFOT, UYO, AKWA IBOM STATE

ABSTRACT

The application of geospatial tools in geomorphic mapping plays an essential role in the understanding of both landscape evolution and natural hazards (notably gully erosion) across scales. This study investigates the pattern and influence of gully erosion in Etim Umana axis of Eniong Offot, Uyo in Akwa Ibom State with emphasis on geospatial assessment of landuse/cover, elevation, and flow accumulation. Map analyses of land use/land cover reveals that urbanization/population growth representing 41.6 percent, scattered cultivation representing 22 percent, and paved surface representing 16.7 percent coupled with high rainfall which together accounted for a total of 80.3 percent of the outstanding drivers of gully migration and expansion in Etim Umana site while secondary vegetation and bared ground accounted for 19.7 percent in the area. The analysis of vegetation using Normalized Difference Vegetation Index (NDVI) and 3 digital elevation model revealed that scarcity of vegetation cover, high to moderate relief, and the bedding plains of the coastal sands deposits also exercised the strong influence on the gully migration in the area. This paper concluded that gully erosion in the Etim Umana area is caused by high incidence of rainfall and surface configuration but accelerated by anthropogenic activities (urbanization, farming, engineering/construction works). This study recommends the construction of existing drainage systems from roads to the nearby rivers for appropriate regulation of surface runoff generated by heavy rainfall from the already over-stressed facilities in the Offot area of Uyo.

Keywords: Geospatial technology, geo-mapping, gully erosion, land use, Humid Tropics.

1. BACKGROUND

The major characteristics of Humid Tropical climate are the high incidences of rainfall and fairly uniform temperature distribution throughout the year, usually with double maxima (during the months of July and September), and is considered the most important climatic factor that controls the extent of geomorphic hazards notably gully erosion and flooding. The concept gully erosion is any erosion channel so wide that it cannot be crossed by wheeled vehicle or eliminated by farm implement [1]. It is one of the geomorphic hazards that have attracted much research attention from landform and process analysts in the Humid Tropics. Although the study of landform and its processes in the Humid Tropics of southern Nigeria have formed the focus of research in geographical and earth sciences in the past centuries, across distinct places and scales, using quantitative viewpoint [2,3,4,5], or theoretical viewpoint [6], each ideology has its strengths and weaknesses based on context and method; thus necessitating the adoption of geospatial mapping of the study area.

Within the 21st century, the application of the state of the art technologies especially geospatial techniques {Geographic Information System (GIS), Remote Sensing (RS), and Global Positioning System (GPS)} have been identified as the vital tools for improved terrain analysis [7]. The rationale is that different techniques and data can be used for different purposes, but great attention is tilted to the accurate determination of land use change and geomorphic hazards (notably gully erosion and flood) detection, and guaranteed appropriate visualization and result interpretation.

Geomorphic hazard mapping is becoming more specialized, and its legends are currently being simplified due to the incorporation of geospatial tools for enhanced precision with definitions, and the separation of thematic layers, so that a convergence with specific landform could become more flexible and more applicable, with a broader range of visualization techniques. Besides, high-resolution DEMs from active remote sensing form a new basis for geomorphological work [7,8], and different visualization techniques (2-D, 3-D, 4-D etc.) are often used to display spatial data [8] for effective communication about the land surface and its features, properties, and temporal evolution.

The image display of topographic information, especially at a small scale, serves as a foundation for accurate determination and quantitative understanding of specific landform. The phenomenon of gully erosion is either naturally-induced or artificially-induced, or both [9,10]. Nature of soil, topography, amount of precipitation and land cover has been named as the natural cause of gully erosion. Anthropogenic factors include construction projects, uncontrolled urbanization, sand mining and quarrying activities, poor drainage network, increase in the areas covered by pavements and structures and a failure to incorporate into the construction design, control measures that adequately stabilize slopes, re-establish cover on exposed soils, or convey runoffs as well as other causative factors like cattle grazing, deforestation, and bad farming habits of the people [3,5,11,12,13,14].

From the agro-ecological dimension, [15] opine that physical forces drive landscape architecture and composition in land uses. Drawing instances from the geomorphological variables, [16,17] observe that driver land use changes such as slope that affects field accessibility with machinery. Altitude gradient can also affect the loss of natural areas in favour of agriculture expansion [18] while [19,20] emphasize the vitality of pedological factors are also important to understand land settlement on fertile soils for example. As explained below, land management is also affected by socio-economical and physical forces. Each driver and the level of influence often vary from one location to another due to scale, time, climate, geology, and man and others.

In Auchi area of Edo State, [21] opines that gully erosion in urbanized areas is one of the most reoccurring disasters with devastating effects on man and global environment. For instance, the continuous sculpturing of the earth's landscape constitutes one of the global environmental problems [10]. [5] group the impacts of soil erosion into a general diminution of cultivable land due to the expansion and migration of gully, and reduction in soil fertility due to loss of nutrients from splash erosion and sheet wash. His empirical study identified high positive correlation of population density, rainfall, vegetation on one side, while relief, lithology, and surface materials also exercised a strong influence on gully development in southeastern Nigeria [see 5].

Generally speaking, the cost of gully erosion is high, with environmental, health, social, and economic impacts; hence [1] argues that it is an unwanted phenomenon and must be eradicated through teamwork in urbanized areas of Calabar and Uyo. Government all over the world have spent a huge amount of resources in an attempt to mitigate their impact on the socio-ecological, economic, and household systems. [9,22] enumerate specific on-site effects of gully erosion to include: reduced access to and on properties; a reduction in the area of arable and other agricultural land, which becomes divided into smaller parcels and leads to increased farming costs; major changes to the patterns of overland flow causing sedimentation and pollution of watercourses; damage to underground utilities such as communication cables, pipes and power cables; increased rates of erosion where more subsoil material is exposed.

The Millennium Ecosystem Assessment [23] identified unwise land-use choices and harmful crop or soil management practices as the major drivers of increasing soil erosion. Soil erosion has multiple on- and off-site consequences such as decreasing crop yields, decreasing water quality (turbidity and particle-born pollutants), sedimentation of reservoirs, and disturbed hydrological regimes such as increased flood risk due to riverbed filling and stream plugging as emphasized in [23,24,25].

