Journal of Scientific Research & Reports
4(3): 253-264, 2015; Article no.JSRR.2015.029
ISSN: 2320–0227

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Applying Satellite Remote Sensing and GIS Tools in the Study of Gully Erosion

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Authors' contributions

This work was carried out in collaboration by all authors. Author GTA wrote the design of the work, provided the materials for and led the field trip as well as wrote the first draft of this manuscript. Author JDN converted all analogue data into digital format and interpreted the Satellite Remote Sensing/GIS processed images. Author MO did the literature review for this work and was a very useful hand in the field. All authors analysed the results, read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2015/12753
Editor(s):
(1) Chun-Gang Zhu, School of Mathematical Sciences, Dalian University of Technology, China.
Reviewers:
(1) Lazarus A. Mbaya, Department of Geography, Gombe State University, PMB 127, Gombe, Nigeria.
(2) Yahya Farhan, Department of Geography. The University of Jordan, Amman, Jordan.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=712&id=22&aid=6501

Original Research Article

Received 16th July 2014
Accepted 18th August 2014
Published 11th October 2014

ABSTRACT

Aim: Gully erosion is the most obvious form of soil erosion in southeastern Nigeria mainly because of the remarkable impressions the gullies make which are also visible manifestation of the physical loss of land due to erosion. In the literature, there are various accounts of the number of gully sites in Imo State as well as the likely causes of the gullies. The very great depths of some of these gullies and the failure of some control measures strongly suggest that they may actually result from interplay of exogenic (such as weathering) and endogenic (tectonic) forces. The aim of this study therefore was to integrate satellite remote sensing data of the study area with GIS to highlight gully erosion hotspots as well as create a database of erosion sites and attributes. Development of 3D – Digital Terrain Models (DTM) of the area for the purpose of studying topography, characteristics and patterns of gully sites. Integration of the DTMs with processed satellite images to generate data for slope analysis and other spatial attributes of gullying.
Study Population: Gully Erosion profiles in Imo State, Nigeria.
Duration of Study: 24 months.

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Methodology: SRTM data and SPOT 5 satellite imageries of Imo State were studied and utilizing the opportunities offered by Remote Sensing and GIS. Google earth images and ground truth were used to confirm gully spots and maps were then generated with vital spatial datasets on the spatial distribution and development of gully erosion in Imo State.
Results: The Digital Elevation Model (DEM) data revealed a correlation of low values with areas of high gully erosion susceptibility. There is also a relationship between the drainage, lineament density and gully erosion in the study area. Gullies are concentrated in the northern western section of Imo State and area underlain by the transition zone between Benin Formation and Bende-Ameki Formation while the Northeast flank though on the same relief height is not that affected because of the shale component of the soil, however, this areas is heavily dissected by streams in dendritic pattern. Finally, a correlation was found to exist between the lineament trend and the strike directions of most gully erosions in the area indicating structural control of gully initiation in the area.

Keywords: Gully erosion; lineament; drainage; relief; GIS; satellite remote sensing.

1. INTRODUCTION

Soil erosion is a worldwide phenomenon which ravages large areas of land particularly in high rainfall or windy locations. It has been documented from the earliest of times as severe environmental hazard [1,2,3]. Recent estimates suggest that about seven per cent (7%) of the world's topsoil is lost yearly to erosion in all ramifications, in fact, the World Resources Institute claims that Burkina Faso loses 25 tonnes of soil per hectare per year (4) Other reports on this issue reveal that Ethiopia loses 42 tonnes, Nepal 70, Decan Plateau (India) 100, and Loess Plateau of North China 251 tonnes [4]. Also, the soil survey of England and Wales reported that 44 per cent of arable soils in the United Kingdom, an area once considered not to be under threat, are now at risk. It has also been estimated that 20 million hectares of agriculturally usable land worldwide is lost to erosion annually [2]. In southeastern Nigeria, gully erosion is responsible for the destruction of transportation routes and communication systems, degradation of arable land, contamination of water supply, isolation of settlements and migration of communities [5,6,7,8]. The area is associated with phases of high intensity rainfall which combines with non-cohesive soil structure to make erosion one of the most serious environmental hazards in the area. Dense gully networks now occupy many catchments in the region and new lines of flow have occurred in response to anthropogenic activity. Their occurrence has caused severe loss of soils, particularly for agricultural productivity [9,10].

In Nigeria, the problem of gully erosion has formed a subject for serious consideration since the early 1920s, it has continued to attract wider attention than before and has formed a topic for spirited speeches by legislators, government functionaries at all levels, the academia and private individuals [11]. Several studies have also been carried out over the decades on the problems of gully erosion in south eastern Nigeria for example [7,12,13,14,15,16]. Despite the several studies conducted on the occurrence of gully erosion in the South East vis-a-vis Imo State, the number of gully erosion sites in Imo State can best be described as "wild –guess". According to [18] over 1,970 gully erosion sites occur in Imo and Abia States, while [19] reported 450 [20] estimated 2,500 active gully erosion sites in Imo State alone. These conflicting figures call for serious concern in planning and budgeting for erosion control. On the factors of gully erosion, there is no consensus, many researchers conclude it is purely a hydrological effect (surface runoff); others conclude it is the nature of the soil [16,17,21,22]. The effects of groundwater and hydro-geotechnical factors as possible additional factors especially in the most dangerous spots where mass earth movement is the dominant mechanism has also been highlighted by [23], that active gullies are located mostly at the discharge areas of groundwater systems and river banks as well as Hillside and besides road drainages have also been reported in the literature

