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Geospatial Analysis of Soil Erosion Susceptibility and Causative Factors in Anambra State, South East, Nigeria

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Abstract

Land degradation is a function of soil erosion leading to soil loss and reduction in crop productivity as well as other socio-economic activities. The menace of soil erosion is challenging due to diverse factors including advertent and inadvertent anthropogenic activities. This study looks at soil erosion susceptibility and causative factors in Anambra State, both static and dynamic with the intent of identifying them, investigating spatial variability of soil loss, relate erodibility to soil properties and causative factors to soil erosion. Eight (8) prominent causative factors (CFs), were identified. These causative factors (CFs) were analyzed using ArcGIS 10.2. Sixty (60) soil samples were extracted randomly, analyzed, and tested.. The study identified CFs such as Drainage Density, Erosion Density, Lineament Density, Slope Length, Land Surface Temperature, and Rainfall Erosivity, which contribute to Soil Erodibility (K - Factor). Land Surface Temperature, Soil Moisture Index, Rainfall Erosivity, and Normalized Difference Vegetation Index contributed to the loss of 8.97 ton/ha/yr, 9.1288 ton/ha/yr, 1,1134.7 ton/ha/yr, and 0.245 ton/ha/yr respectively to erosion in Anambra State. Conclusively, the dynamic causative factors influence soil susceptibility and trigger erosion in the State.

Keywords: Geospatial; Causative factors; Soil erosion; Susceptibility; Anambra.

1. Introduction

Soil erosion as a very severe environmental and socio-economic problem, does not only degrade land and soil productivity; but also instability and threatens the health of societies and sustainable development [1-4]. However, the challenges associated with soil erosion and how it is being managed; attract attention and growing interest in the assessment of the distribution spatially and the susceptibility levels [5].

Assessment of susceptibility requires the measurement of the relative probability of soil erosion occurring in an area based on the relationships of past events and some causative factors. This approach is necessary and paramount to land-use type, soil management, and erosion prevention [6].

Problems of soil erosion have been a challenging one to the government and people of Anambra State and other States in Southeastern Nigeria for decades. Despite the number of various scientific and engineering research studies, and control efforts carried out so far in the study area, the underlying causes of these problems remain a mirage and are still not clearly understood [7]. Ofomata [8] maintained that even though human factors are apparently dominant, the physical factors of soil erosion are very important that even where the physical factors are the same, the level of susceptibility is not the same. Research findings by many authors including Ofomata [8]; Chikwelu and Ogbuagu [9]; Okoyeh, *et al.* [7]; Igwe and Egbueri [10]; Emeh and Igwe [11] and Egbueri and Igwe [12] revealed that anthropogenic activities, geotechnical properties of the soils and improper land use types are responsible for soil susceptibility to erosion in the study area. These authors, having carried out quite a number of research works in this region have proffered several mitigation measures and recommendations which are "construction of check dams, planting of vegetation cover, roadway grading, landscaping, stabilization of soils, terracing of soil slopes, dewatering, and construction of embankments and establishment of soil conservation schemes". Unfortunately, these measures have achieved little or no results possibly because itemizing the possible component of causative factors responsible for the rate of the erosional processes is still elusive to researchers [6, 12]. Our elementary geography has both physical and human-induced factors of soil erosion as detailed by Ofomata [13]. The physical include soil, slope, geology, rainfall, vegetative cover, and human factors generally called anthropogenic which include deforestation for development, climate change induced by man, overgrazing, bush burning, faulty methods of agriculture, and many others [12]. Despite the knowledge and understanding of these factors and mitigation measures adopted so far, soil erosion processes are yet to be arrested, pointing to the fact that there are other geomorphologic, hydrological and soil processes and interactions not fully understood by various actors and researchers in soil erosion and land management. The mitigation measures failed according to Egbueri and Igwe [12] because all the factors responsible for soil erosion have not been fully accounted for and this study seeks to generate these unaccounted causative factors that make the soils susceptible to erosion. Identifying and arranging appropriately the erosion causative factors (CF's) is critical in building valid and accurate models for susceptibility assessment. Some important dynamic CFs were not considered in most of the previous soil erosion studies such as rainfall erosivity, land surface temperature (LST), and soil moisture index (SMI), hence the need for this research to quantitatively and qualitatively investigate and evaluate the impacts of additional "dynamic CFs" to the most frequently used "non-redundant static CFs" in the studies of erosion susceptibility and map analysis in the study area using GIS, remote sensing and statistical techniques (in the form of SVM – Support Vector Machine, a supervised machine learning algorithm) which is suitably used for image classification and or solving regression problems. Therefore, this research will assess the susceptibility level of the various soil erosion causative factors as in rainfall, slope, land use – land cover, soil erodibility and anthropogenic activities in the study area and pinpoint the percentage contributions of these dynamic causative factors and other non-redundant factors in order to determine which of them is more favourably affecting soil loss in the study area.

