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GULLY IDENTIFICATION AND MAPPING OF SOIL EROSION RISK USING REVISED UNIVERSAL SOIL LOSS EQUATION OF ORLU ZONE, IMO STATE

Okorondu, U. V[1], Owuama, C. O[1], Amangabara G. T.[1]
Okeke P.N.[1] and Chukwuocha A.C.[2]
[1]Department of Environmental Technology
[2]Department of Surveying and Geoinformatics
Federal University of Technology, Owerri, Imo State, Nigeria
victorugochukwu568@gmail.com, amangabaragt@gmail.com

Abstract

Gully erosion is a serious geo-environmental problem globally, the areas in Orlu Senatorial Zone of Imo State, Nigeria has experienced varying degrees of erosion menace leading to land degradation and loss of valuable properties. Identification of gully locations from satellite images, development of erosion risk maps and calculation of rate of soil loss are important advancement in GIS technologies. Gullies in the study area were identified using Earth Explorer and Sas Planet remote sensing software. Investigations were carried out to distinguish gullies from other existing open cavities. Gully heads were picked as points using Global Positioning System (GPS) receivers. Soil erosion risk map was prepared based on rate of soil loss, determined using the Revised Universal Soil Loss Equation (RUSLE). The RUSLE factors of soil erosion (R, C, LS, K and P) were computed from collected rainfall data, landsat imagery, soil analysis and Digital Elevation Model to develop the soil erosion risk map. A total of 91gully erosion sites were identified out of which 80 were active. The resultant erosion map was compared to the satellite remote sensing based maps of identified gully sites. The erosion risk showed dominance of gullies and high annual soil loss in the northern part of the study area respectively.

Keywords: Gully erosion, GIS, Remote Sensing, RUSLE

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1.0 INTRODUCTION

Soil erosion is a common environmental issue in Southeastern Nigeria today. It is visible in the form of gullies where it degrades the environment leading to loss of valuable land use for agricultural, domestic, industrial and aesthetic purposes, as well as loss of property and even human lives. Adeniji (1990) defined soil erosion as the detachment and transportation of soil particles by one or more agents such as gravity, glaciers, raindrops, running water and wind with or without interference of man

The spread and magnitude of problems caused by soil erosion in many parts of Nigeria varies under different geologic, climatic and soil conditions (Onu, 2011; Amangabara, 2014). Though, soil erosion is a physical process, but its underlying causes are firmly rooted in the socio-economic, political and cultural environment in which land users operate (Stocking and Murnaghan, 2001).

Most gullies in Orlu Zone, Imo State originates as soil is being removed along natural drainage lines by surface water run-off, occurring through channeling of water across unprotected land. It is primarily a result of rain drop impact, washing away by running water which creates rills that later develop into gullies (Nwilo, Olayika, Uwadiegwu and Adzandeh, 2011). Thus, different activities of man that do not respect the conservational laws have resulted to degradation of soil. Erosion problems arise mainly from natural causes but their extent and severity are increasingly being attributed to man's ignorance and unintentional actions, thus making the genesis and development of rills to gullies more complex, involving subsurface flows and sidewalls processes (Bocco, 1991).

The aim of this study therefore is to Integrate Satellite Remote Sensing and GIS Technologies in Identifying Gully Sites and Evaluating Erosion Risks in Orlu Zone, Imo State.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study area (Orlu Zone) is a senatorial district comprising 12 LGAs in Imo State, South Eastern Nigeria geographically referred as Longitude 6.662E -7.121E and Latitude 5.274N -5.949N. It occupies an estimated area of 2292.13sqkm and a population of 1,648,086 at the 2006 census. According to NIMET, (2015), the study area is situated within the sub-equatorial region that is characterized by high annual rainfall (over 2000mm/yr), high relative humidity (90%) and temperatures

(24 - 27^{o}C). The area experiences two main seasons – rainy season and dry season. The onset of rainy season starts about March to October with its peak in July and September, and a short break in August. The dry season begins from November to about February with the influence of harmattan felt between the months of December to early February. The vegetation of the area are majorly lowland forest and minor freshwater swamp, though has been greatly disturbed as most parts are cultivated farmland.