Generally, the growing interest in studying gully erosion reflects the need to increase our knowledge on its impacts and controlling factors that vary under a wide range of causes [24] and this has led to the development of numerous stochastic and process-based models, with increasing emphasis on the use of the Geographic Information Systems (GIS) and Satellite Remote Sensing (SRS). According to [25], technological advancements have brought about new ways through which large volumes of geographic information can be analysed and displayed faster and better; thereby producing a system with a set of tools for collecting, storing, retrieving, transforming, and displaying spatial data from the real world for a particular set of purposes. This system is known as Geographic Information System (GIS). The term Geographic Information System (GIS) has come to mean a tool, a product, a technology and a science. As such, the term involves difference perceptions depending on whether the viewpoint is that of the software developer, the system marketer, the data provider, the application specialist or the academic researcher, among others. For this study, GIS is defined as a computerized tool for capturing, storing, checking, integrating, manipulating, analysing and displaying data, which are spatially referenced to the earth. Essentially, it is a computer based system that uses spatially referenced or geographic data, and carries out various management and analysis task on these data including their input and output.

The aim of this study therefore is to integrate satellite remote sensing data of Imo State, Nigeria such as SRTM and SPOT images with GIS to highlight the gully erosion hotspots as well as create a database of erosion sites and attributes as well as highlight the strength and the weaknesses of the use of satellite remote sensing data. Also identify the drainage and lineament patterns and their relationship and contribution to the development of gully erosion in the study area.

1.1 The Study Area (Imo State, Nigeria)

The study area (Imo State) is located in the South eastern section of Nigeria and is one of the 36 States of the Nigerian Federation, with Owerri as its capital and largest city. It lies between latitude 4°45'N and 5°50'N, longitude 6°35'E and 7°30'E. It occupies an area of about 5,329.17 sq. km with a Population of 2,938,708 [26]. The State derives its name from Imo River, which takes its course from the Okigwe/Awka upland. Imo State is located between the lower River Niger and the upper and middle Imo River. The Area experiences the humid, semi-hot equatorial climate. The rainfall is heavy, with an average annual rainfall of 2000-2400 mm and an average number of 152 rainy days particularly during the rainy season (April–October). Rainfall distribution is bimodal, with peaks in July and September and a two weeks break in August. The rainy season begins in March and lasts till October or early November [27].

Geologically, Imo State is underlain by the sedimentary sequences of the Benin Formation (Miocene to recent), and the Bende-Ameki Formation (Eocene). The Benin Formation is made up of friable sands with minor intercalations of clay. The sand units are mostly coarse-grained, pebbly, poorly sorted, and contain lenses of fine grained sands. In some areas like Okigwe, impermeable layers of clay occur near the surface, while in other areas, the soil consists of lateritic material under a superficial layer of fine grained sand. Imo State is characterized by three main landform regions: a highland region of elevation of 340m in the northern sections covering Orlu, Ideato, Okigwe and Ihitte Uboma local government areas. The main stream - Orashi (Ulasi) River, rises near Dikenafai in Imo State, flows northward to Ozubulu in Anambra State and then turns round in a wide loop and heads for the Atlantic Ocean. The second main landform region is midway between the north and the southern section of the State and is of a moderate elevation of between 175m - 240m above msl. They provide elevated, well drained topography with few isolated undulating topography and valleys. The third landform region is the lowland/plains lie South of the high and moderately elevated highlands; the Orashi River plain, south of Oguta, and the inter-basin area between Oguta and Egbema.

The main rivers draining the State are Imo, Otamiri, Njaba, Orashi, Nwaorie, Oraminiukwa and a couple of other smaller streams all of which have very few tributaries. These rivers constitute the five sub basins in the Imo-Anambra River Basin draining an average area of about 3,777.76km^2 of Imo State. Imo River flows through the area underlain by the Imo Shales, other rivers rise within the coastal plain sands. The width and depth of majority of these rivers ranged between 10m to 350m and 0.5m to 2.8m respectively. The Drainage Density is medium texture with a D_d of 0.21, Stream frequency is 0.02 and the drainage intensity is 2.00. Oguta Lake and Lake Abadaba also constitute significant water body in the State.