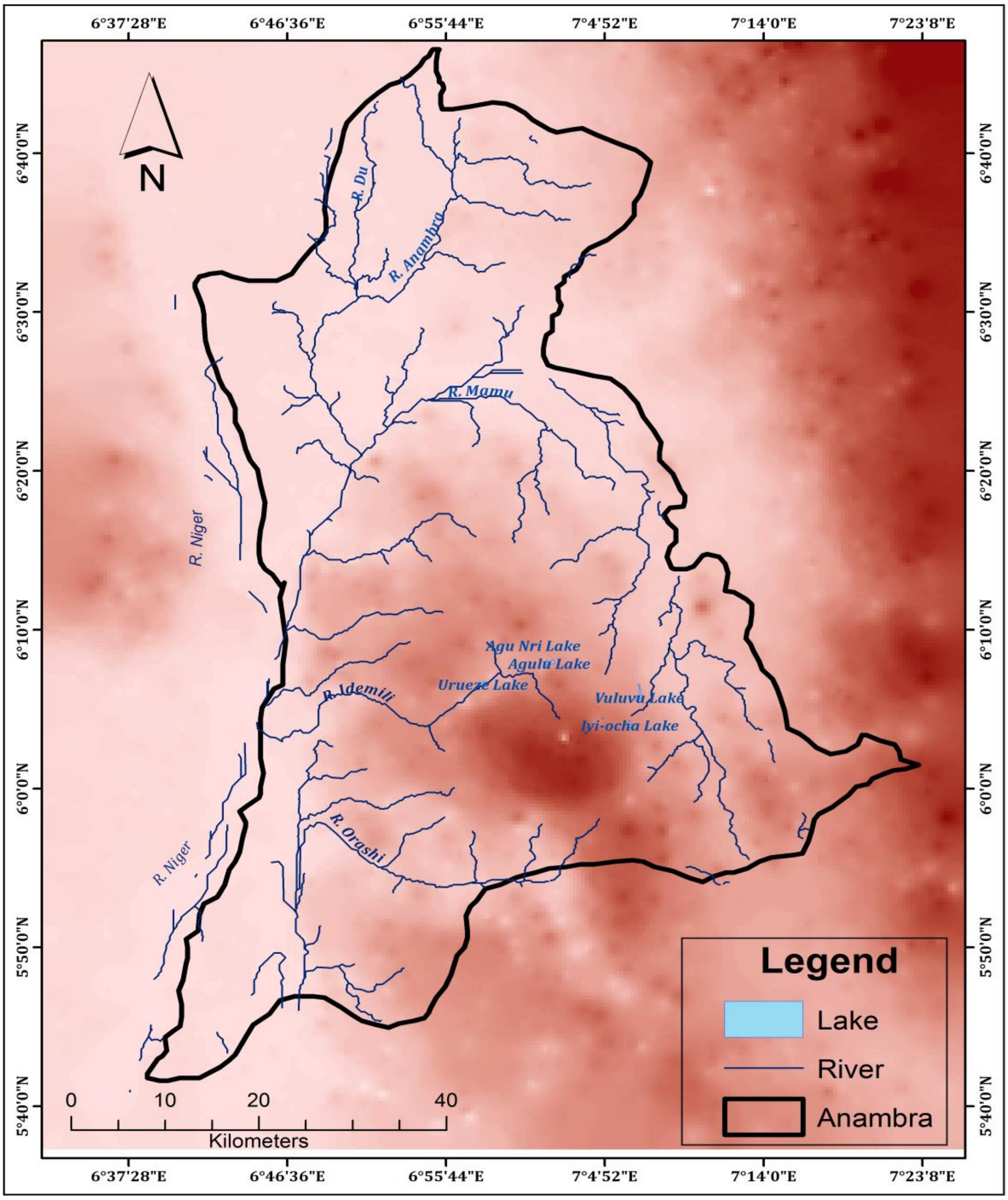
2. Matrials and Methods

2.1. Study Area

The study area, Anambra State South East Nigeria is located between latitudes $6^{o}00'$ and $7^{o}00'$ N and longitudes of $6^{o}45'$ and $7^{o}20'$ E with a landmass of about 4844 km^2 [14, 15] (Figure 1). Anambra State shares boundary with Enugu and Kogi States in the North, Imo and Abia in the South and Delta State in the West. The State is made up of twenty-one (21) Local Government Areas (LGAs) with one hundred and seventy nine (179) communities; Anambra State is situated within the former humid tropical rainforest zone of West Africa as human activities such as agriculture, urbanization, infrastructural development like road construction and other forms of deforestation and quarrying activities have led to loss of the original ecosystem and biodiversity. The study area has two distinct seasons, rainy or planting season and dry or harvesting season. The rainy season starts from April – October with two peaks in June and September, and Little Dry Season in August known as August Break. Dry season starts from November – March with harmattan as its characteristics. However, climate change is altering the existing pattern of rainfall in the study area with August Break disappearing leaving the area with what seems like one maxima duration of rainfall which is short and heavy and is devastating the area with gully erosion together with the already existing unsustainable anthropogenic activities going on by land users [14].

Anambra State has two distinct topographic landscapes – the highland area specifically the Awka-Orlu upland with highest point of 384m in southeastern part and the low-lying regions of the lower Anambra Basin of 30m above mean sea level around Umumbo in Ayamelum LGA. A network of rivers, streams and lakes drain the study area. The major rivers include River Niger, Anambra, Mamu, Nkisi, Idemili and Orashi rivers. Lakes are Agulu, in Agulu, Anaocha LGA, Uchu, Otajiri and Vuluvu lakes in Awgbu, Orumba North LGA among others (Figure 1).

Figure-1. Rivers and Lakes in the Study Area



Source: USGS, Modified by the Authors, (2020)

2.2. Methodology

This research applied the use of both primary and secondary data. The primary data involved field survey and observations using Global Positioning System (GPS) for ground truth verification and collection of soil samples for extraction of soil properties. Secondary data include satellite imageries, aerial photos, topographic maps, meteorological and population data collected from different governmental and non-governmental organizations, other published and non published literature. The identified causative factors – Drainage Density (DD), Erosion Density (ED), Lineament Density (LD), Slope Length (LS), Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Rainfall Erovisity and Soil Moisture Index (SMI), were analyzed using ArcGIS 10.2 software to determine and predict the contributions of the various identified causative factors that can induce, initiate and or trigger soil erosion in the study area using the following under listed models:

Table-1. Models applied in determining and predicting the contributions various identified causative factors (CFs)