There are clear indications that landowners and users across the world, are considered to be disproportionately vulnerable to climate change because of changes in rainfall, temperature, and the frequency or intensity of extreme weather events directly affect their health, agricultural productivity, buildings, food security, income, and their well-being [see 12,25,27]. The extreme weather and climatic (rainfall and temperature) events accelerate the dimension of occurrence of diverse geomorphological hazards which gully erosion and flooding stand out among the focal geophysical elements in the Humid Tropics of southern Nigeria.

There is urgent need to map gully erosion for the purpose of monitoring the extent of land degradation and resident vulnerability in the urbanized parts of Uyo. Various approaches have been adopted by different researchers in gully erosion assessment. Among the variously available frameworks, the use of geospatial technologies which integrate Geographic Information System (GIS), Global Positioning System (GPS), and Remote Sensing (RS) resources have been very effective, enhance accuracy, and save time. This work deploys the expertise offered by the geospatial technologies in the evaluation of gully erosion in Uyo. The results will facilitate the planning and implementation of suitable management and mitigation programmes for the vulnerable area and the State in general.

2. THE STUDY AREA

Eniong is one of the gazetted communities of Offot Clan in Uyo, the Akwa Ibom State Capital. The community is bounded in the north by Ekpri Nsukara, in the south by Anua and in the west by Ewet as portrayed in Figure 1. Specifically, the study area is located between latitudes 5.028157^{o} – 5.039566^{o} north of Equator and longitudes 7.944702^{o} – 7.953807^{o} east of Greenwich Meridian. In 1991, the total population of Eniong Offot stood at 4,901with a male population of 2,333 and female 2,568 [28]. With an annual growth rate of 3.4 percent, the projected population of the community as at the end of 2017 stood at 11,690 people with male and female population being 5,565 and 6,125 respectively. This growth rate is a clear indication of increasing pressure on landscape and land use/resources resulting from housing, road/drainage building, farming, infrastructure, and mining activities. The geology of the area composed of coastal plain sands deposits of the tertiary formation with poorly consolidated sands. Soils are loose, friable, and ferrallitic in nature and are mostly deficit of weatherable mineral reserves [29].

According to the [29], Uyo especially Eniong Offot is under the influence of (Kwa Iboe and Ikpa) rivers, urbanization, and infrastructural development as the dominant drivers of the dynamic in rainfall amount, frequency, and intensity. The area recorded a mean annual rainfall of 2443.3mm between 1977 – 2012 [29,30,31].

3. RESEARCH METHODOLOGY AND MATERIALS

This article adopted three approaches in data generation, which are: the field survey data acquisition method, data acquisition through the internet and remote sensing, and finally data processing for the final results. GIS operations include scanning and geo-referencing of the administrative map, the Google earth imagery, shape files and attribute table creation, on-

screen digitizing, layer extraction and map compilation for the study area. Others are the creation of signatures for supervised classification of the satellite image, generation of normalized difference vegetation index (NDVI) and many other operations. The hydrological functions of the spatial analytical tools were used to create a smooth surface for the production of various topographic details and the watershed of the catchment area for analysis. The capability of Surfer was also deployed to assess the terrain in 3D view.

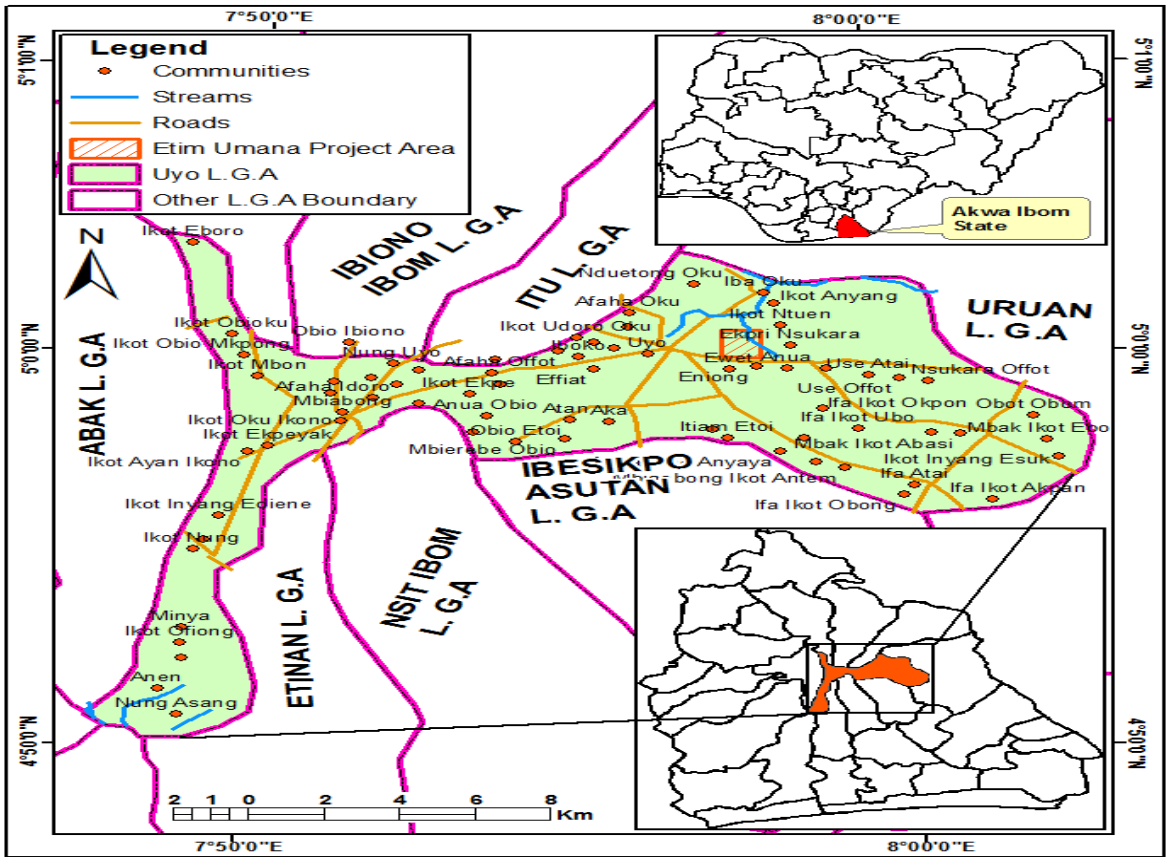

Figure 1: Uyo showing Study Area (compiled by authors, 2017).