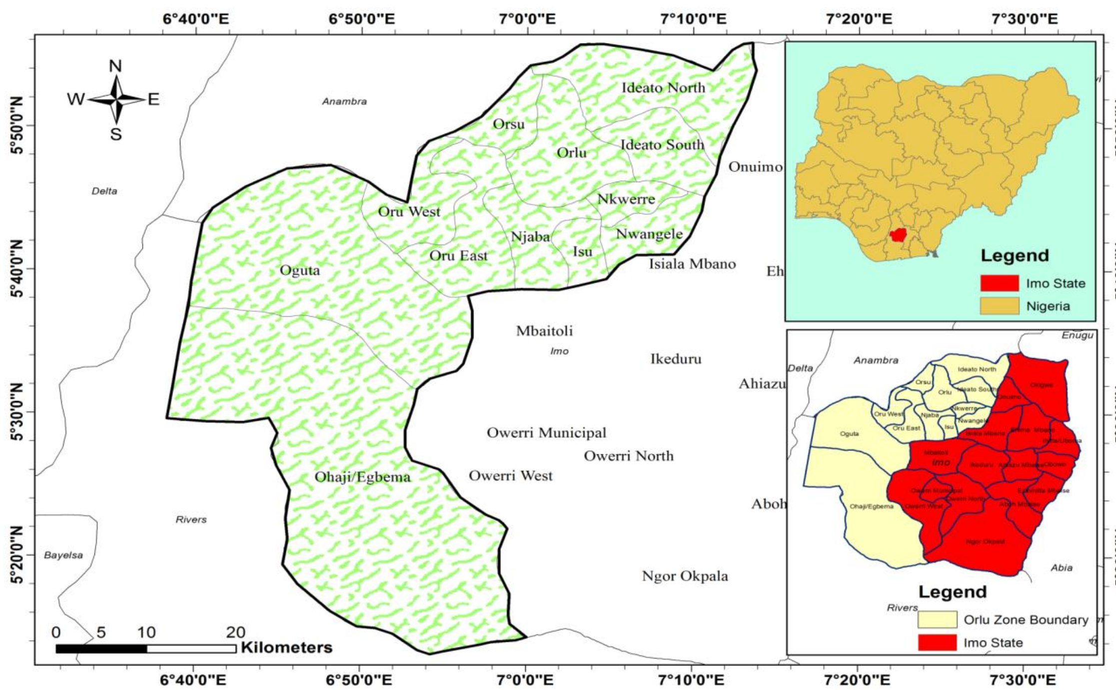

fig 1 study area map

Study area geology is characterized by five major geologic formations; Bende-Ameki, Ogwashi-Asaba, Benin, Imo Shale formation and Alluvium deposit. But majorly by the sedimentary sequences of the Benin Formation (Miocene to recent), and the Bende-Ameki Formation (Eocene). 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 while Bende-Ameki consists of medium to coarse-grained white sandstone; which may contain pebbles, gray-green sandstone, bluish calcareous silt, with mottled clays and thin limestone (Amangabara, 2014).

Orlu Zone is characterized by three main landform regions. A highland region ranging from 180 to 324m of elevation in major parts of Orlu, Nkwere, Nwangele, Ideato North and South Local Government Areas, A moderate region with an elevation ranging from 92 to 180m covers Orsu, Njaba, Isu Local Government Areas. The entire Oguta and Ohaji/Egbema Local Government Areas are generally low land region with elevation ranging from 16 to 92m. The main water bodies draining the study area are; Njaba River, Nwangele River and Urashi River. The areas that charge these water bodies constitute four sub basins within the Anambra-Imo River Basin.

2.2 Methodological Framework and Data Description

The local map of the study area was delineated from map of Imo State Local Government Areas acquired from the Imo State ministry of lands, survey Urban Planning. The hard paper base map was scanned to convert to raster format, the data was called up in ArcGIS version10.2 software environment and georeferenced on the World Geodetic System 1984 (WGS1984) coordinate system. The digital map of Nigerian States procured from the Regional Centre for Training in Aerospace Survey (RECTAS) Ile Ife, Osun State was integrated with the map of Local Government Areas to produce the study area map shown in fig 1. High resolution satellite imagery from Earth Explorer and Sas Planet software were used to delineate gully locations within the study area. ground truthing survey was carried out on identified gullies to differentiate it from other existing open cavities like borrow pits and the resultant gully head coordinates picked using Global Positioning System (GPS) as shown in fig2A and 2B.