2. MATERIALS AND METHODS

A 1975 Administrative map of Imo State (scale 1:200,000) was acquired from the Imo State Ministry of Land and Survey. This map served as base map. From the Regional Centre for Training in Aerospace Survey (RECTAS) Ile Ife, Osun State; SPOT 5 satellite imageries of 2012 with a resolution of 10m and Shuttle Radar Topography Mission (SRTM) data of 2010 with a resolution of 30m were acquired. The base map (which was in analogue form) was scanned and converted into raster image and imputed into ArcMap GIS version 9.3 environment, geo-referenced to a universal transverse Mercator (UTM) grid to allow compatibility and comparison with other data sets to enable the extraction of Imo from the rest of Nigeria. Various data enhancement techniques such as linear enhancement and image enhancement operations were carried out for better visual interpretation, to reduce noise distortion in the image prior to a multi-band image classification and to detect line features in the satellite image to aid structural interpretation. Gully sites in the area were identified and characterized, the pattern of spread of gullies was mapped using image classification; accuracy was assessed using overlay technique including Median filtering for smoothening homogeneous areas of the image, Contrast Manipulations to reduce cloud cover and haze over the image, Laplace Filter operator to sharpen the image Line and Edge enhancement operator to highlight all linear features, non gully features eliminated by applying thresholds derived from known gullies, On-screen measurement of gully parameters such as areas, lengths, widths and perimeters. Various imageries and maps were then produced in order to determine the actual numbers and location of gully erosion sites in Imo State, the various watersheds and their drainage pattern as well as relief maps were also generated from this exercise.

3. RESULTS AND DISCUSSION

Figs. 1 – 8 are maps generated from the above exercise. Fig. 4 shows that there are a total of 72 gully erosion sites in Imo State; however, a “ground truth” survey of the area show that some of the features which were captured as gully erosion sites are actually sand excavation ponds and borough pits (Appendix 1 is gully morphometric of the study area). This clearly indicates that contrary to the various number of gully erosion sites cited in literature, the total estimated number of gully erosion sites in Imo State may not be more than 100. Fig. 5 indicates the area covered by each gully in Imo State. This makes it possible to determine the total area coverage of the gully erosion sites vis-à-vis the total land cover of Imo State.

Figs. 6 and 7 show the number of gully erosion sites less than 100m to roads and streams/water bodies. The deduction from this shows that road networks and associated poorly designed drainage systems together with the soil types of the zone are key factor that should be considered seriously as causing erosion in the State. Fig. 8 is the digital elevation model of Imo State. The DEM is employed for structural geologic and tectonic interpretations such as locality faults, drainage pattern, geomorphology, lineaments and the boundary between geologic units, etc. The DEM of the study area shows the elevation differences and a quick estimation of the geomorphology of the area. From the DEM map, the northern area is characterized by a rugged topography, while the southern area is purely a lowland plain. The difference in elevation of the area is not consistent. The north western part of the area is on a high elevation ranging from 240-340 meters which is the highest peak in the area, the central part is between green and yellow with an average elevation of 175-240 meters above sea level and it is observed to be trending NW-NE. The elevation of the area increases from south to north and characterized by low hills with steep slopes which when correlated with the intense rainfall can be a causative factor of gully erosion in the area

The dendritic drainage pattern of the area trends in the NE-SW direction (Figs. 7 and 8) shows a homogeneous, uniform soil and rock materials mostly in soft sedimentary rocks and old dissected coastal plains. The dendrite pattern reveals a lithological, structural and topographical homogeneity of the study area. This occurs on homogenous gentle, uniformly sloping sedimentary surfaces whose main collector streams may indicate a fault or fracture. The geological interpretation of the satellite imagery revealed a number of lineaments and mega- lineaments over 15km in size trending in the NE-NW, much less in NW-SE & N-S. The trend surface analysis in relation with the interpreted lineaments show that the dominant structural trend is in the NE-NW direction which corresponds to the major lineament trend of the Imo-Anambra basin. This also shows that the area has a rugged topography and it is partly deformed by tectonic activities. The lineament trends are in line with the results of previous works which suggested that the south eastern part of Nigeria has a complex network of fractures trending NE-SW, NW-SE, N-S and E-W [16].

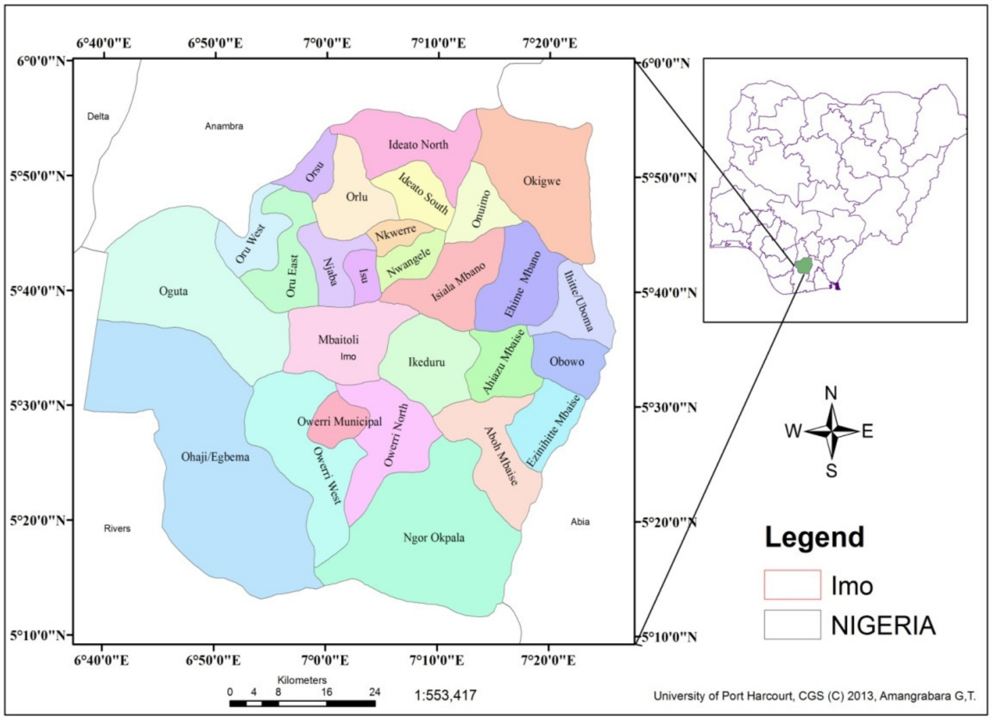

Fig. 1. Map of Imo state showing the local government areas (source: author's fieldwork)