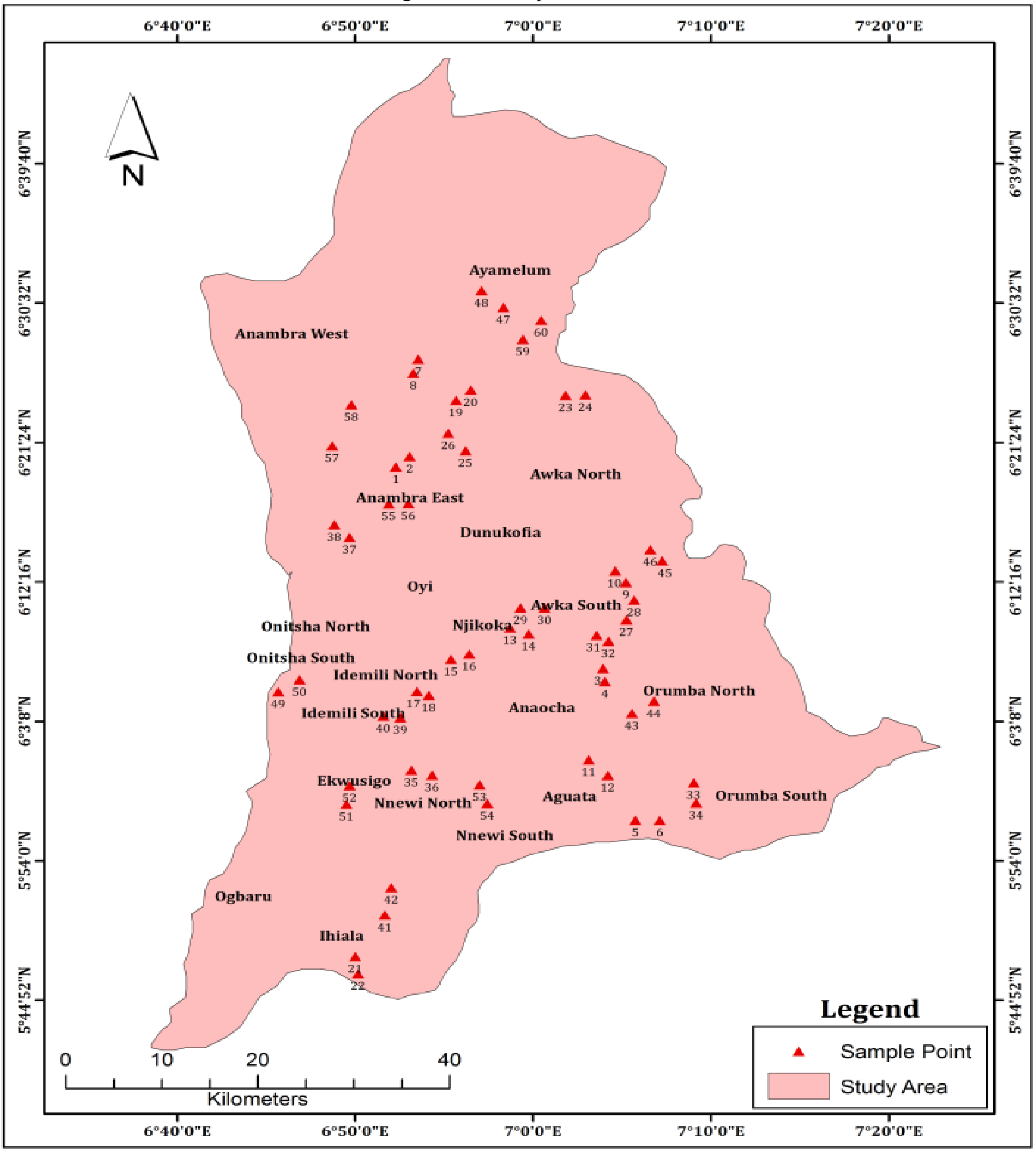
No	Models	Equation	Description	Source
1	RUSLE	$A = R.K.LS.C.P$	Where 'A' is the average annual soil loss in tons per acre per year. 'R' is the rainfall-runoff erosivity factor, 'K' is the erodibility factor, 'LS' is the slope length and degree, 'C' is the land cover management factor and 'P' is the conservation practice factor	[16].
2	Drainage Density (DD),	$Dd = \frac{C_t}{A}$	Where C_t = Total Length of Stream; A = Area	[17]
3	Erosivity Density (ED),	$Ed = \frac{R}{P}$	Where ED (MJ ha−1 h−1) [52] is the erosivity density, P annual rainfall (mm) and R is the rainfall erosivity.	[18]
4	Lineament Density (LD),	$Ld = \frac{L}{A}$	Where L = total length of all the recorded lineaments; A = area under consideration	[19]
5	Slope Length (LS),	$L_{i.j} = \frac{\left(A_{i.j-in+D^2}\right)^{m+1} - A_{i.j-in}^{m+1}}{D^{m+2} . X_{i.j}^{m} . (22.13)^m}$ $M = \frac{\beta}{1+\beta}; \beta = \frac{sin\theta/0.0896}{3(sin\theta)^{0.8}+0.56}$ $S_{i.j} = \begin{cases} 10.8 \sin\theta_{i.j} \div 0.03, tan\theta_{i.j} < 9\% \\ 16.8 sin\theta_{i.j} - 0.50, tan\theta_{i.j} \geq 9\% \end{cases}$	Where Li.j = slope length factor for the grid cell with coordinates (i.j); D = the grid cell size (m); Xi.j = $sin\alpha_i + cos\alpha_{i.j}$; $ai.j$ = aspect direction for the grid cell with coordinates (i.j); Ai.j-in = flow accumulation or contributing area at the inlet of a grid cell with coordinates (i.j) (m2), β = the ratio of inter-rill erosion and θ = the slope in degrees	[20]