Gully boundaries and break lines were measured using DTM and feature collection functionalities. Gully profiles were demarcated by positioning straight lines at regular intervals along the gully length. Then the gully sections were defined as portions of a gully between neighbouring profiles. By applying the relevant software, the gully volume was computed for every gully section. Gully boundaries and break lines were measured using DTM and feature collection functionalities. The profiles were demarcated by positioning straight lines at regular intervals along the gully length. Then the gully sections defined as portions of a gully between neighbouring profiles. By applying the relevant software, the gully volume was computed for each gully section. In order to generate topographic features (DEM) for modelling soil loss, contour of the topographic maps were digitized and integrated

into GIS as applied in [13,32]. Field survey techniques were also employed in the measurement of gully depths, width and lengths for the computation of volume of soil displaced by gully erosion as emphasized in [13,33]. The rationale is to identify appropriate management options that will prevent further expansion and transformation the existing gully erosion site to a vial land resources site through sustainable man-environment interaction. The statistical tools used include percentage and graphs.

The materials used include the administrative map of Uyo LGA from achieves; Garmin GPS receiver with a spatial resolution of 3 meters; High-resolution Satellite Image from downloaded from Google Earth; 30 meters ASTER-DEM data from USGS; XYZ coordinates data of the gully sites were acquired for cross section and center line profile, as well as for horizontal alignment/Plan view; and software used for the data processing are: ArcGIS 10.2 version (for map compilation and spatial analysis), Erdas Imagine 9.2 Softwares (for image processing and classification as well as vegetation analysis), Surfer 10 software (for 3D modelling).

4. MAP ANALYSES AND DISCUSSION OF RESULTS

The maps analysis on the Figures 2, 3, and 5 were used in generating data in the field and through secondary sources. All the GIS/RS procedures were strictly followed. In figure 5 the land use and land cover analysis based on satellite imageries of the study area was explored and the outcome reveals a high level of anthropogenic interferences. The result presented on Table 4 and graphical analysis presented on figure 6 reveal that population growth/ urbanization occupied 41.6 percent, scattered cultivation represented 22 percent, and paved surface represented 16.7 percent; thus, constituting a total 80.3 percent of the proportion of the accelerate indices. Also, secondary vegetation represented by 11.3 percent and bared ground represented by 8.4 percent; together accounted for the remaining 19.7 percent of the land use/cover indices. The accelerated indices in the study area are the most outstanding drivers of gully migration and expansion in Etim Umana site facilitated by the high incidence of precipitation and surface runoff.

Indeed, the results of the map analyses of land use/cover attests [5] observation that population density, rainfall, vegetation possessed high positive influence on erosion in the southeast Nigeria in spite of the locational and methodological differences. However, this result cannot be discussed in isolation without considering the role of natural factors (rainfall (the originator), relief, lithology, and magnitude of surface runoff) which define the propensity of the erodibility rate in the area. For instance, in event of policy interventions, the

most vulnerable households can be directly targeted with the aid of figure 2. Also, spatial coordinates of measured location are vital in land/environmental recovery exercise with the aid of figure 3, tables 1 and 2. The terrain analysis using a three – dimensional perspective is essential in gaining more insight on the extent of land degradation as a result of headward migration and lateral expansion of gully erosion as depicted in figure 4 and 5.