Revised Universal Soil Loss Equation (RUSLE) was used to estimate annual soil loss in the study area (equation1). Monthly rainfall data of 2017 was acquired at the Nigerian Meteorological station (Sam Mbakwe Airport, Imo State). Digital Elevation Model downloaded from global mapper software was integrated with SRTM procured from RECTAS at 5m spatial resolution. Landsat 8 imageries covering the entire study area was acquired from USGS Earth Explorer. The study area was divided into sub drainage basins “Urashi, Njaba and Imo River basin” based on the existing Imo Anambra River basin from which soil samples (10 sample locations) were randomly collected at depth of 0-20cm and analysed in a laboratory. Soil erodibility (K) factor was estimated from soil organic matter content, particle distribution and permeability using soil textural triangle and Wischmeier and Smith (1978) method. Average K factor obtained were keyed in against the coordinates of soil sample collection points (x, y) as the Z values for interpolation in ArcGIS software environment to establish soil erodibility raster for the study area.

$$A=R*K*LS*C*P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (1)$$

Where

A is the average soil erosion (t ha^{-1} y^{-1}),

R is the rainfall erosivity factor (MJ mm /ha1year1),

K is the soil erodibility factor (t ha h /MJ1ha1mm1),

L is the slope length factor (m),

S is the steepness factor (%),

C is the cover management factor and

P is the conservation practice factor.

2.3 Generation of R, K, C, Ls and P Factors

Rainfall Erosivity Factor (R) The runoff factor or rainfall erosivity is an index showing how much erosive force a typical storm has on surface soils; it was computed using the Fournier Index (MFI) formula on equation (2.1). The average annual rainfall erosivity factor (R-factor) calculated was interpolated by kriging in the ArcGIS software environment Spatial Analyst tool of the ArcToolbox. Firstly, average rainfall erosivity was assumed to be uniform because of the absence of weather stations in the study area, random points were selected and the average rainfall erosivity value (262.595 $MJmmha^{-1}h^{-1}y^{-1}$) for 2017 was inputted into the attribute of the selected random points (fig 3). This value served as the Z value for the interpolation

$$FI = \frac{P_{max}^2}{P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

$$MFI = \sum_{i=1}^{12} \frac{P_i^2}{P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

Where

p_{max} is the average monthly amount of rainfall of the rainiest month (mm)

P_i = monthly average amount of rainfall for the month i (mm)

P = annual average amount of rainfall (mm)

Slope Length and Slope Steepness Factor (LS) The slope and steepness factor (LS) is a combination of slope steepness and slope length, to high degree affecting the total sediment yield from site. It is considered to be one of the most challenging to derive (Fu *et al*., 2005). The LS factors were estimated applying the equation proposed by Renard *et al.*1997) which is dependent on flow accummulation. Flow accumulation is one of the most highly studied variables likely effecting soil erosion, represented by the total concentration of the water flow over a selected area (Chelsea, 2013). It computes the accumulated number of cell upstream in the flow direction. The relationship for LS estimation is as follows:

$$\left(\frac{Flow\ Accumulation\ *\ cell\ size}{22.13}\right)^{0.6} * \left(\frac{\sin slope\ *\ 0.01745}{0.09}\right)^{1.3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where; LS is the combination of slope length and steepness;

The slope and steepness factor was computed using the Raster Calculator function in the Spatial Analyst toolset of ArcGIS software. Flow accumulation was generated from the (SRTM) DEM using the arc hydro extension tool of ArcGIS software and the formula above was employed in raster calculator tool to generate LS factor (fig4).

Soil Erodibility Factor (K) The soil erodibility factor is an empirically derived index that indicates susceptibility of soil to rainfall and runoff detachment and transport (rates of runoff) based on soil texture, grain size, permeability and organic matter content. It thus represents the combined effects of soil detachment and runoff on a particular soil. Wischmeier and Smith (1978) estimated soil erodibility based on the characteristics of the soils were used

$$K = 27.66 \times m^{1.14} \times 10^{-8} \times (12 - a) + 0.0043 \times (b - 2) + 0.0033 \times (c - 3) \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where,
K = Soil erodibility factor in (ton.hr^{-1}.ha^{-1}.MJ.mm)
a = % organic matter content
b = soil structure class (e.g. very structured or particulate, fairly structured, slightly structured, and solid).
c = soil permeability class (e.g. rapid, moderate to rapid, moderate, moderate to slow, slow, and very slow).