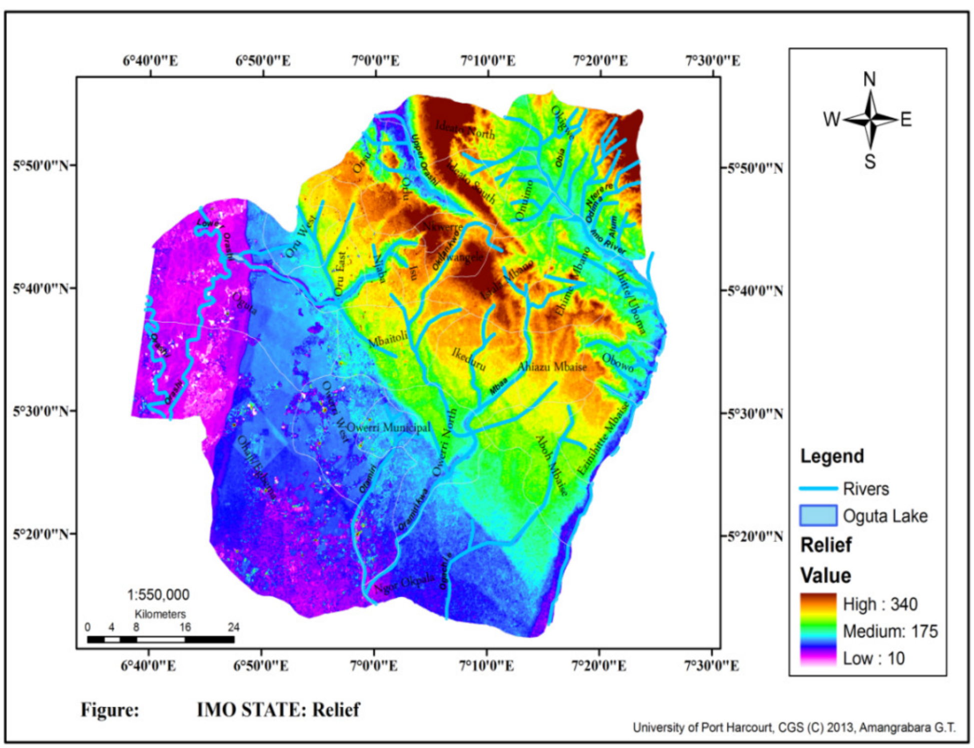

Fig. 2. Relief map of Imo state (source: author's fieldwork)

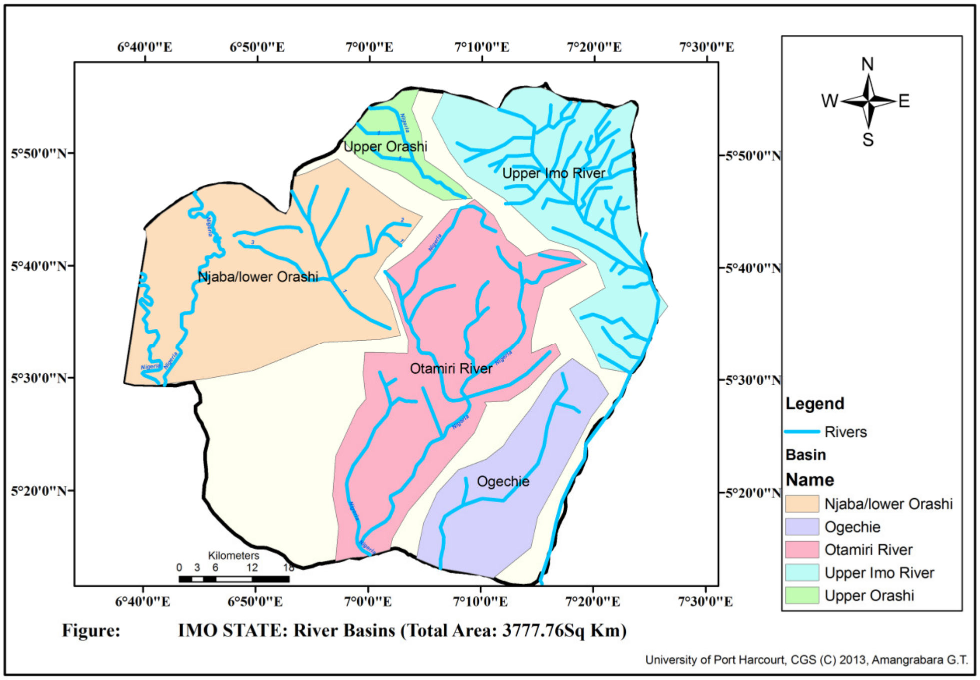

Fig. 3. River basins in the study area (source: author's fieldwork)