6	Land Surface Temperature (LST),	$LST = BT/1 + W^* (BT/P)^* ln(e)$	Where BT = AT Satellite temperature; W = Wavelength of emitted radiance; P = h*c/s (1.438*10^ – 2mK); h = Planek's constant (6.626*10^ –34JS); S = Boltzmann constant (1.38*10^ –23J/K); C = Velocity of light (2.998*10^ gm/s); P = 14380	[21]
7	Normalized Difference Vegetation Index (NDVI),	$NDVI = \frac{Near\ IR\ Band - Red\ Band}{Near\ IR\ Band + Red\ Band}$	Yielding values between -1.0 to +1.0, higher NDVI values correspond to a greater abundance of chlorophyll, an indication of vegetation productivity	[22]
8	Rainfall Erovisity	$EI_{30} = (EC)(I_{30})$	Where EI_{30} is the erosivity index for an event in mj.mm/ha/h, EC is the total Kinetic of rain in mj/h, I_{30} is the maximum intensity of rain in 30 min in mm/h.	[23]
9	Soil Moisture Index (SMI),	$SMI = \frac{(NIR - SWIR)}{(NIR + SWIR)}$	SMI is seen as the proportional difference between the current soil moisture, the permanent wilting point or the field capacity of soil moisture and the residual soil moisture.	[24]
10	Erodibility Factor,	$K = 2.1 \times 10^{-5} \times M^{1.14} \times (12 - OM) + 0.03 \times (P - 2) + 0.03 \times (S - 3)$	Where K = the USLE soil erodibility factor, M = (% silt + % fine sand) (100% clay); OM % Organic matter; P = Permeability class; and S = Structure class.	[25].