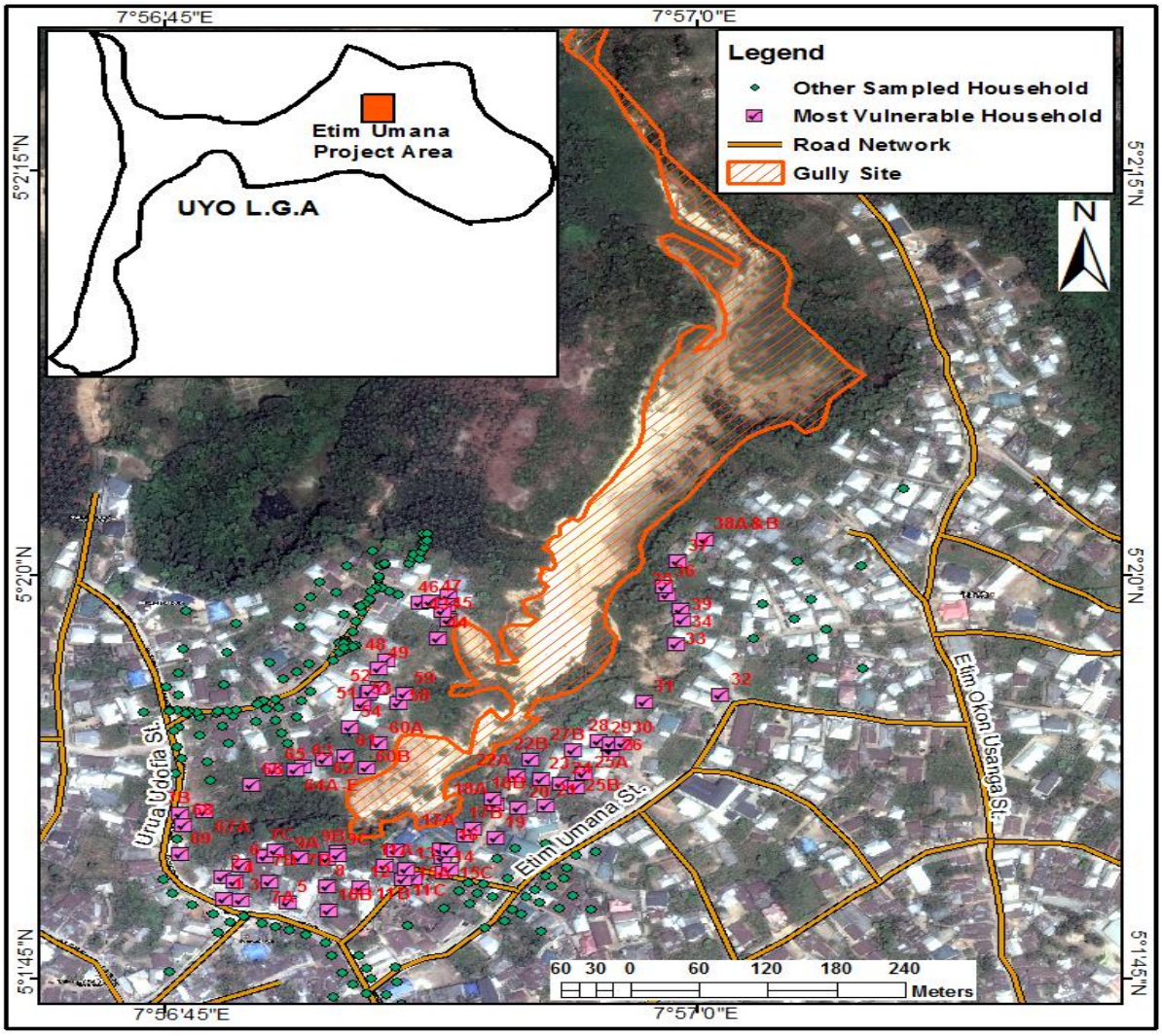

Figure 2: Base Map of Etim Umana Gully Site Showing Some of the Captured households and Key Features

Table 1: Determination of Points along Gully Site in Etim Umana, Uyo.

Points	Latitude	Longitude	Elevation (m)	Usage
M1	$5^0\ 1^I\ 50.353^{II}$ N	$7^0\ 56^I\ 50.199^{II}$ E	60	Length
M2	$5^0\ 1^I\ 52.208^{II}$ N	$7^0\ 56^I\ 50.199^{II}$ E	60	Width
M3	$5^0\ 1^I\ 50.924^{II}$ N	$7^0\ 56^I\ 52.864^{II}$ E	60	Width
M4	$5^0\ 1^I\ 52.589^{II}$ N	$7^0\ 56^I\ 51.960^{II}$ E	58	Depth
M5	$5^0\ 1^I\ 57.918^{II}$ N	$7^0\ 56^I\ 54.482^{II}$ E	48	Width
M6	$5^0\ 1^I\ 57.966^{II}$ N	$7^0\ 56^I\ 54.577^{II}$ E	46	Width
M7	$5^0\ 2^I\ 0.63^{II}$ N	$7^0\ 56^I\ 56.908^{II}$ E	34	Depth
M8	$5^0\ 2^I\ 8.243^{II}$ N	$7^0\ 56^I\ 59.335^{II}$ E	24	Width

M9	$5^0\ 2^I\ 7.577^{II}$ N	$7^0\ 57^I\ 4.712^{II}$ E	36	Width
M10	$5^0\ 2^I\ 8.91^{II}$ N	$7^0\ 57^I\ 2.475^{II}$ E	22	Depth
M11	$5^0\ 2^I\ 19.611^{II}$ N	$7^0\ 56^I\ 56.766^{II}$ E	20	Length

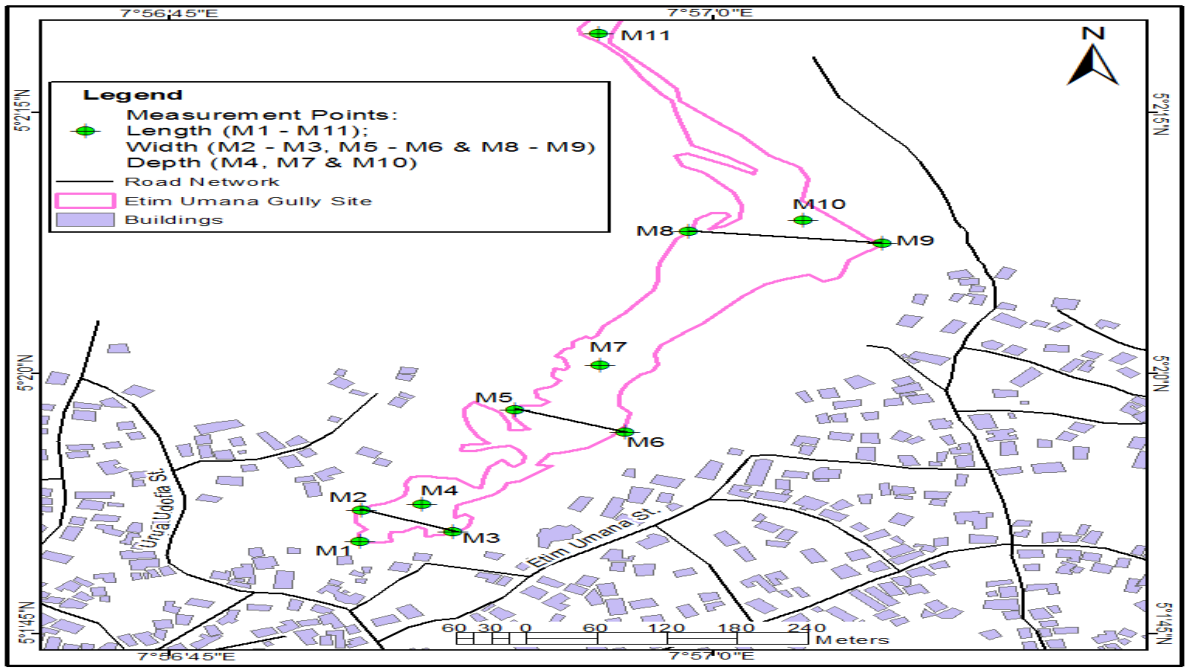

Figure 3: Base Map of Etim Umana Gully Site Showing Key Features and Parameters Measurement Points

The length and width of the gully depicted in figure 3 and Table 2 respectively showed spatial variations. The length from M1 to M11 covers a total of 1,043.94 meters. The width of M8 – M9 attracts the highest proportion of 167.07 meters, follows by M5 – M6 with a width of 100.418 meters, and M2 – M3 with a width of 93.68 meters respectively. Apart from that, the gully depth also reflect variation ranging from M7 with 26.83 meter, follow by M10 with 22.46 meter and M4 with 20.27 meter. Thus, the middle part of the Etim Umana gully site records the highest depth and width. This is attributed to the volume of runoff processes and the anthropogenic activities prevalent in the area without appropriate mitigation measures by the landowners/users.