Average soil erodibility estimated from soil textural triangle and Wischmeier and Smith (1978) method were keyed in against the coordinates of soil sample collection points (x,y) as the Z values for interpolation in ArcGIS software environment (fig 5).

Cover Management Factor (C) The cover and management factor is an index that indicates how crop management and land cover affect soil erodibility. The value of C-factor is defined as the ratio of soil loss from a certain kinds of land surface cover conditions (Wischmeier & Smith, 1978). It is used to express the combined effects (reduction of runoff velocity and protection of surface pores) of plants and soil cover as well as those of all other interrelated cover and management variables (Karaburun, 2010). According to Prasannakumar *et al*. (2012), the Normalized Difference Vegetation Index (NDVI) can be used as an indicator of the land vegetation vigor and health. Landsat imagery downloaded from USGS website (www.glfc.com) with the reflectance values in bands green, red and near-infrared, were converted to NDVI using the equation below

$$NDVI = \frac{rNIR - rRed}{rRed - rNIR} \quad \text{…………………(5)}$$

where;
rNIR is the reflectance value in near-infrared band;
rRed is the reflectance value in visible red band.
NDVI was calculated in the ArcGIS environment using the **Image Analysis** function, where NDVI was an option in the Image Analysis dialogue box. In this option, the respective bands were selected accordingly using the formula in equation (5).

Thus, the C-factor was estimated by applying the relationship used in Zhou *et al*. (2008) on the raster calculator tool in the spatial analyst toolbox of ArcGIS software (fig 6).

$$C = C = exp\left(-\alpha \frac{NDVI}{\beta - NDVI}\right) \quad \text{……………………..(6)}$$

Where; C is the calculated cover management factor; NDVI is the vegetation index, and α and β are two scaling factors. Van der Knijff *et al*. (2000) suggest that by applying this relationship, better results are obtained using the values for the two scaling factors α and β to be 2 and 1, respectively.

Support Practice/Conservation Factor (P) The P-factor refers to the level of erosion control practices such as contour planting, terracing and strip cropping, put in place in a watershed, and depends on the average slope steepness within the study area. It represents the soil-loss ratio after performing a specific support practice to the corresponding soil loss, which can be treated as the factor to represent the effect of soil and water conservation practices (Omuto, 2008; Renard *et al*., 1997).

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The range of P factor varies from 0 to 1. The lower the value is the more effective the conservation practices are. On the study area, fewer conservative practices were found at the northern part while other areas were chosen as 1 and interpolated in ArcGIS software environment (fig 7).

2.4 Erosion Risk Mapping

The erosion risk map for the year 2017 was generated by integrating all the parameters of RUSLE factors using map algebra in the ArcGIS 10.2 version software environment. Produced 2017 soil erosion map was reclassified into five classes of erosion risk is in accordance with RUSLE standards as it provides better identification of the area most prone to erosion in the study area (fig 8).

