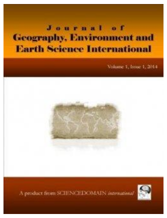

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An Assessment of Gully Erosion Progression and Vulnerability in Auchi Area in Edo State

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Authors' contributions

This work was carried out in collaboration between all authors. Author OUH designed the study, wrote the protocol, first draft of the manuscript and managed the literature searches, and analyses of the study performed. Authors ATA and EOE managed the experimental process and contributed in data acquisition and field work. All authors read and approved the final manuscript.

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ABSTRACT

Soil erosion is one of the serious forms of land degradation in the Auchi area in Edo State. Efforts have been made to control the phenomenon but these have met with limited successes. Part of the problem is a poor understanding of the dynamics of the phenomenon in time and space. The general objective of the study is to evaluate the dynamics of Auchi gullies in the past three decades. The primary data were collected with the use of Global Positioning System (GPS) receiver to obtain the coordinates of locations of gully sites in the study area while field work and measurements were carried out to determine the characteristics of the gullies. The secondary data include: 1:50,000 topographic map, soil and geology maps as well as multi date satellite imageries of the area including: LandSat TM of 1981 and ETM of 2001, 2006 and 2014. The geo-data sets were processed and analyzed using Geospatial techniques. The results of the computation reveal noticeable changes in the gully area between 1987 and 2014 with most area vulnerable to the gully progression. The study concluded that the gullies are active, expanding with alarming annual

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frequencies and positive magnitude of change, engulfing other land area with diverse use. This has increased the vulnerability of the entire area to gully erosion while adopted control measures are only successful in area with gentle slope and less hydro activity.

Keywords: Gully erosion; remote sensing; vulnerability; morphology; DEM.

1. INTRODUCTION

Soil erosion is one of the serious forms of land degradation in the world. Soil erosion is the detachment and displacement of soil particles from the surface to another location by agents of erosion such as water, wind, ice and gravity [1-9]. It continues to be a primary cause of soil degradation throughout the world and has become an issue of significant and severe societal and environmental concern [10,11], see soil erosion as "soil cancer" with a complex process affecting all aspects of man and his environment.

The adverse influences of soil erosion on soil quality, agricultural production, hydrological systems and the other features of the environment have long been recognized as challenges to human sustainability [3]. In southern Nigeria, gullies are the predominant ecological problems. A large proportion of the region's landmass is under severe gulling and landslide activities while a large proportion of its population is at a risk of losing farmland and therefore their livelihood [5].

The Auchi gully in Edo state has become monstrous in dimension and is causing fear and panic among the people living in the area. The gull system which was probably initiated more than four decades as a result of interrelated natural and adverse anthropogenic activity is still on the increase. Despite various efforts to stabilize the affected areas, the gullies are expanding in the expense of other valuable land resources.

The impact of gully erosion in Auchi on the local and socioeconomic land resources has further validated that soil erosion is not only prevalent within the rural or country side but also in urban environment [12,13,14,8].

In recent times, emphases have been placed on the need for proper inventory, mapping, dynamics and vulnerability study of gully erosion in urban areas. This informs the different stakeholders meeting on erosion held periodically. Examples are that of Abuja in June 2004 and the National workshop on erosion held at Owerri in 1986. Beside these numerous stakeholder meetings and workshops, individual research studies have also increased over time. For example, [3,2,14,8,15,16,17,9], and other prominent researches have examined soil erosion problems in different parts of southern Nigeria. [8,15] in particular focused on urban erosion in Auchi, Effon Alaaye and Benin City. He classified the gullies in these towns on the bases of their physiographic locations viz-, hill slope, road aligned and valley side gullies. However, despite the contribution from this study, little was done to explain the dynamics and vulnerability level of these gullies.

Over the years, the output of various studies has aided the provision of engineering responses by Government through the Ecological Fund Office and Program in order to stabilize and control the gullies. However, the success has been limited and sometimes difficult to pinpoint in many areas. Part of the problem is the limited understanding of the dynamics and vulnerability process of the phenomenal in terms of the rate and extent of expansions. This has resulted in the provision of mitigation measure without spatial evidence. Proper application of GIS and Remote Sensing techniques can assist in addressing these challenges. It can also provide necessary data and Information to aid the mitigation processes and other engineering measures. This precisely is what this study attempt to address.

2. STUDY AREA

The study area (Fig. 1) is located within Orle river basin between Latitude 7°7'1.52'' N and 7°1' 45.72'' N and Longitude 6°13' 7.615''E and 6°18' 22.618'' E. The study area falls within Etsako Local Government Area (LGA) which comprises of different urban and rural settlements, some of which include: Auchi, Iyakpe and Jattu.