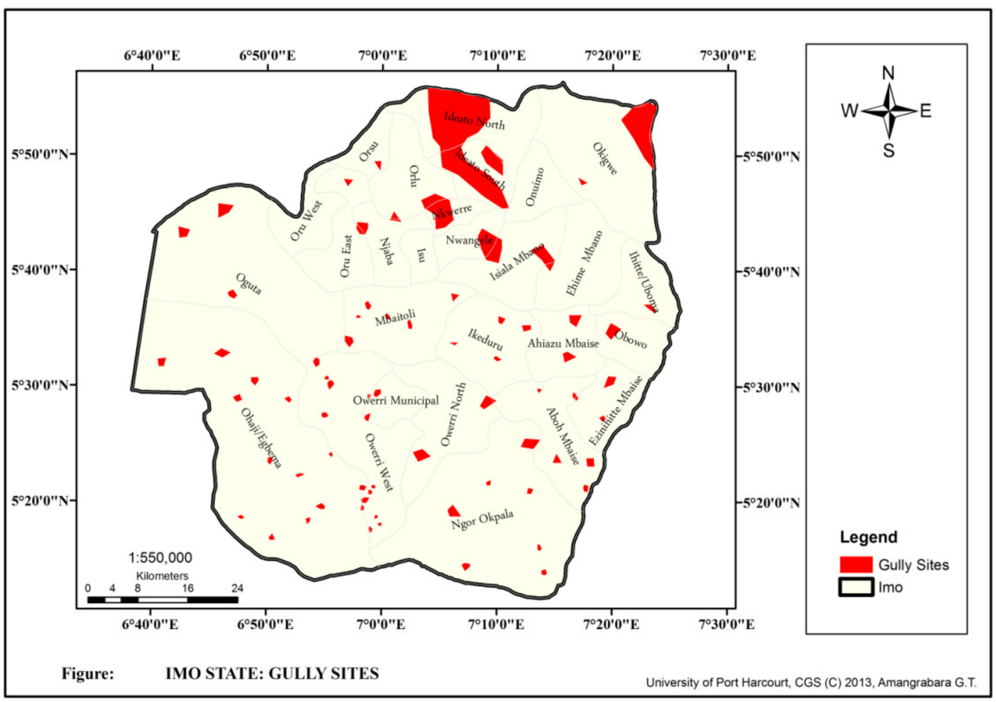

Fig. 4. Gully erosion sites in each LGA of Imo state (source: author's fieldwork)