3 RESULT AND DISCUSSION

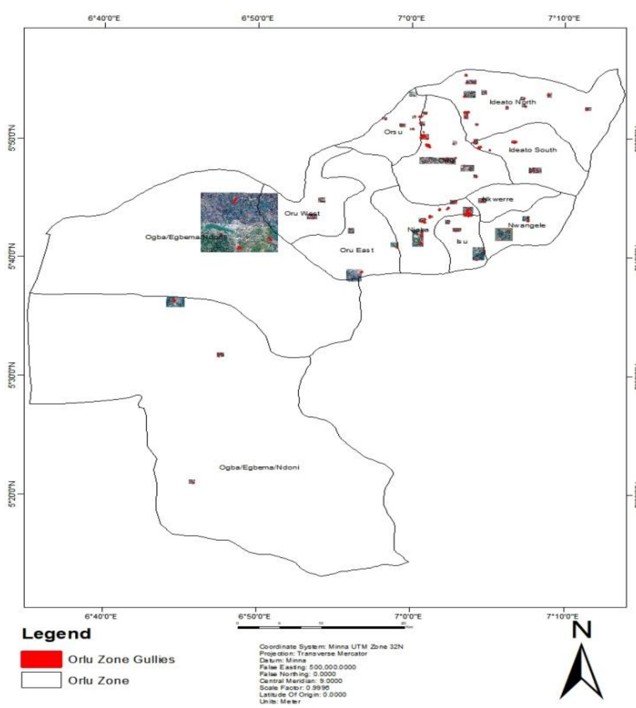

fig 2A satellite remote sensing gully identification

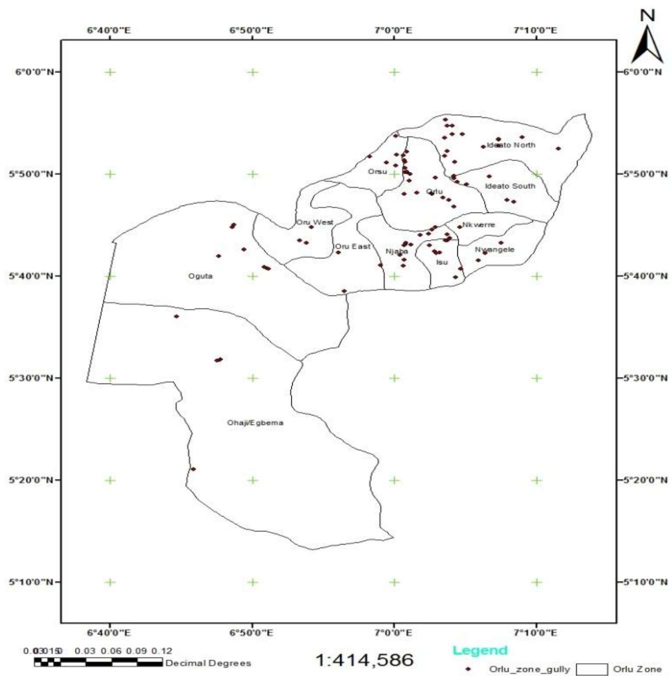

fig 2B Study area gully profile

Table 1 Orlu Zone LGAs, Areas, Coordinates and Number of Gully Sites and areas

LGA_Name	LGA_Area (KM^2)	LGA Latitude (Dec. Degrees)	LGA Longitude (Dec. Degress)	Number Of Gully Erosion
Ideato North	190.24	5.879756	7.13083	15
Ideato South	88.43	5.807549	7.13654	8
Orsu	55.82	5.84375	6.9811	5
Orlu	131.55	5.80359	7.03775	19
Nkwerre	38.06	5.749805	7.1043	1
Nwangele	63.27	5.713085	7.12613	3
Njaba	83.98	5.705869	7.00821	13
Isu	40.04	5.689741	7.05521	9
Oru East	135.56	5.714352	6.94152	3
Oru West	93.29	5.743794	6.89134	3
Ohaji/Egbema	888.93	5.425383	6.82279	5
Oguta	482.96	5.666011	6.79932	7
Total	**2292.13**			**91**

Table 2 Revised Universal Soil Loss Equation Factors Result

Community	Easting	Northing	LGA	Ave_K	R	Ls	C	P
Okwudor	278245.153	632505.815	Njaba	0.09	262.595	1	0.9	0.8
Ogberuru	282232.192	646051.505	Orlu	0.12	262.595	1	0.9	0.5
Osina	289064.207	650791.215	Ideato North	0.14	262.595	1	0.86	0.7
Umuozu	294102.819	634864.08	Nwangele	0.09	262.595	0.8	0.8	0.6
Izombe	261762.313	624212.23	Oguta	0.05	262.595	0.6	0.81	1
Obosima	264627.543	610388.093	Ohaji Egbema	0.03	262.595	0.6	0.99	0.9
Umuagwo	267698.101	590187.057	Ohaji Egbema	0.05	262.595	0.4	0.9	1
Ndiuche	298842.529	645709.904	ideato	0.12	262.595	1	0.81	0.7
Obiakpor	251698.88	617498.858	Ohaji Egbema	0.03	262.595	0.6	0.99	1

Table 3: Class Statistics for soil erosion risk map of the study area

Erosion Risk Class	Level t $ha^{-1}y^{-1}$	Area (km2)	Percentage Occurrence	Cumulative	Ratio
Very High	17.30-28.27	197.8	8.63	8.63	1
High	13.53-17.30	403.46	17.60	26.23	2.0
Moderate	10.87-13.53	409.87	17.88	44.11	2.1
Low	8.54-10.87	701.56	30.61	74.72	3.5
Very Low	<8.54	579.44	25.28	100	2.9
Total		**2292.13**	**100**		**11.5**