The study area and its environs fall into the Guinea savannah vegetation belt. The vegetation here is prominently made up of sparsely distributed trees, herbs, shrubs, and grasses. The vegetation in this area is mostly

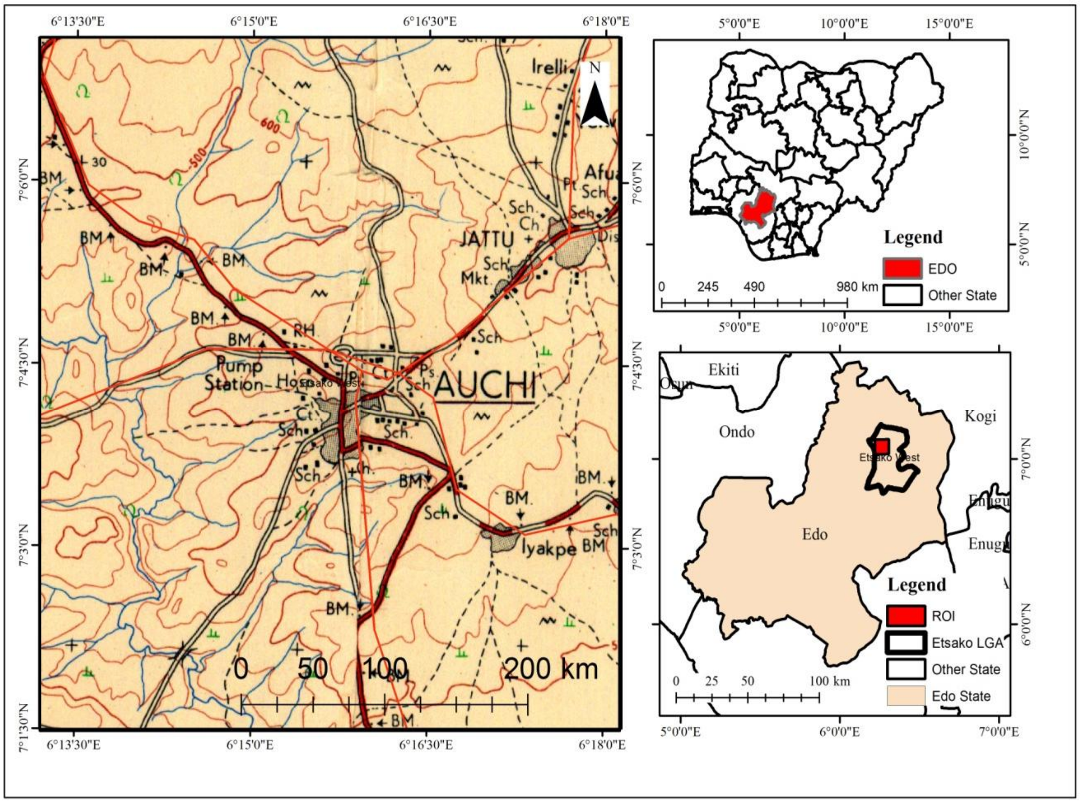

Fig. 1. Study area

secondary i.e. the natural vegetation is being altered and replaced with agricultural crops such as Maize, Groundnut, Cassava, Cashew, Mango, and Sugar cane [18].

2.1 Geological Setting

Based on regional geological maps of Southern Nigeria, Edo State occurs within the region underlain by the Sedimentary rocks of the Anambra and the Niger Delta basins which constitute part of the Southern Nigeria Sedimentary basins. The origin of the Southern Nigeria sedimentary basins are closely linked to the break-up of the South America and African continents in the early Cretaceous [17]. Stratigraphic sequence of the basin consists of the Santonian to Early Paleocene-Nkporo shale as the oldest unit. The overlying strata include: Mamu Formation, Ajali Sandstone, Imo Shale and Ameki Formation [19,20]. The study area falls within the Ajali strata.

The Ajali Sandstone also referred to as the False-Bedded Sandstone consists of mainly friable poorly sorted, whitish; fine to coarse-grained, non-fossiliferous sandstone. The sandstone is frequently cross-bedded and Sometimes contains thin interbeds of mudstone and occasional plant impressions. Fossils remains are rare within this formation and only fragments of plants and worms tracks recorded from the unit were used to date it as Maastrichtian.

2.2 Drainage and Climate

The area is drained by Orle River and few tributaries such as Omemi, Okami, and Awie River. These rivers have their source areas from both flanks of major water divide and contribute to the morphology of the gullies found within the region.

The Auchi area lies within the tropical region characterized by two climatic conditions namely, the rainy season and dry season. Early rainfall in some cases starts from January / February with full commencement of rainy season in March and ends in November of each year. The dry season lasts between four to five months. While the rainy season is characterized by heavy thunderstorm that lasts from April to October, the dry season extends from November to March with high temperature and dusty atmosphere known as the harmattan. The mean annual rainfall is about 1952 mm. The temperature pattern has mean daily and annual temperature of 28^0C and 27^0C respectively. The high conventional rainfall intensity and the concomitant large volumes of runoff are of significant environmental issue and an important factor in formation of gully in the study area.

3. METHODOLOGY

To achieve the objectives of the study, both primary and secondary data which contain both spatial and non-spatial attributes were used. The primary data which include: Ground Control Point acquired using hand held GPS, field measurements, 'ground truth' observation and oral interview were acquired via field work carried out in different stage of the study.

Beside this, secondary data including: Digital Elevation Model (DEM), 1.50,000 topographic, soil and geology maps were also utilized. Detail and characteristics of some of the above listed data are shown in Table 1.

3.1 Ground Truth Data

Ground truth data are vital references for supervised classification, accuracy assessment and validation. The acquisition of reference data involved collecting physical attribute information and observation of phenomena in the study area that can be sensed remotely. In carrying out the field work, transverse was set to enable organized acquisition of references coordinate, while the topographic map and false colour composite (FCC) image of the study area was carried along in other to tie points to the map and image and also to validate some unclear features on the image. These data were used to carry out supervised classification on the images covering the study area, and also imperative for general interpretation of obtained results.