3. Results and Discussions

3.1. Soil Sample Locations

Soil samples were collected randomly from sixty (60) point locations in the three (3) geopolitical zones due to the complex nature of the study area. These soils were tested both physically and chemically at the Departments of Soil Science Laboratory, Faculty of Agriculture, University of Nigeria, Nsukka. Sample locations are shown in figure 2 below.

Figure-2. Soil Sampled Locations



Source: USGS, Modified by the Authors, (2020)

3.2. Soil Analysis

Soil samples were collected randomly from sixty (60) point locations in the study area based on geological formations. These soils were tested for both physical and chemical constituents of soil capable of encouraging susceptibility to erosion (Table 2).

3.2.1. Particle Size

This was done to ascertain the bonding vis-à-vis the susceptibility level of these soils to detach between varying soils particles and to ascertain the aggregate stability of the soils.

The particle size distribution of the soils across the study area shows that the soils are predominantly sandy (57 - 89 % sand) with very low clay (8 - 23%) and silt (3 - 28%) contents.

3.2.2. Moisture Content

High or low moisture content leads to high erosion rates [26, 27]. Moisture content also has positive impact on erosion resistance of finer soils and negative effect on erosion resistance of coarse-grained soils. Researchers like Grissinger [28]; Hanson and Cook [29] and Kemper, *et al.* [30] suggested that moderate soil moisture content favours rapid bond strengthening among soil particles.

Larionov, *et al.* [27], discovered that there is the lowest erosion rate in heavy loamy Chernozem soils with an initial water content of 22% – 24%. It should be noted that soil moisture contents of soils of the study area range from a low of 11.93% to a high of 38.86%.

3.2.3. Dispersion Ratio (DR)

This has been successfully used to predict soil erosion by water [31]. Igwe [32], indicated that soils with high DR have the potentials to erode more easily than those with lower DR. According to Middleton [33] and Ayadiuno and Ndulue [15], soils having a dispersion ratio greater than 0.15 are erodible in nature. The higher the DR, the more there is the ability of the soil to disperse and the more the soil loss.

The dispersion ratio (DR) values range from 0.429 to 0.865. The dispersion ratio (DR) being an index from water-dispersible silt and clay and their corresponding total form has also been successfully used to predict erosion by water [6, 31]. According to Igwe and Udegbunam [31], the ability of the soil to disperse, increases with increasing DR.

3.2.4. Saturated Hydraulic Conductivity (KSat)

This is a measure of soil permeability and an important soil hydraulic property that affects water flow and transportation of dissolved solutes [34]. Soils with low Ksat in the topmost soil layer may not favour water movement freely within the soil layer culminating in a high runoff and soil loss. According to Okoyeh, *et al.* [7], hydraulic conductivity, transmissivity and plasticity index in the Nanka formations range from 1.20 x 10^{-1} to 5.93 x 10^{-1}cm s^{-1}, 1.15 x 10^{-5} to 13.05 x $10^{-3}m^2s^{-1}$ and 12.50% to 36.57% respectively. The saturated hydraulic conductivity (Ksat) of the soils varies from rapid (12.7 - 25.4 cm hr^{-1}) to very rapid (>25.4 cm hr^{-1}) in most of the locations investigated except at Omor and Umumbo that were within the moderately rapid (6.3 - 12.7 cm hr^{-1}) range. Generally, soils with low Ksat in the topsoil layer may not support water movement within the soil layers, resulting in considerable runoff and soil loss.