Table 2: Gully Parameters in Etim Umana Gully Site

Length (m)		Width (m)		Depth (m)	
M1 – M11	1,043.94	M2 – M3	93.68	M4	20.27
		M5 – M6	100.418	M7	26.83
		M8 – M9	167.07	M10	22.46

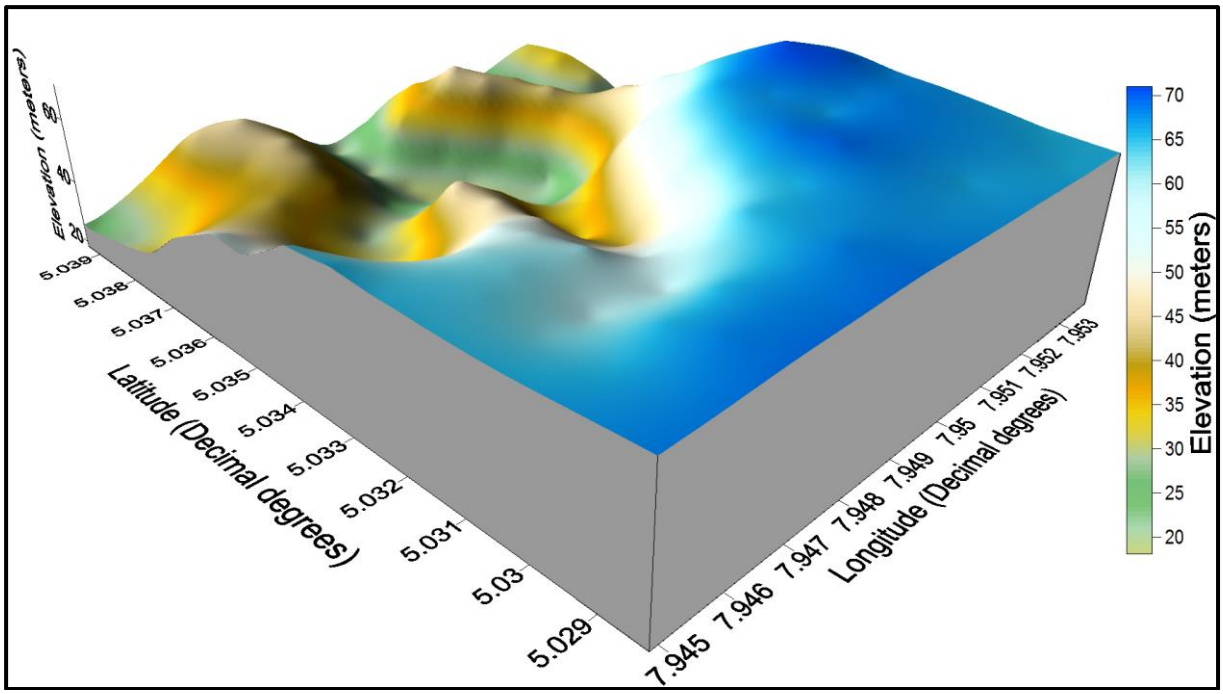

Figure 4: 3D Model of Etim Umana Gully Site

The vulnerability assessment of household to gully in Etim Umana site as mapped in figure 2 suggests the relationship between land use/land cover on gully formation. As seen in figure 5, urbanization and other human activities have really crept into areas that should be regarded as ecologically sensitive. Their distributions are shown in figures 5 and 6 as well as altitude and size in tables 1 and 2 respectively of the Etim Umana gully site. Flow accumulation, slope, contour, and relief are of immense benefits in understanding the morphological dynamics of gully site in order to ascertain appropriate restoration and reclamation programmes for the people in the vulnerable areas.

The 3-D visualization of the Etim Umana gully site as exemplified in Figure (4) enhances the examination of the area from different viewpoints. The 3-D model of gully site reflects a degree of dynamism. For instance, the headward migration yields relatively V-shape valley and continue to expand downward forming U-shape valley due to the effect of landslide and timescale. Furthermore, the topographic individuality of the concave to the almost constant slope (relief) is enhanced with respect to the dominance of the coastal plain sands deposits of the tertiary time, heavy rainfall attribute of the humid climate, and local geomorphology.