3.2 Data Preparation

3.2.1 Study area delineation

To delineate the study area, the topographic map (Auchi, Sheet 266, at the scale of 1:50,000) covering the study area was geo-referenced (with RMS error of 0.0002). Subsequently, the Region of Interest (RoI) which lies between Longitudes 6^0 13' 00''E and 6^0 18' 0'' E and Latitude 7^0 1' 30''N and 7^0 7' 30''N covering the perimeter of the gully area and environs was marked-out. The mark out area was exported as shape file into a working folder from where it was imported or added into the different software as a layer. The marked-out RoI was also used to subset all the participatory thematic geo-referenced data set and images used for the project.

Table 1. Spatial data characteristics

S/n	Type	Format	Scale/Resolution	Path/Row	Sheet no.	Date	Source
1	Topography	Analogue	1:50,000		Auchi 266	1970	*OSGOF
2	Geology	Analogue	1:250,000		Lokoja 62	2004	*NGSA
3	Soil	Analogue	1:25000		301	1987	Wageningen Netherlands/1987
4	DEM	Digital	30 m				ASTER GDEM
5	LandSat TM	Digital	30 m	p189r55		1986, 2001	GLCF*
6	LandSat ETM	Digital	30 m	P189r55		2006	GLCF
7	LandSat ETM	Digital	30 m	p189r55		2014	GLCF

** Office of the Survey General of the Federation (OSGOF), Nigeria Geological Survey (NGSA), Global Land Cover Facility (www.glcf.umd.edu/data/landsat)*

3.2.2 Satellite image data preparation

The image was imported in Geo-tiff format. The generated frame marking the study area (RoI) was used to subset the satellite images. Band 4, 3 and 2 combinations was used to generate False Colour Composite (FCC) of the individual image. Further on, the colour composite band 4 (Near infrared band) was loaded for Red, band 3 (Red band) and 2 (Green band) were loaded for green and blue respectively. The band combination has been regarded as efficient and adequate when using LandSat and other similar image data to study land use/land cover, especially if it have to do with vegetation, farmland, water body, wetland, bare surface and built-up area [21,22]. The FCC image was trained using the supervised method based on the modified Land Use Land Cover (LULC) classification scheme of Balogun [23] and subsequently classified using maximum likelihood. They classified outputs were vectorized while the generated attributes was used for statistical analysis.

3.2.3 Thematic layer preparation

The thematic layers of interest includes: Contour, Drainage network, Soil, Settlement, Geology, Land use / Land cover and Road.

Analogue data such as topographic, geology and soil map containing the required thematic data set were scanned, geo referenced, subset and digitized into a personal geo-database which was created to store the needed thematic layers and enable spatial analysis. The process is shown in Fig. 2.

Outside the needed thematic feature classes, other surface terrain information was generated from DEM. This includes: Triangulated Irregular Network (TIN), contour (with Z attribute value), slope, steepest path and terrain profile. The Land use Land cover and its class statistics were generated from the classification of the FCC image covering the study area.

3.3 Evaluating the Rate and Trend of the Gully Erosion for the Past Three Decades

The classified classes, particularly the gully and built-up areas were post classified and converted into vector shape file, and were overlaid, visualized in order to appreciate the changes in surface area and morphology. The class statistics of each year of interest were used to generate statistical chart. The end products of this process generated change detection and gully maps of each year of interest, their class statistics and statistical chart depicting the noticed changes.

3.4 Model Building and Output Analysis for Mapping Vulnerability to Erosion Damage Using Multiple Spatial Criteria

The gully erosion vulnerability model was mapped out using grid method and weighting analysis of influential factors of erosion. The grid model approach is a weighting process or weighted sum model, in which weights for each layers are assigned according to its significance in promoting or reducing erosion. The applied equation is defined as follows:

$$Gv = S_w S_i + LULC_w\, LULC_i + SLP_w\, SLP_i + DG_w\, DG_i + Elv_w Elv_i + Gl_w Gl_i + Dst_w Dst_i$$

Where, Gv is the gully erosion vulnerability index, S is the soil index, LULC is the Land use Land cover index, SLP is the slope index, DG is the distance to gully index, Elv is the elevation index while Gl and Dst are geology and distance to stream index respectively. The subscripts ‘w’ and ‘I’ refer to the weight of the theme and the rank of individual features of a theme respectively. Ranks assigned to each participatory parameter influencing gully erosion vulnerability are given in Table 2. For the maximization case, the best alternative is the one that yields the maximum total performance value [24,25].

Table 2. Weight assigned to the parameters influencing gully erosion vulnerability

Criteria layers	Weighted percentage (%)
Distance from gully	15
Slope	20
Soil	10
Geology	10
Elevation	25
Land use/land cover	10
Distance from stream	10
Total	100

Furthermore, each layer is classified into a number of classes with each having its own specific weight. The weight was not arbitrary assigned but generated via per review of each layer’s importance and influence on the occurrence, dynamics and level of vulnerability of the gully. These layers were assigned a weight in accordance to their contribution to development of the erosion which must sum up to one hundred present (100%). The assigned weight was multiplied by it constant class which is also ranked (or valued), after which, the critical index for each cell of the overlaid grid was obtained by the addition of all the computation results of the cell for each layer. The assigned rank to the attributes of the selected criteria (See Table 3) was adopted based on the Analytical Hierarchy Process (AHP) by Saaty [26], and modified in line with gully erosion vulnerability as in [27], [28,29]. Using specific query and Geo-statistics operation, the critical index value of each cell which ranges from 0 to 100 was analysed and also interpolated to produce the vulnerability assessment and severity classification. Cell with critical index range of 0 to 30 was rated fairly vulnerable while others ranging between 31 and 60 and 61 to 100 were classified as marginally and highly vulnerable respectively. The process is shown in Fig. 3.