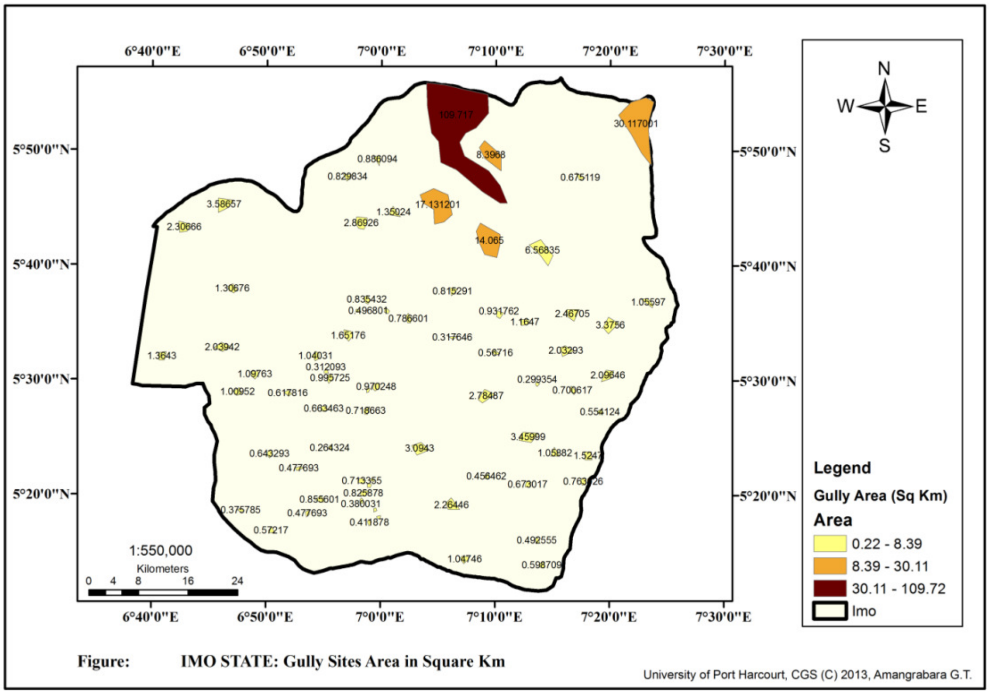

Fig. 5. Area occupied by each identified gully erosion sites

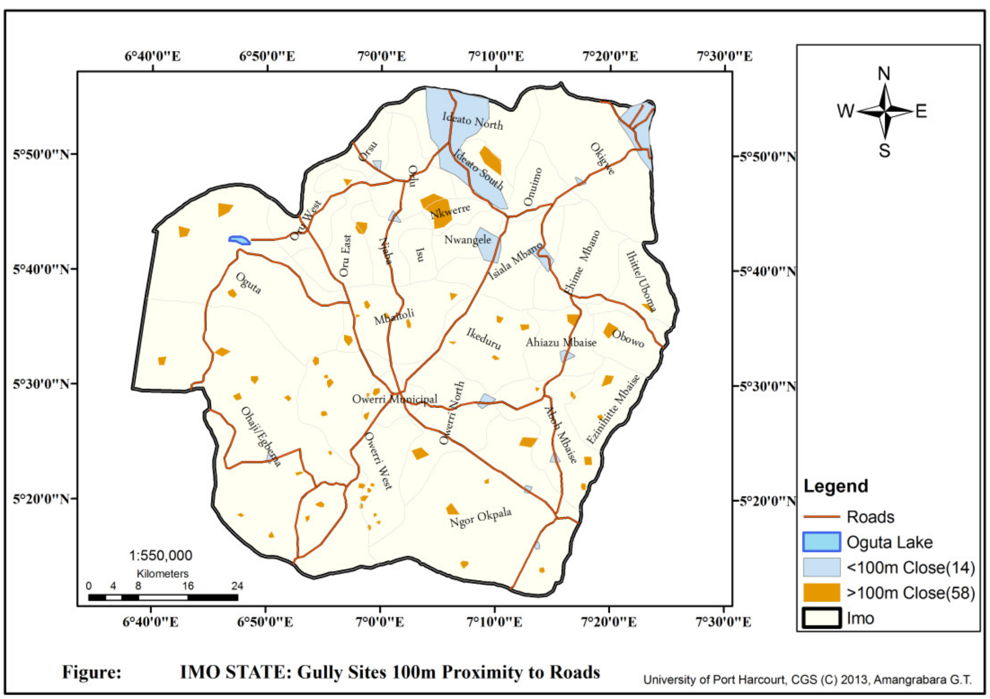

Fig. 6. Number of gullies approximately 100m to roads (source: author's fieldwork)

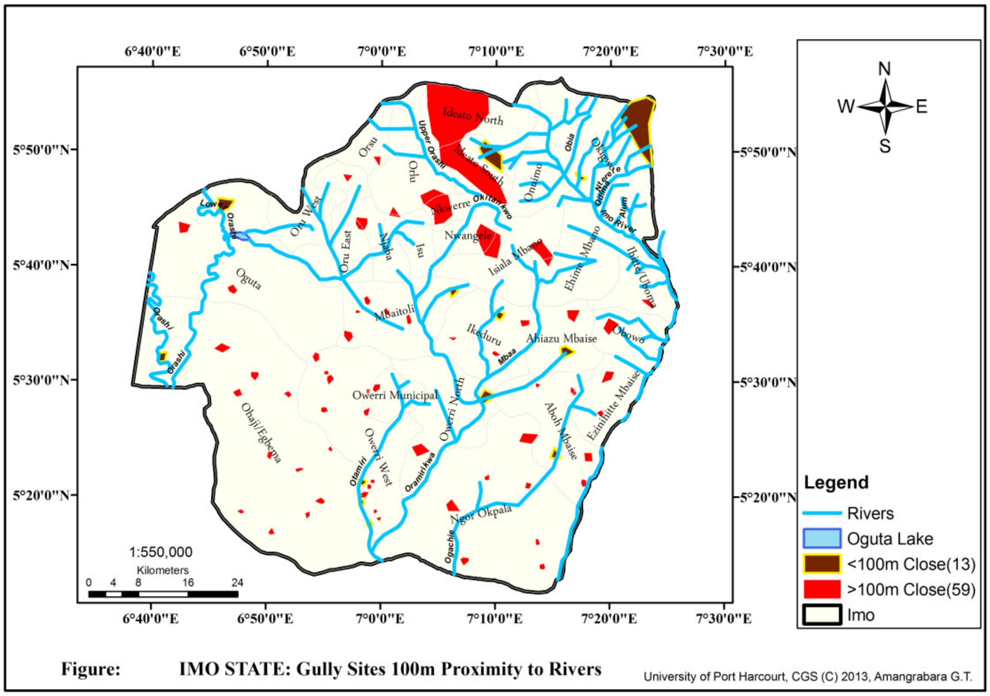

Fig. 7. Number of gullies approximately 100m to water bodies (source: author's fieldwork)