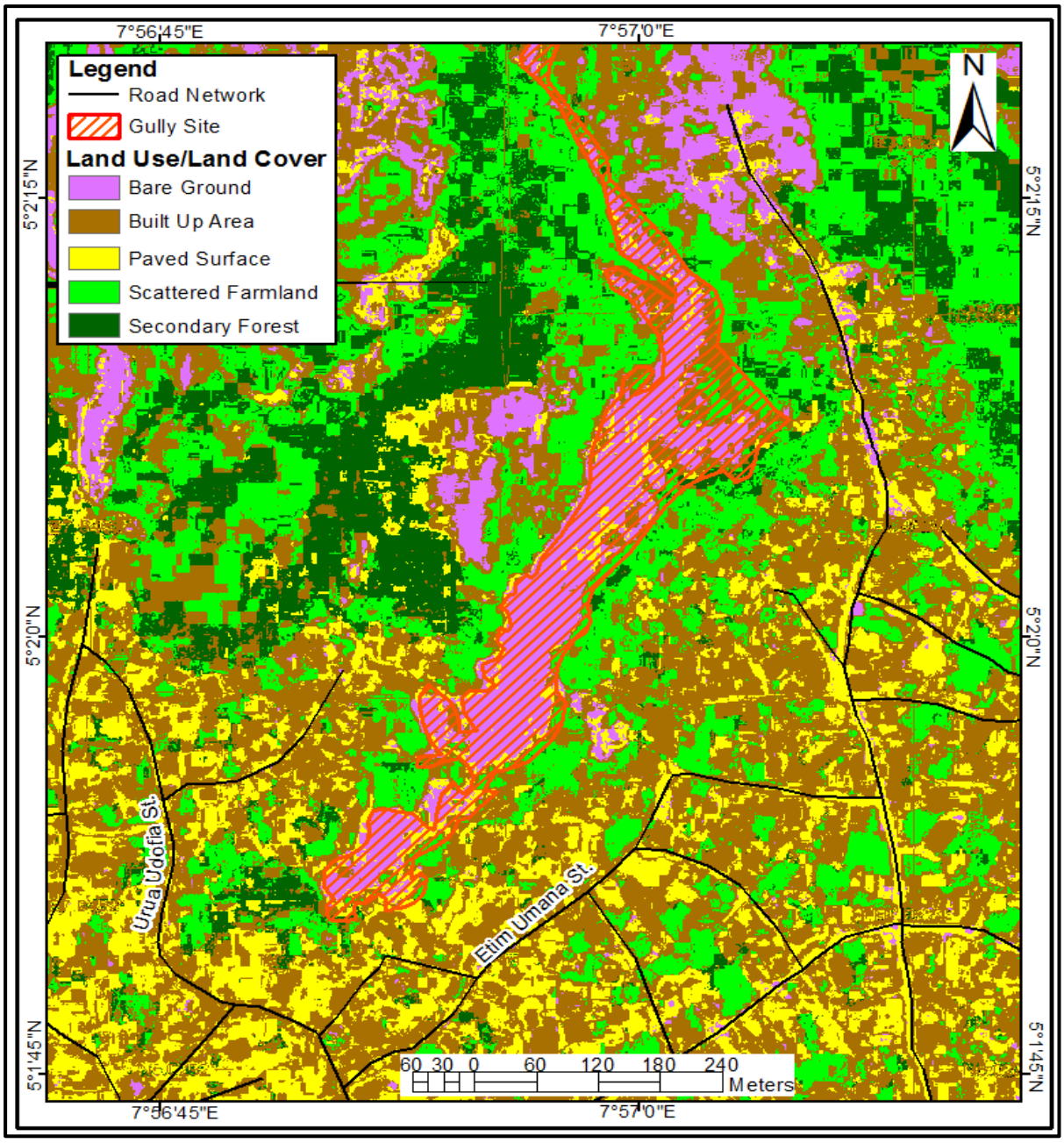

Figure 5: Land Use/Land Cover of Etim Umana Gully Site (Extracted from High Resolution Google Earth Imagery – USGS, 2016).

Table 4: Percentage Coverage of Land Use/Land Cover of Etim Umana Gully Site.

S/No	Land Use/Land Cover Class	Coverage Area (m^2)	% Coverage
1.	Bare Ground	107172.4	8.4
2.	Built Up Area	530525.1	41.6
3.	Scattered Farmland	280251	22
4.	Secondary Forest	143533	11.3
5.	Paved Surface	213237	16.7
	Total	**1274718.5**	**100**

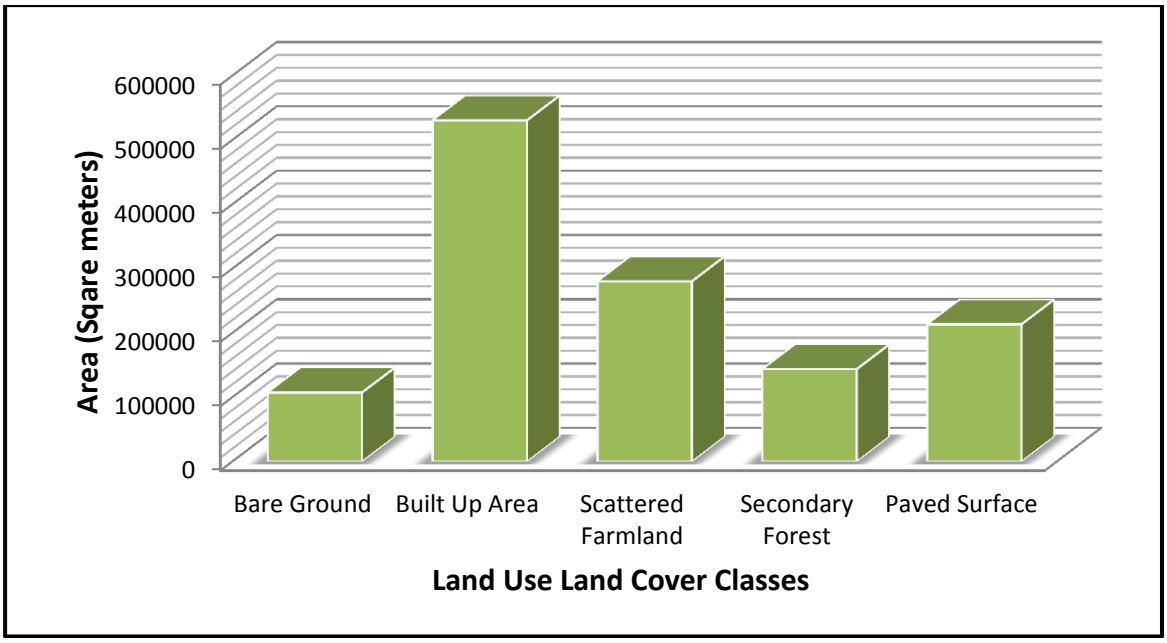

Figure 6: Land Use/Land Cover Chart of Etim Umana Gully Site.