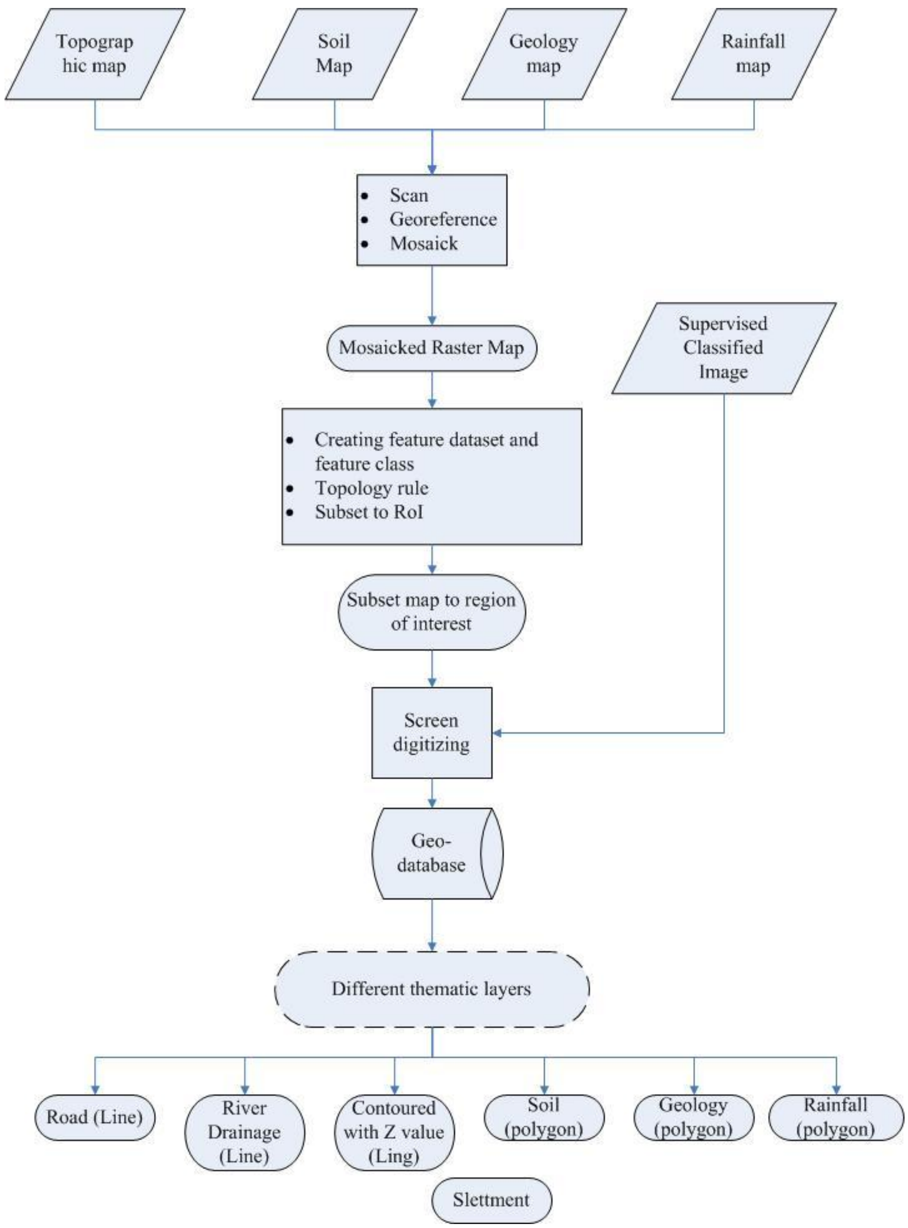

Fig. 2. Thematic layer preparation flowchart

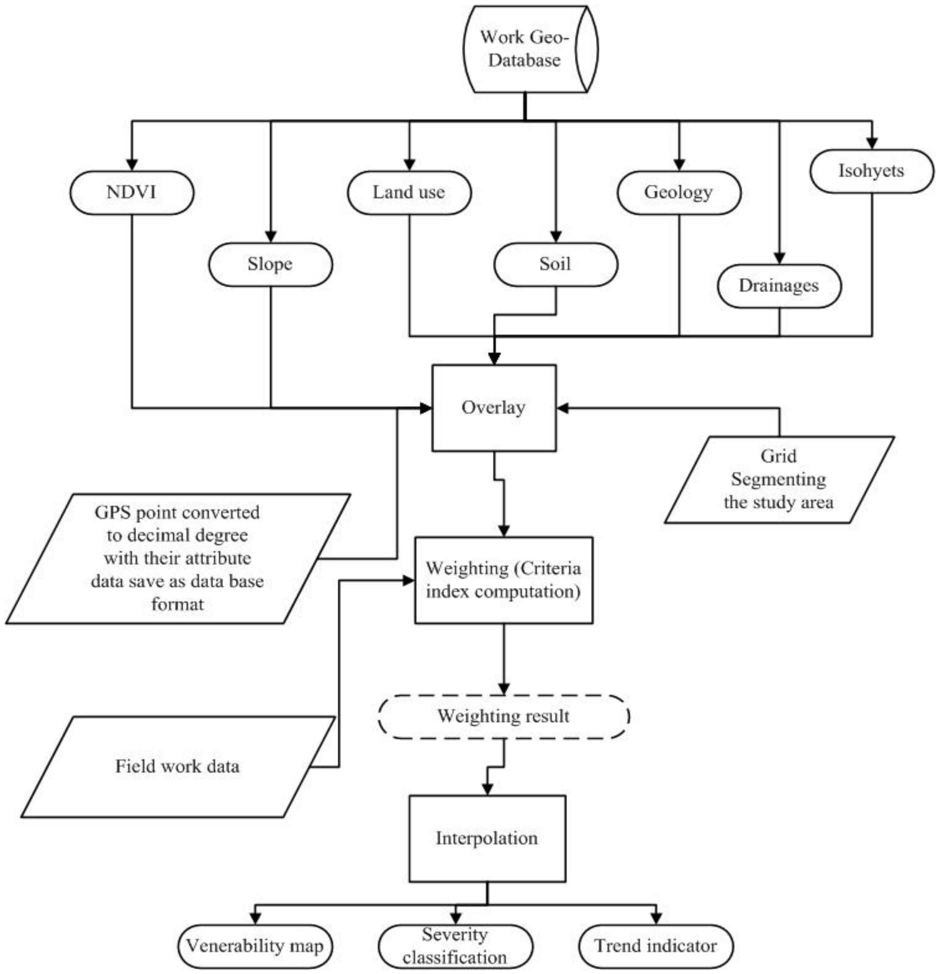

Fig. 3. Flowchart of the multi criteria analysis

Table 3. Ranks assigned to the parameters influencing gully erosion vulnerability (modified after)

Theme	Weight assigned	Features attributes	Rank assigned
Elevation	25	>436 m	5
		355-436	4
		270-355	3
		179-270	2
		< 179 m	1
Land use / land cover	10	Built up	5
		Agricultural land	4
		Land with scrub	3
		Sand deposit	3
		Water body	2
		Fallow land	1
Slope	20	>72°	5
		57-72	4
		39-57	3
		14-39	2
		<14°	1

Theme	Weight assigned	Features attributes	Rank assigned
Soil	10	Clayed loam	1
		Sandy loam	2
		Loamy	3
		Loamy sand	4
Distance from Gully	15	<50 m	5
		>50 m<200 m	4
		>200 m<400 m	3
		>400 m<1 km	2
		>1 km	1
Distance from stream channel	10	<50 m	5
		>50 m<200 m	4
		>200 m<400 m	3
		>400 m<1 km	2
		>1 km	1
Geology	10	Sandstone	1
		Alluvial	2

4. RESULTS AND DISCUSSION

The different satellite imageries which include; Landsat TM of 1986 and ETM of 2001, 2006 and 2014, acquired within the same anniversary date of December and January, were classified with ENVI 4.7 with an average Kappa coefficient and overall accuracy of 0.9198 and 92.7% respectively (See Table 4).

Table 4. Image classification kappa coefficient and overall accuracy of different image used

Year	Kappa coefficient	Overall accuracy (%)
1986	0.9393	94.9007
2001	0.9671	97.2917
2006	0.8965	90.147
2014	0.8763	88.4621
Average	0.9198	92.70038

The main categories of land use / land cover classification scheme developed for the study are: Built up, wetland and Riparian vegetation, water body, gully area and natural vegetation. Apart from the above classes, other land uses in the study area include: open space (bare surfaces) and cultivated land etc. from these classes built-up and the gully area were extracted and converted to vector. Other thematic data such as elevation, slope, drainage and geomorphology where also generated in order to establish better understanding of the gully process.