3.2.5. Bulk Density (BD)

This is the measure of soil compactness and one of the main physical properties of soil that have been used to show soil erodibility. The high compactness of soil reduces permeability and limit water infiltration thereby increasing runoff and soil loss. The high bulk density obtained in this study could be attributed to the low organic matter contents of the soils. Evrendilek, *et al.* [35] reported that an increase in soil bulk density by 10.51% increases soil erodibility by 46.2%. The BD of the soils range from < 1.4 g cm^{-3} (less compaction) in few locations to > 1.5 g cm^{-3} (highly compacted) in most of the locations. Highly compacted soils reduce soil permeability and limit water infiltration into the soil, resulting in increased runoff volume and soil loss. The high BD obtained in the study area could be attributed to the low organic carbon contents of the soils because the soils are poorly enriched with organic matter, and subsequently decreases the porosity of the soils. Soils with high BD and low organic content do not support the growth of plants. Okpuno, a town near Awka has the lowest organic matter content and is highly ravaged by soil erosion. Bulk density across the study area ranges between 1.30 – 1.63 g/cm^3. Areas with soil BD less than 1.4 g/cm^3 have soils that are not compacted but friable, leading to erosion. Communities like Umueri and Aguleri have soils that are highly compacted compared with communities like Ozubulu, Ihiala, and Enugwu-Ukwu whose soils are not compacted, hence the relics of gully sites in these non compacted communities. The results of Nanka and environs like Agulu, Nise, and Nkpologwu show that the soils are of loose materials and require little force to detach and transport the particles. As these soils are loose in nature, they influence their water holding capacity and hydraulic conductivity which makes the soils more prone to erosion.

3.2.6. Soil Porosity (SP)

This measures the level of available pore spaces for water flow and storage in soil, and are mostly high ranging from 38.49 – 55.66%. Such high SP will enhance water infiltration into the soil and consequently reduce surface runoff and soil loss. This further confirmed the findings of Lima, *et al.* [36] who reported that soil erodibility had a negative correlation with SP.

3.2.7. Plastic Limit (PL), Liquid Limit (*LL*) and Plasticity Index (PI)

These are Atterberg limit test that deals with form change from solid to viscous fluid state respectively. PL and LL depend on soil composition like clay and soil organic matter content, and by implication, high plastic soils show more resistance or are less erodible than low plastic soils. The plastic limit is the point at which a soil specimen when exposed to moisture begins to change from a solid-state to a semi-solid or plastic (flexible) state while the liquid limit means the amount of moisture that if added to a soil specimen, causes the soil to change from semi-solid or plastic to a viscous fluid state [37]. The plasticity index (PI), plastic limit (PL), and liquid limit (LL) obtained from this study are presented in Table 2. From the results (Table 2), PI ranges from 3.92 - 20.88%, while the plastic limit (PL) ranges from 10.23 - 31.98%. Similarly, the liquid limit (LL) ranged from 15.49 – 43.00%. Generally, the PI, PL, and LL are low and could be attributed to the clay type, which is mostly Kaolinite, low organic matter, and clay contents of the soils. Zhuang, *et al.* [38], also reported that PI, PL, and LL depend on soil properties such as clay and organic matter. According to Zhuang, *et al.* [38] and Deng, *et al.* [39], PL and LL had a significant and positive correlation with organic matter and by implication, they increase with increasing organic matter content. It has been reported that highly plastic soils generally show more resistance i.e. less erodible to erosion as compared with low plasticity soils [40].

3.2.8. Mean Weight Diameter (MWD)

This shows the structure of the soil macro-aggregate, and integrates aggregate size and class distribution into one number. MWD was analyzed to check the stability of the soils. MWD values obtained in this study were less than 2 mm which are unstable based on Le Bissonnais, *et al.* [41] Classification. Troeh, *et al.* [42] noted that stable aggregates increase soil resistance to detachment and transportation and can also improve soil permeability. Parwada and Van Tol [43] reported significant negative correlation between soil loss and MWD indicating that as the MWD increased, the rate of soil loss decreased. Most of the MWD values obtained across the study locations were less than 2 mm (Table 2), which are considered to be "unstable" based on the classification of Le Bissonnais, *et al.* [41]. These types of soils would be eroded very easily. MWD is used for explaining, quantifying, or predicting soil erosion and other problems such as crusting and sealing.