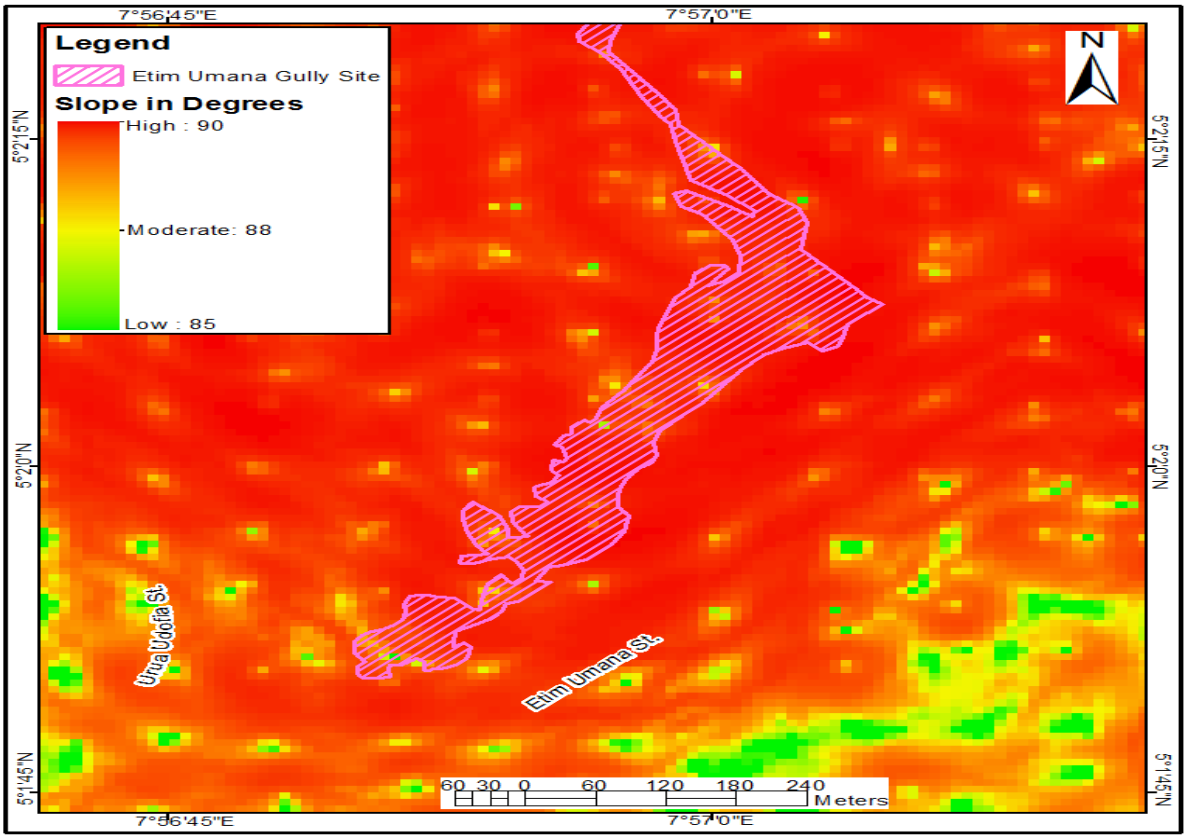

Figure 7: Etim Umana Gully Site showing varying Degrees of Slope.
Source: Extracted from High Resolution Google Earth Imagery – USGS (2016).

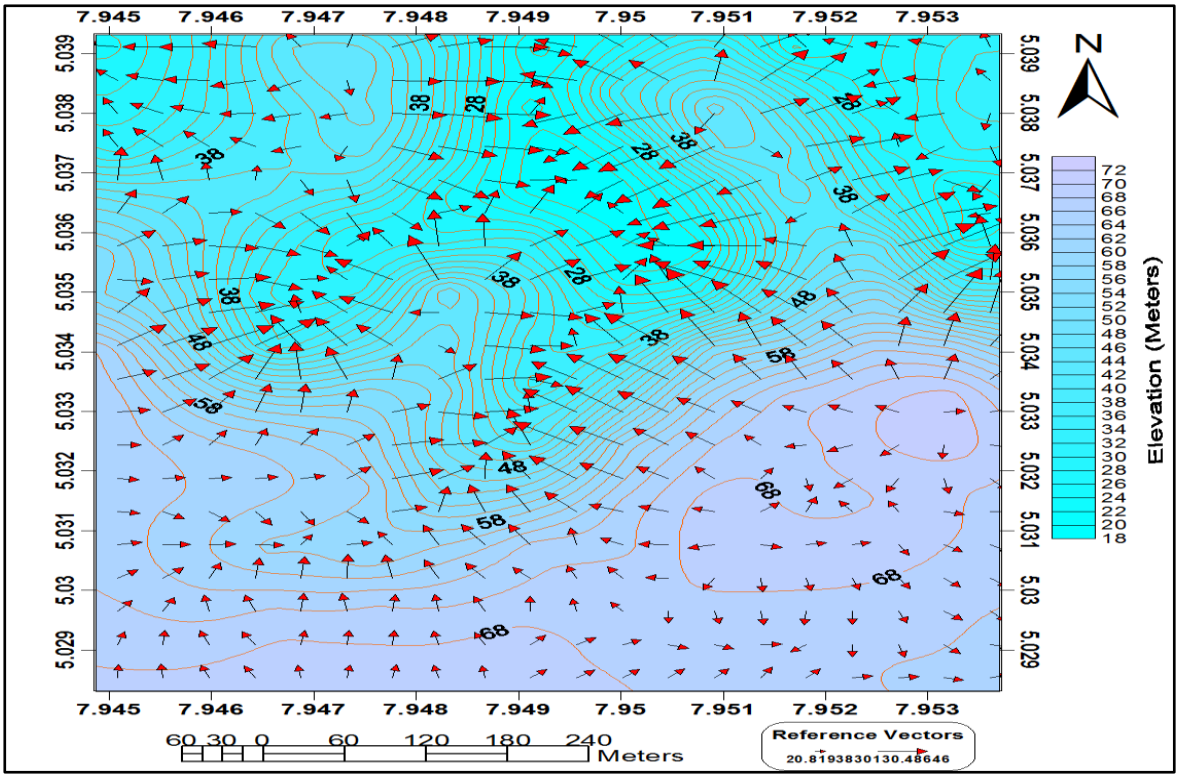

Figure 8: Vector Flow Map of Etim Umana Gully Site Overlaid on Filled Contour Map (Note: Longer arrows depict areas of steeper slopes).