The identified stream pattern is dendritic with a fourth order degree of stream branching which characterizes the area to be homogenous, with little variation in the resistance to the flow of water. The first order stream is within the gully head which is synonymous to the basin upper course, while the third and fourth orders are within the middle and lower course of the gully area.

The physical characteristics of the gully were also assessed during the field work. The area is characterized with sequence of poorly consolidated sand underlain by thick shale and sandstone formation; with films of clay layers indicating clear spatial mixture of different formation. The study area, are predominantly lateritic with thin clay stones and silt stone bands, lenses and laminations. The sand is poorly-sorted, cross-bedded and medium to coarse grain, this combination is clearly visible from the exposed profile on some deep cut within the study area (See Plate 1). The unconsolidated nature of this profile with little disturbance, water infiltration and the influence of slope gravity cause the soil to erode (See Plate 2). Down slope, the deposits also exhibit well developed patterns of alternating cross-bedded sands and layers of dark-grey shale with a visible stratified arrangement intermix with eroded materials within deep undercut.

The geomorphologic relief, slope and elevation analysis are important to this study. With the elevation analysis and its output such as slope, steepest path index, line of sight, elevation profile graph, 3-Dimension (3D) rendering and 2D thematic layer draping, the gully area is better appreciated. This enabled the appropriate delineation of the gully area which subsequently provided the base area for gully area change detection.

Plate 1. Exposed profile on some deep cut along the gully channel

Plate 2. Eroding building along the gully advancement path influence by slope

The elevation profile graphs are cross sectional chart with elevation plotted against distance; this gives terrain explanation of a selected line of sight over a set distance. The measured profiles of the gully (see Fig. 4) show that the gully exhibits regular steep slope and V-shaped valley channel indicating prevalent influence of the stream network laterally flowing through the gully.