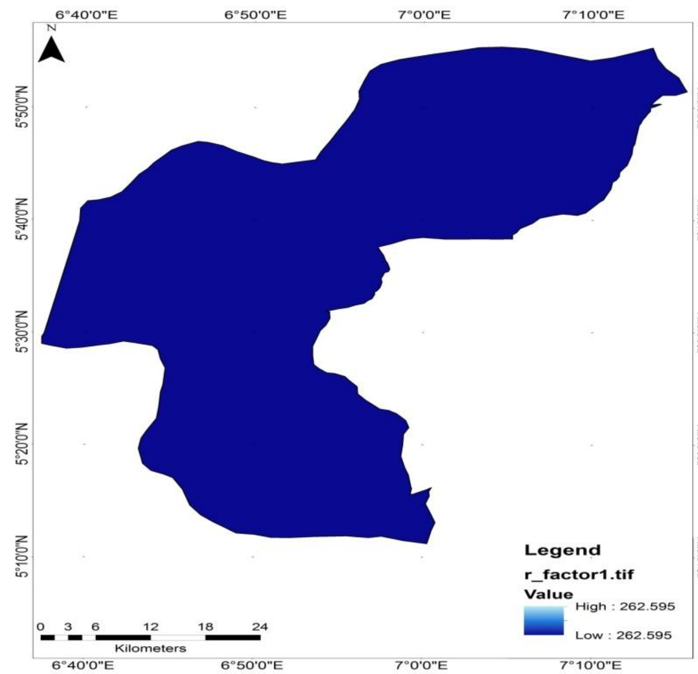

fig 3 the R factor

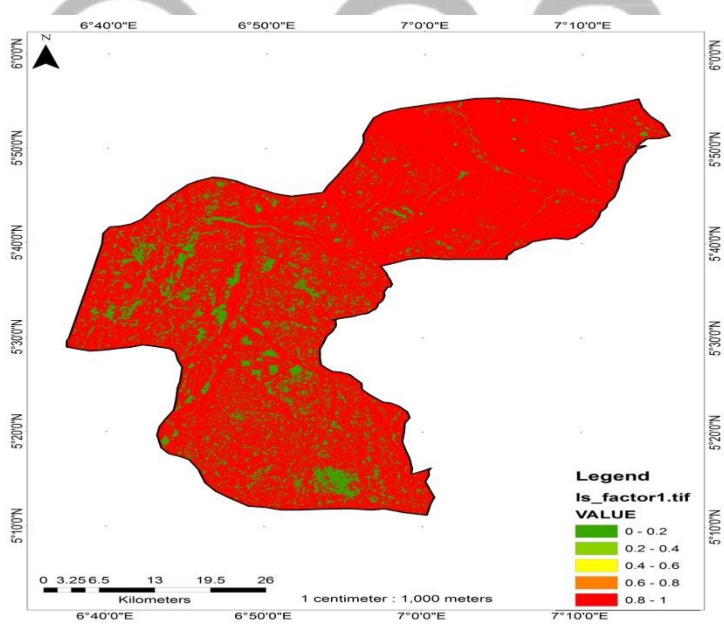

fig 4 Ls factor

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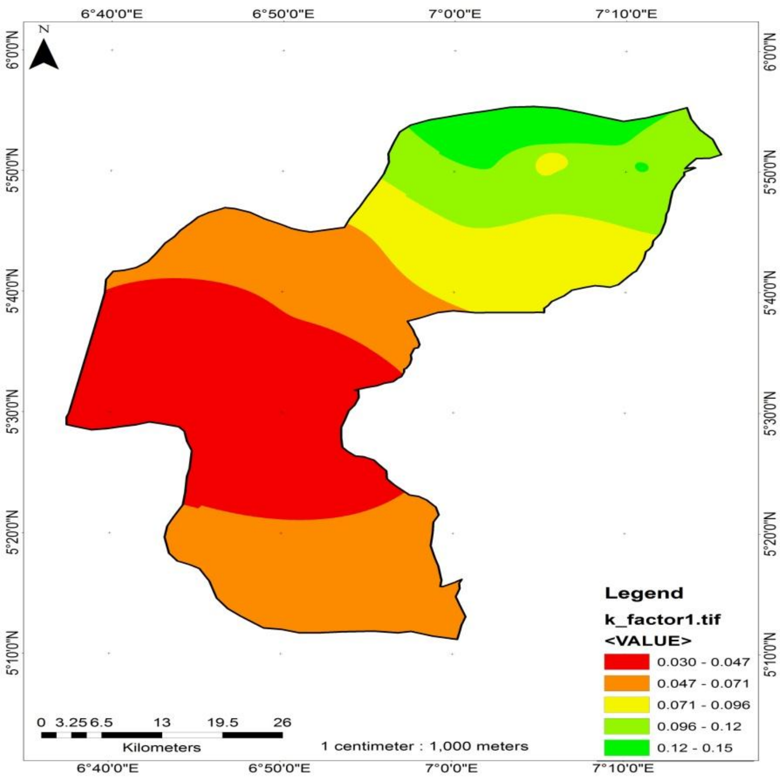