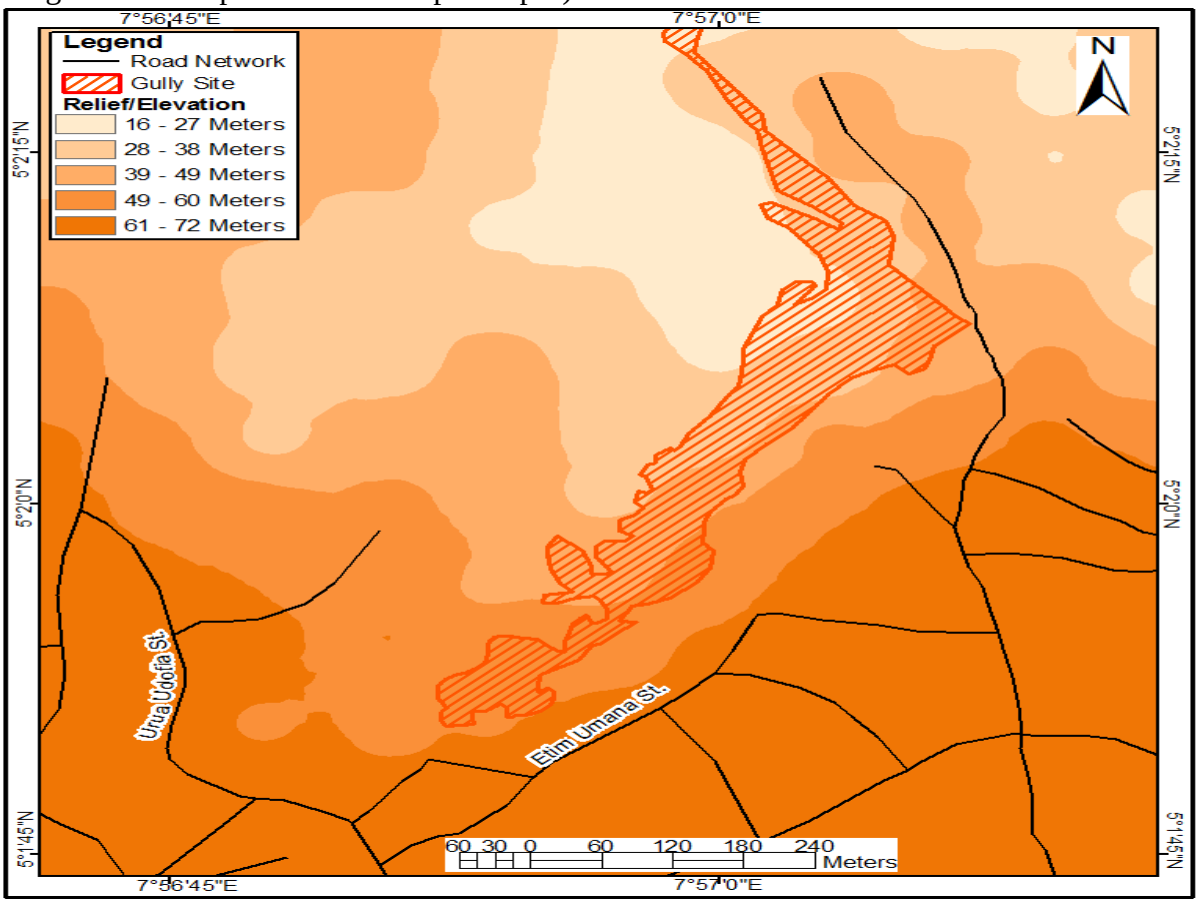

Figure 9: Relief of Etim Umana Gully Site.
Source: Reproduced from Extracted High Resolution Google Earth Imagery – USGS, 2016).

Modern geomorphologists, environmentalists, hydrologists, and engineers will find figures 7, 8, and 9 are useful in making an informed decision regarding roads, drainages, water resource development and use in the area. For instance, Figure 8 and 9 yielded that runoff generation from the heavily urbanized part of Eniong Offot area and beyond is diverted to the Etim Umana gully site and the flow is enhanced by the underlying natural relief as depicted in figures 8 and 9 respectively. The state of vegetation and its health is also essential since only a small proportion 11.3 percent of the area is cover by secondary vegetation, 41.6 percent is the build-up, and 22 percent is scattered cultivation (see Table 4). By implication, 80.3 percent of the study area is directly under pressure from anthropogenic interferences, thus suggesting that 80 percent of the gully erosion in the area is induced by human factors. Similar finding has been reached outside the study area [see 31].

5. CONCLUSION AND RECOMMENDATIONS

The discipline of geography especially geomorphology is rich in theory and concepts related to time, processes, systems, and landforms [8]. In this context, the processes (gully erosion and flow accumulation), system (land use/land cover), and landform (topographic features) have been formalized and assessed using geospatial technologies and modeling to establish the scientific basis of geomorphic hazard in the urbanized part of Etim Umana in Uyo, the Akwa Ibom State Capital. Visualization technique based on 3 digital elevation model has enabled effective communication about the land surface and its features, and allied properties in the coastal plain sands of Etim Umana gully site. Consequently, the results presented in this paper tend to provide a framework for future researchers to make comparisons with their results regarding the effect of topography, flow accumulation, and land use/cover change on gully development, as well as to select from the available management options to avert the impact of gully erosion in their domain.

Moreover, apart from providing the ground-truthing and more detailed information on gully in Etim Umana area of Uyo, the State Capital; the outcome of our field surveys have provided more prospects for GIS/RS professionals especially in this era where emphasis is on the sustainable management of ecological and environmental issues triggered by climate change impacts. Indeed, the [5] observation that the exploitative excesses of the people and government in the Humid Tropical environment need to be effectively regulated especially infrastructural development, urbanization, deforestation, and agricultural practices is quite instructive in this regards. Hence there are clear indicator of prolong human and environment interactions. Consequently, this paper recommends for the adoption of two groups of

approaches to mitigate the impacts and manage gully erosion in the Humid Tropics of Eniong Offot, Uyo.

First is the non-structural approach: To guide against further headward migration and lateral expansion of gully, appropriate conservational control notably zero tillage, afforestation, regulation of housing development using appropriate Town Planning laws, appropriate sanitation for enhancing drainage maintenance, and implementation of existing land use policy in the City. The identified options will not only mitigate the impact of gully erosion on the vulnerable people and property but also sustain sounds ecological relationship between man and his environment in the Etim Umana area of Uyo for a long period of time.

Second is the structural approach: There is need for the adoption of appropriate engineering control especially land reclamation and sand filling of existing gullies/rills, construction of high capacity-based drainage systems to regulate the high volume of surface runoff generated from the urbanized parts of Uyo to the nearby rivers, reinforcement of the existing drainages and clearing of obstructions along the channels. Such engineering works will stabilize the surface and avert gully expansion and landslide associated with it.

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