4.1 Gully Area Dynamics

The gully area dynamics between 1986 and 2014 was analyzed and computed from the extracted gully and built-up areas of 1986, 2001, 2006 and 2014. The area value was analyzed for magnitude and frequency of change. The computation results are shown in Tables 5 and 6 while the area visualizations are shown in subsequent section.

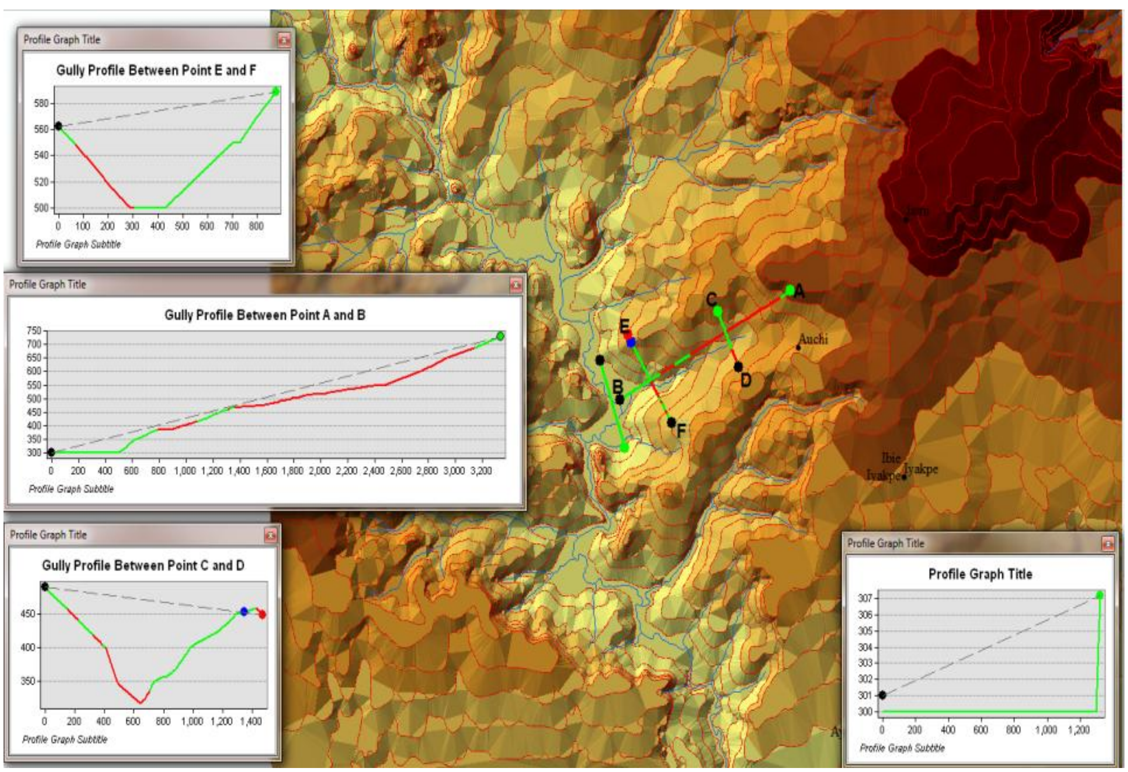

Fig. 4. Measured profiles of the gully

The average area of the gully is 0.63 km^2. Table 5 shows that in 1986 the gully area occupied 0.48 km^2 representing 48.33 ha of land area. In 2001 and 2006 the gully area occupied 0.46 and 0.52 km^2 respectively, representing 46.1 and 52.47 ha respectively. While in 2014, the gully area occupied 0.56 km^2 representing 57 ha of land area.

Table 6 presents the magnitude of change of the gully area in terms of land gained and lost and the annual frequency of change over the study period. The results of the computation reveal noticeable changes in the gully area between 1987 and 2014.The gully area decreased from 0.483 km^2 in 1987 to 0.461 km^2 in 2001 with -0.0223 km^2 negative magnitude of change representing the land loosed by the gully to other landuses (mostly farmland and built up area). Between 2001 and 2014 there was an increase in the gully area from 0.461 to 0.524 km^2 with 0.12 km^2 magnitude of change in 2006 and increased to 0.57 km^2 in 2014 representing land gained by the gully. The land gained from gully to other landuse classes between 1987 and 2001 is due to combined reclamation and mitigation measures put in place to fight the gully spread. In reversal, between 2001 and 2014 there was a gradual increase of the gully area from 0.461 to 0.57 km^2 representing 23% increase and 0.11 km^2 magnitude of change indicating land gain to the gully and land lost from other land use / land cover classes.

Further computation shows that annual frequencies of change which represent the total gully area change for a given year is -0.0016 km^2 between 1987 and 2001, representing 0.16 ha of land. 0.01274 km^2 representing 1.274 ha was recorded between 2001 and 2006 while 0.313 ha was recorded in 2014. This shows that an average of 0.313 ha of land was lost annually to gully between 1987 and 2014. In addition, the built-up area is also in the increase with its growth morphology affected by the gully progression. Presently, the choice of land and development within Auchi is strongly determined by the gully process. Outside computation of the gully area to ascertain attribute dynamics over time, comparative visualization and overlay operation was also applied to provide Geo-visual evidence of the identified changes, see Figs. 5 and 6.