fig 5 the K factor

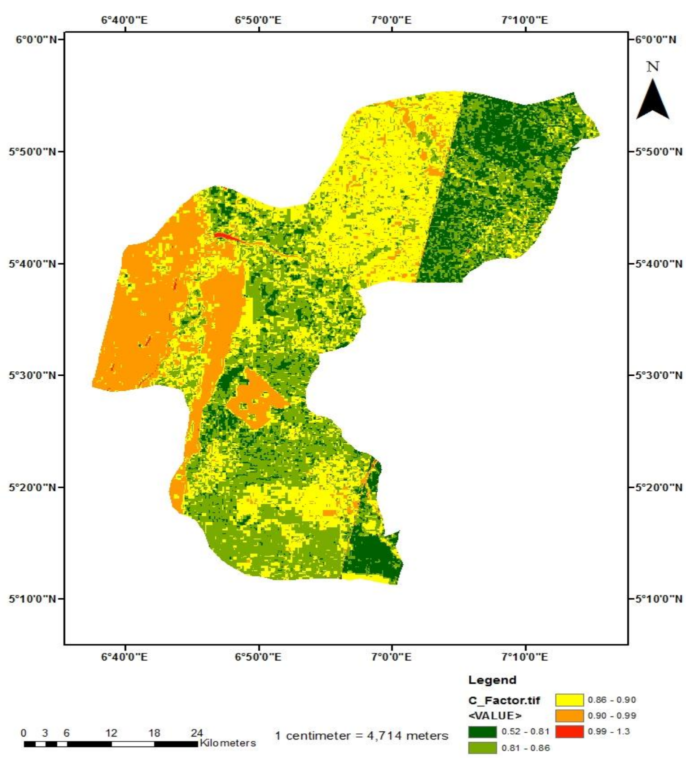

fig 6 the C factor

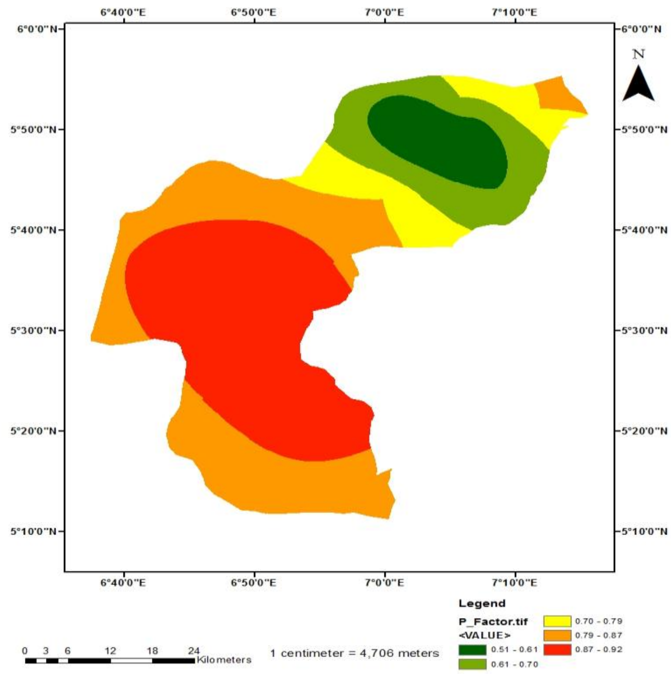

fig 7 the P factor

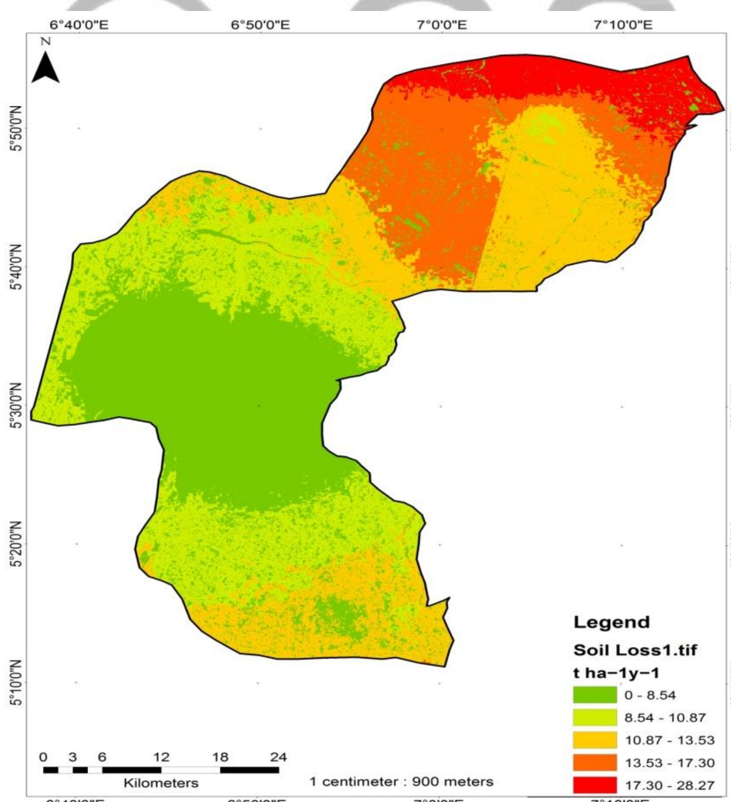

fig 8 Erosion risk map of the study area

Fig 2 – 3 and Table 1-3 are generated from this operation. 91 gully erosion sites were identified in the study. 80 out of the 91 identified gully sites were active while 11 were inactive (dormant). Gully sites dominated the northern part of the study area. Gully profile in table 1 showed that Orlu LGA has nineteen (19) gully erosion sites which represent the highest number of gully occurrence per LGA in the study area. Ideato North fifteen (15) and Njaba thirteen (13) follows as major LGAs populated with gully erosion sites, meanwhile, Nkwere LGA has the least number of gully erosion profiles in Orlu Zone

Erosion risk map (fig 8) produced through multiplication of the RUSLE factors (R, Ls, K, C and P) under the same pixel showed the quantity of sediment transport to range from 1-28.5(t ha^{-1} $year^{-1}$) for 2017. Annual soil loss for the study area were classified into five different scales from very low (<0-8.54t/ha-1 yr-1), low (8.54–10.87t/ha-1 yr-1), moderate (10.87–13.53t/ha-1 yr-1), High (13.53–17.30t/ ha-1 yr-1) to very high (17.30–28.27t/ha-1 yr-1). The study produced an estimated average annual soil loss of upto 28.27tha-1 yr-1 for 2017 on a total soil erosion area of 2292.13km2 for the study area.