3.2.9. Aggregate Stability (AS)

The result shows that the aggregate stability (AS) varied from low (below 20 %) to moderate (20% - 55%). This implies that these soils are made up of mostly unstable aggregates which break down resulting to the pores collapse and produces finer particles and micro aggregates that contribute immensely to soil erosivity [11]. On the contrary, Toy, *et al.* [44] discovered that soils with aggregate stability have the capacity to resist the direct impact of raindrop, and protect the soil even as runoff occurs. Similarly, Troeh, *et al.* [42] noted that stable aggregates increase the soil resistance to detachment and transportation agents and in addition, it can improve soil permeability. Wang, *et al.* [2] and Singh and Khera [45] found that water stable aggregates (WSA) > 0.50 mm (AS) was significantly negatively correlated with soil erodibility. Generally, soil erodibility decreases with increasing aggregate stability which is related to the organic carbon content, clay content and infiltration capacity [46, 47].

3.2.10. Soil pH

High pH value of soils promotes dispersion, sealing and runoff [48]. Soil pH of this study ranges from strongly acidic (5.1 – 5.5) to slightly alkaline (7.4 – 7.8). Soils high in silt content, increased pH, increases erodibility especially when the structure is very fine or fine granular. Erodibility therefore increases with increased pH for medium or coarse granular [49].

3.2.11. Organic Carbon (OC)

The chemical composition of soil has an impact on the erodibility of both fine- and coarse-textured soils. The soil result shows that the soils have less than 2% of soil organic carbon content across the sampled locations. The average soil organic carbon content of the soil sampled ranges from 0.17% to 1.81%. According to Evans [50], soils with less than 3.5% organic carbon content i.e. 2% soil organic carbon content can be considered erodible [11].

3.2.12. Organic Matter (OM)

Soils with soil organic matter content that are very low are susceptible to soil erosion [51], as soil organic matter increases, there will be stability of the soils. Kemper and Koch [52] and Greenland, *et al.* [53] opined that soil organic matter content critical level is at 2%. Critical level below the suggested level will lead to soil structural stability decline [11]. Such decline in structural stability increases the susceptibility of the soils to erosion. The poor organic matter contents of these soils makes them to become loose and consequently slides may occur under heavy rainfall that may easily detach the soils.

3.2.13. Cation Exchange Capacity (CEC)

Dimoyiannis, *et al.* [54], reported that CEC negatively affect the instability of soil aggregates that lead to the collapse of soil structure, slow infiltration rate and low permeability. Erodibility is weakly correlated with CEC [48]. The soil result shows that Anaku and Umueze Anam have soils with high CEC and may not be easily erodible.

Table-2a. Particle Size Distribution, Moisture Content and Dispersion Ratio of Soils across Anambra State

S/N	Location	FS (%)	CS (%)	TS (%)	Silt (%)	Clay (%)	Textural class	Moisture content (%)	DR
1	Aguleri 1	38	48	86	3	11	LS	36.13	0.713
2	Aguleri 2	34	48	82	7	11	LS	29.70	0.777
3	Agulu 1	18	64	82	7	11	LS	16.96	0.473
4	Agulu 2	15	63	78	9	13	SL	17.65	0.387
5	Akpo 1	19	61	80	7	13	SL	34.95	0.498
6	Akpo 2	25	52	77	9	13	SL	33.11	0.635
7	Anaku 1	34	42	76	11	13	LS	21.95	0.833
8	Anaku 2	44	24	68	19	13	SL	23.00	0.484
9	Awka 1	30	50	80	9	11	SL	11.36	0.426
10	Awka 2	27	51	78	11	11	SL	12.74	0.478
11	Ekwulobia 1	31	51	82	5	13	SL	30.71	0.665
12	Ekwulobia 2	31	49	80	5	15	SL	29.87	0.598