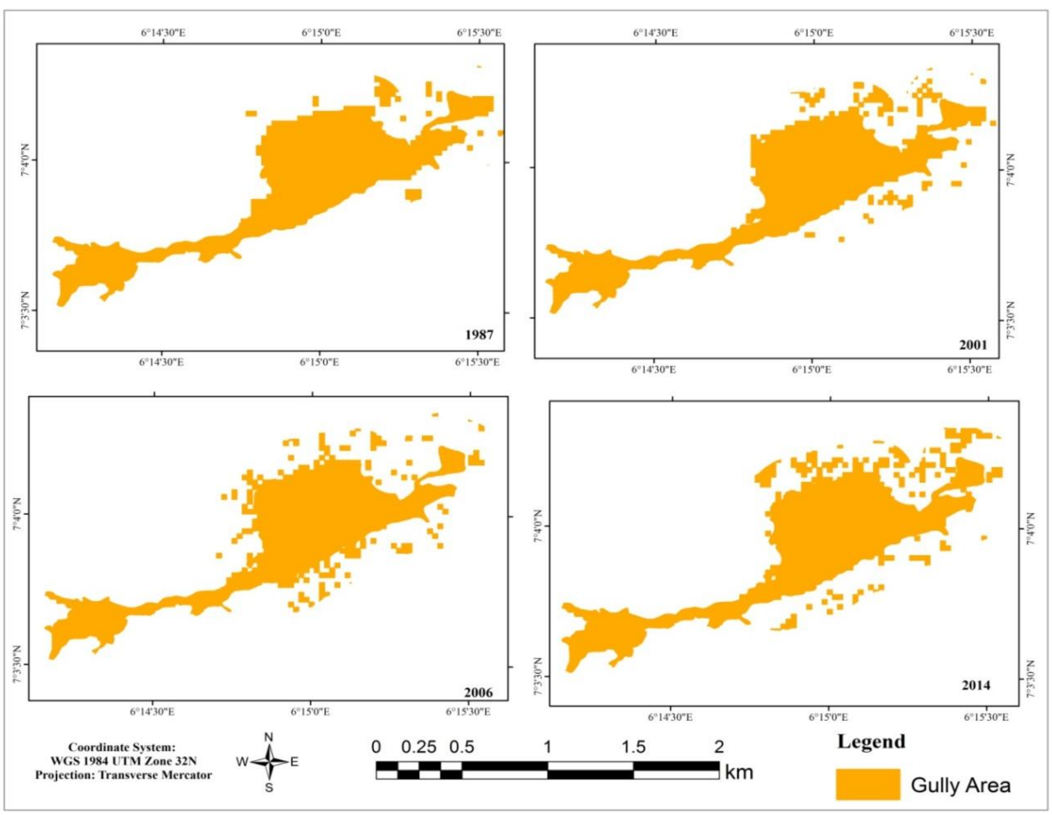

Fig. 5. Gully areas between 1987 and 2014

Fig. 7 shows the vulnerability map of the area after the multi-criteria analysis. This map reveals that about 25% of entire study area is Highly Vulnerable to gully erosion, while the remaining areas were labelled Fairly Vulnerable and Marginally Vulnerable. To further validate the result, the vulnerability map was draped on the 3D visualization of the gully area. The output shows that areas labelled H.V are devastated areas within the gully corridor and areas of deposition down slope. The other areas labelled Vulnerable are within High elevation and stabilized gentle slope.

Table 5. The computation results of gully area between 1970 and 2010

Year	Area (m2)	Area (km2)	Area (ha)
1987	483300	0.4833	48.33
2001	460545.75	0.461	46.1
2006	524700	0.5247	52.47
2014	567900	0.5679	56.79

Table 6. Magnitude and annual frequency of change of the gully

Year	Area (m2)	Area (km2)	Area (ha)	Magnitude of change area (ha)	Magnitude of change (ha) between 1987 and 2014	Annual frequency of change	% of change
1987	483300	0.4833	48.33				
2001	460545.75	0.461	46.1	-2.23		-0.16	-4.6
2006	524700	0.5247	52.47	6.37		1.274	13.8
2014	567900	0.5679	56.79	4.32	8.46	0.313	8.23