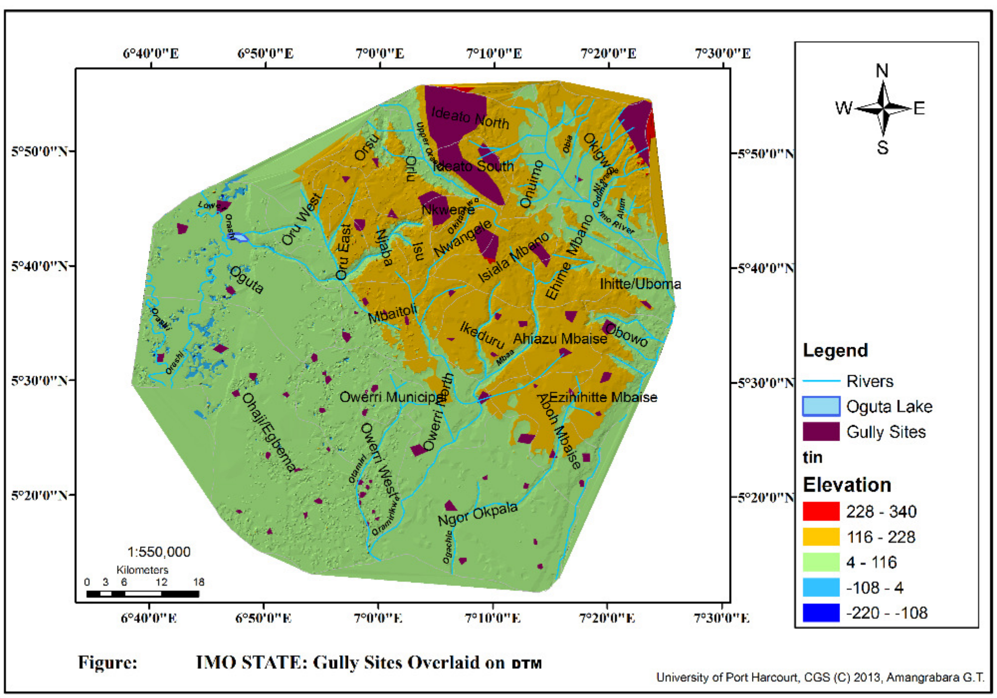

Fig. 8. Digital terrain model of Imo state showing gully erosion sites (source: author's fieldwork)

4. CONCLUSION

The conclusion drawn from this study is that remote sensing techniques (satellite imagery) are applicable in gully identification and characterization with high and desirable levels of accuracy. The processed data reveal several lineaments striking predominantly in NE- SW and NW-SE directions corresponding to the major lineament trend of the Imo-Anambra basin and the orientation of gullies in the study area. It shows the distribution of the river systems in the area as well as the distribution of gully erosion sites. The study revealed that the inherit susceptibility of the study area to gully erosion is derived from the effects of activities on the geologic formations of the area which is characterized by poor geotechnical properties based on previous studies in south eastern Nigeria as a whole.

A very good and properly designed GIS package has the capability of providing new and flexible forms of output such as customized maps in both digital and analogue formats, reports, address lists, etc. It should be able to support quick and easy access to large volume of data, to select terrain detail from the database by area or theme, to merge one data set with another, to analyze spatial characteristics of data, to search for particular characteristics or features in an area, to update data quickly and be able to answer to complex land-related questions. This study has demonstrated the potentials of image data from satellite imageries in mapping and monitoring of gully erosion spread in South-Eastern Nigeria with particular reference to Imo State. However, there are some drawbacks which must be carefully studied. For example, the overall classification accuracy for this study is 86.17% which indicates some difficulty in discriminating features due to spectral quality of the image. Burrow pit, sand excavation sites and ponds were also captured as gully erosion sites in satellite imageries because of their similarity in nature; they were not easily detected as separate geomorphic phenomenon requiring “ground truthing”.

CONSENT

All authors declare that written informed consent ws obtained from the patent (or other approved parties) for publication of this work.

ETHICAL APPROVAL

Authors were very mindful of ethical regulations and hereby submit that all relevant authorities consulted were cited unless where unintentional omitted (if any). The study (both field and laboratory work) were done under strict ethical code of conduct and was privately financed.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Appendix Table 1. Gully Morphometry of Imo State 2012