From table 3, it was observed that the very high potential areas were found in the northern areas covering parts of Ideato North, Orsu, Ideato South and Orlu LGAs with area of 197.8km^2 representing about 8.63% of total area. High risk areas cut across many local government areas in northern part of the study area (Ideato North, Orsu, Orlu, Njaba, Isu, and Ideato South) with an area of 403.46km^2 maintaining 17.6% of total area of study. Moderate potential areas cut across all the LGAs excluding Orsu and dominated in Nkwere, Nwagele, parts of Orlu, Isu, Oru and Ideato South with area of 409.87km^2 covering 17.88%. Low and very low potential areas domintated at the Southern part of the study area (Oguta and Ohaji/Egbema LGAs) at an area of 701.56 km^2 and 579.44km^2 representing about 30.61% and 25.28% respectively.

4 CONCLUSION

This study explored the combined use of Geographic Information System (GIS) and Remote Sensing tools in satellite gully identification and soil risk mapping using revised universal soil loss equation (RUSLE) in Orlu Zone, Imo State. It was observed that gully locations dominated Northern part of the study area. Also, erosion risk values in the erosion risk map were bigger than 28tons/ha/year for 2017, thus, reclassification of this map into categories of potentials resulted in a concentration of values in the most potential category occurring in the North too.

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