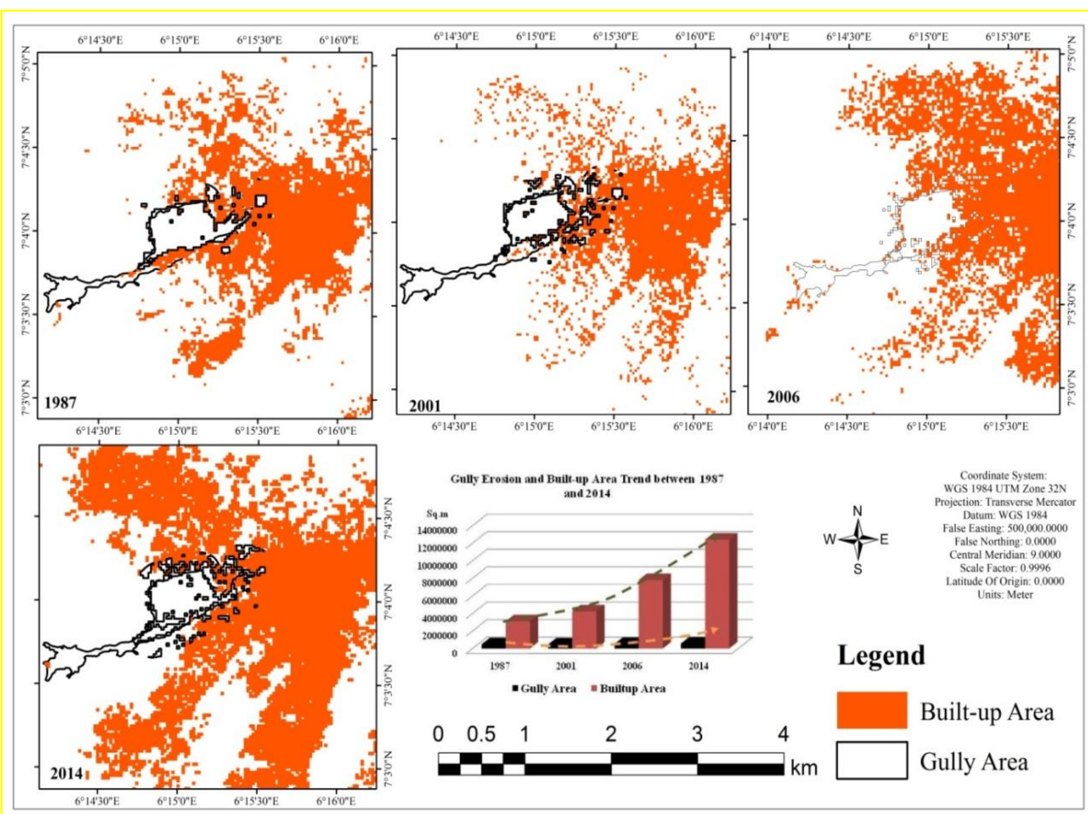

Fig. 6. Gully and built-up areas distribution and growth pattern between 1987 and 2014

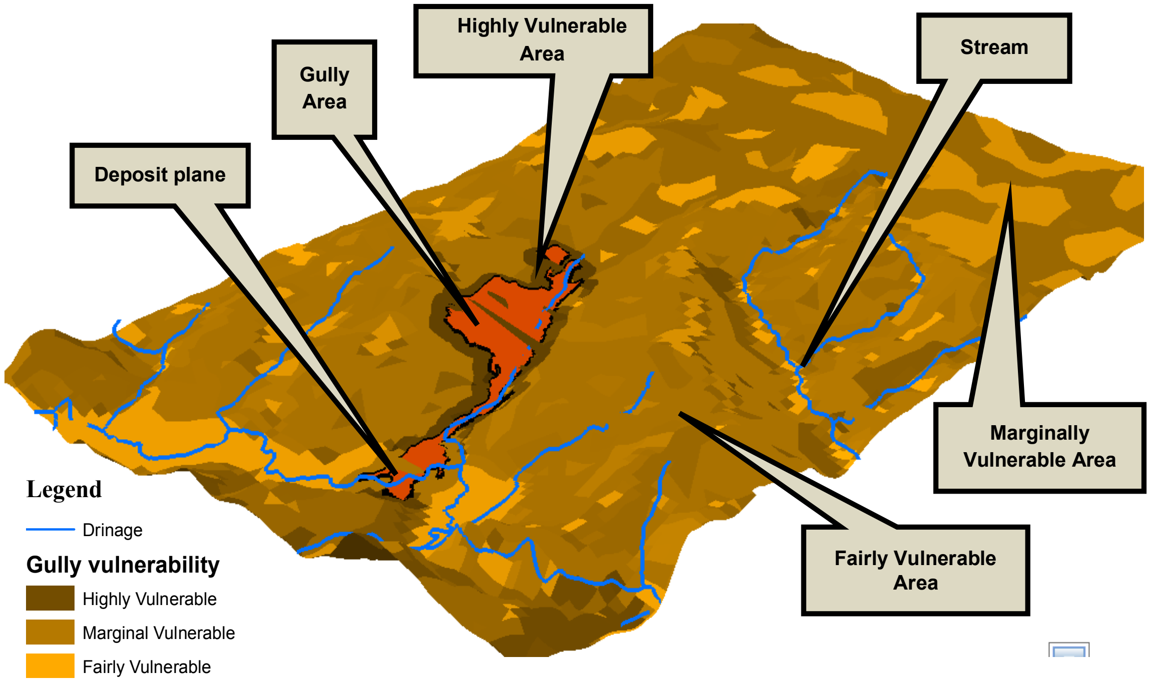

Fig. 7. Vulnerability map of the study area draped on the 3D terrain layer

5. CONCLUSION

This study has narrowed its aim at evaluating the dynamics of Auchi gullies over the past three decades and assessed the vulnerability of the areas to gulling using geospatial method and multi-criteria analysis, which involved the integration of different thematic data and field coordinate with uniform spatial reference. The result of the study show that the gullies are active, expanding with alarming annual frequencies and positive magnitude of change engulfing order land area with diverse use. This has increased the vulnerability of the entire area to gully erosion while adopted control measures are only successful in area with gentle slope and less hydro activity. The settlements growth pattern and morphology are also affected by the dynamics of the gully. The resultant vulnerability map and the methodology employed in this study will possible serve as a guideline for gully erosion management. Spatial related changes are constant, therefore proper management and planning with geospatial technique should be enacted and enforced to manage and mitigate the expansion of gully erosion.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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