S/N	Watershed	Gully location	LGA	Geographic coordinates		Elev (m) Seg 1	Elev Seg 2	Elev Seg 3	Elev seg 4	slope (°) Seg 1	Slope Seg 2	Slope seg 3	Slope Seg 4	direction	Sub stratum	Shape	Stream	Stream order
		Upper Imo River (822.10 sqkm)		Lat (N)	Long (E)													
1	Upper Imo River	Ikpeze Arondizuogu	Ideato North	5º53' 36"	7° 8' 0"	223	223	222	220	5.0	5.0	4.8	4.2	NW -SE	Imo Shale/Mamu		Iyodo	Ist
2		Umuago, Urualla	Ideato North	5º 51' 128"	7° 04' 14.8"	139	139	138	139	7	5.0	4.5	4.0	N-S	Imo Shale/Mamu		Orashi	1st
3		Osina	Ideato South	5º 52'46.60"	7° 07' 19.20"	263	263	260	255	9.97	9.0	8.0	6.0	NW -SE	Imo Shale/Mamu			
4		Umuoshi	Ideato South	5º49' 41.2"	7° 06' 41.6"	261	261	260	259	9.09	8.0	7.5	5.5	E-W	Imo Shale/Mamu		Orashi	1st
5		Eziala/Avatu	Ezinihitte-Mbaise	5º31' 33.0"	7° 21' 18.1"	72.6	70	70	69	4.57	3.5	3.0	3.0	S-E	Imo Shale/Mamu		Onoyiri	1st
6		Mbaise Road Umuezeala Ward	Obowo	5º34' 3.6"	7° 23' 18"	154	154	155	150	2.29	2.0	2.0	1.9	S-E			Izah	1st
7		Okigwe - Umuahia Road	Okigwe	5º49' 44.0"	7° 20' 0.1"	154	153	151	150	3.43	3.4	3.0	3.0	N-E				
8		Umuowuibu	Okigwe	5º53' 04.0"	7° 18' 1.1"	151	151	151	150	1.15	1.0	1.0	1.0	N-E			Aham	1st
9		Amainyi Ukwu	Ihitte Uboma	5º 36'54.38"	7°20' 48.72"	108	108	107	105	6.84	6.0	5.0	2.0	W			Ogechie	1st
Orashi (152.4 sq.km)																		
10	Orashi	Ihioma	Orlu	5º41' 30.9"	7°02' 40.2"	146	145	145	144	2.29	2.0	2.0	1.6	N-S	Bende-Ameki		Ezize Asa	1st
11		Ogberuru/Acharaba	Orlu	5º51' 12"	7° 00' 44.9"	155	155	156	153	5.0	4.0	3.5	3.5	N-S	Bende-Ameki		Orashi	1st
12		Omundam - Okwabali	Orlu	5º49' 22.9"	7° 01' 04.2"	149	149	150	145	2.3	2.0	2.0	1.4	N-S	Bende-Ameki		Orashi	1st
13		Ihitte-Owerre	Orlu	5º51' 54"	7° 00' 15"	130.1	130.0	128.0	128.0	4.0	4.3	3.2	3.0	NE-SW	Bende-Ameki		Orashi	1st
Njaba (1197.7 sq.km)																		
14	Njaba/ Lower Orashi	Umuaka	Njaba	5º43' 00.8"	7° 02' 27.4"	64.7	63.0	62.0	60.0	9.1	8.8	7.0	5.0	N-S	B-A/Benin Trans		Njaba	1st
15		Nnenassa	Njaba	5º33' 44.8"	7° 09' 29.9"	72.0	71.0	70.0	70.0	5.7	5.0	4.0	3.5	N-S	B-A/Benin Trans		Njaba	1st
16		Amucha	Njaba	5º41' 56.3"	6° 47' 39.0"	81.9	81	80	79	9.91	9.0	7.0	5.0	N-S	B-A/Benin Trans		Orashi	3rd
17		Nkwensi (Oru Ward A)	Oguta	5º40' 54.5"	6° 50' 52.2"	81.9	80	79	78	3.43	3.0	2.0	1.8	N-S	Benin/Oguta		Orashi	3rd

18		Mgbenle	Oguta	5º40' 47.1"	6° 51' 0.36"	60.5	60	58	55	3.43	3.0	2.6	2.2	N-S	Benin/Oguta	Orashi	3rd
19		Eziama – Egbe	Oguta	5º42' 37.1"	6° 49' 25.7"	56.5	56	56	55	4.1	4.1	3.5	2.1	NE-SW	Benin/Oguta	Awbana	1st
20		Mgbidi	Oru West	5º43' 29.3"	6° 53' 20.8"	53.5	53	52	52	5.71	5.6	4.0	3.8	NE-SW	Benin	Awbana	1st
21		Umuehi Uzurumu	Oru West	5º43' 39.8"	6° 52' 58.2"	63	63	60	58	6.84	6.5	6.5	6.0	NE-SW	Benin	Orashi	3rd
22		Awo Ndemili	Oru East	5º48' 28.3"	6° 55' 24.8"	53.5	53	53	52	4.33	4.0	3.8	3.5	NW-NE	Benin	Awbana	1st
23		Umuoke Ubiri – Elem	Orsu	5º50' 49.8"	7° 00' 06.1"	120	118	110	108	4.57	4.5	4.0	3.2	NW-NE	Benin		
24		Umuomi Uzoagba	Ikeduru	5º33' 21.7"	7° 08' 34.2"	112	112	109	108	9.09	9.1	7.3	6.0	N-E	Sandstone/lignite/Shale	Orashi	2nd
Otamiri (1121.09 sqkm)																	
25	Otamiri	Ogwa	Mbaitoli	05 127 28		240	240	238	235	3.43	3.0	3.0	2.9	S-W	Sandstone/lignite/Shale	Mbaa	1st
26		Isiala Umuozu (Amaigbo)	Nwangele	5º43' 17.5"	7° 07' 31.2"	190	190	188	185	2.29	2.3	2.2	2.0	NE-SW	Sandstone/lignite/Shale	Otamiri	3rd
27		Nekede Gully (Umuokoto)	Owerri West	5º27' 56.3"	7° 02' 14.2"	64	64	62	60	3.43	3.4	3.3	2.9	SW-SE	Benin		
28		FUTO Ihiagwa	Owerri West	5º23' 18.0"	6° 59' 18.2"	65	63	62	60	1.15	1.2	1.0	1.0	SW-SE	Benin	Otamiri	2nd
29		Akwaokuma	Owerri North	5º31' 23.9"	7° 01' 02.1"	69	69	64	62	2	1.5	1.4	1.2	E-W	Benin	Nwaorie	1st
Ogechie Rv (483.85 sqkm)																	
30	Ogechie	Umueneke	Ngor/Okpalla	5º20' 12.57"	7° 08' 35.44"	55	53	52	49	1.15	1.1	1.0	0.8	SW-SE	Benin	Ogechie	1st

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