13	Enugwu-Ukwu 1	35	46	81	9	10	LS	11.36	0.650
14	Enugwu-Ukwu 2	30	57	87	3	10	LS	12.49	0.695
15	Eziowelle 1	38	45	83	3	14	SL	16.41	0.647
16	Eziowelle 2	38	47	85	3	12	LS	15.87	0.738
17	Ideani 1	32	49	81	9	10	LS	16.82	0.546
18	Ideani 2	32	57	89	3	8	LS	17.23	0.757
19	Igbariam 1	64	16	80	9	11	SL	20.05	0.799
20	Igbariam 2	59	19	78	11	11	SL	21.25	0.818
21	Ihiala 1	11	63	74	13	13	SL	19.33	0.460
22	Ihiala 2	35	43	78	11	11	SL	18.91	0.453
23	Mgbakwu 1	36	53	89	3	8	LS	17.92	0.757
24	Mgbakwu 2	39	50	89	3	8	LS	16.55	0.757
25	Nando 1	24	62	86	3	11	SL	19.76	0.856
26	Nando 2	32	46	78	9	13	LS	20.34	0.726
27	Nibo 1	35	50	85	7	8	LS	17.51	0.558
28	Nibo 2	47	40	87	5	8	LS	16.01	0.794
29	Nimo 1	33	54	87	5	8	LS	16.28	0.794
30	Nimo 2	27	62	89	3	8	LS	13.38	0.936
31	Nise 1	31	43	74	9	17	SL	17.64	0.460
32	Nise 2	20	41	71	11	18	SL	18.20	0.398
33	Nkpologwu 1	17	63	80	9	11	SL	31.23	0.498
34	Nkpologwu 2	23	51	74	15	11	SL	32.62	0.460
35	Nnewi 1	26	50	76	11	13	SL	19.62	0.498
36	Nnewi 2	20	60	80	9	11	SL	20.77	0.498
37	Nsugbe 1	38	30	68	9	23	LS	18.69	0.561
38	Nsugbe 2	50	26	76	3	21	SCL	15.87	0.498
39	Ojoto 1	27	60	87	5	8	LS	13.89	0.794
40	Ojoto 2	28	59	87	5	8	LS	15.34	0.794
41	Okija 1	24	52	76	11	13	SL	12.74	0.498
42	Okija 2	31	45	76	9	15	SL	13.89	0.498
43	Oko 1	26	40	66	13	21	SCL	18.62	0.410
44	Oko 2	20	62	82	7	11	LS	19.48	0.554
45	Okpuno 1	43	38	81	3	16	SL	15.74	0.650
46	Okpuno 2	48	39	87	3	10	LS	16.14	0.794
47	Omor 1	48	28	76	9	15	SCL	18.91	0.833
48	Omor 2	36	50	86	3	11	SL	17.23	0.713
49	Onitsha 1	28	58	86	3	11	LS	21.65	0.713
50	Onitsha 2	39	47	86	3	11	LS	20.34	0.856
51	Ozubulu 1	28	50	78	11	11	SL	19.05	0.544
52	Ozubulu 2	30	34	64	11	25	SCL	20.63	0.588
53	Ukpor 1	27	43	70	9	21	SCL	31.93	0.465
54	Ukpor 2	34	48	82	7	11	LS	30.72	0.665
55	Umueri 1	60	22	82	7	11	LS	15.20	0.554
56	Umueri 2	75	11	86	3	11	LS	16.41	0.713
57	Umueze-Anam 1	39	23	62	15	23	SCL	39.41	0.262
58	Umueze-Anam 2	47	13	60	17	23	SCL	38.31	0.399
59	Umumbo 1	50	8	58	27	15	SL	17.50	0.571
60	Umumbo 2	48	9	57	29	15	SL	18.34	0.636
	Average	**34.23**	**44.42**	**78.82**	**8.33**	**12.85**		**20.53**	**0.62**
	STDEV	**12.23**	**14.90**	**7.95**	**5.37**	**4.21**		**7.01**	**0.15**

Table-2b. Structural and Hydraulic Properties of Soils across Anambra State

S/N	Location	Ksat (cm hr^{-1})	BD (g cm^{-3})	SP (%)	LL (%)	PL (%)	PI	MWD (mm)	AS (%)
1	Aguleri 1	40.40	1.55	41.51	13.51	12. 65	.86	1.5559	23.95
2	Aguleri 2	42.42	1.57	40.75	18.35	14.35	4	1.4902	29.86
3	Agulu 1	18.03	1.49	43.77	14.55	12.22	2.33	0.6761	17.95
4	Agulu 2	20.61	1.39	47.55	21.99	17 .32	4.67	0.7308	24.07
5	Akpo 1	15.45	1.44	45.66	20.92	14.81	6.11	0.4929	13.62
6	Akpo 2	18.67	1.63	38.49	35.07	21.42	13.65	0.5868	14.02
7	Anaku 1	33.94	1.53	42.26	17.98	14.47	3.51	1.1462	40.51
8	Anaku 2	28.85	1.41	46.79	47.33	39.49	7.84	1.0256	38.76
9	Awka 1	33.48	1.55	41.51	16.46	11.79	4.67	0.6814	19.62

10	Awka 2	38.64	1.68	36.60	26.06	15.92	10.14	0.6012	16.60
11	Ekwulobia 1	14.14	1.54	41.89	19.09	13.68	5.41	1.2178	38.45
12	Ekwulobia 2	11.16	1.49	43.77	19.79	15.77	4.24	1.1865	40.44
13	Enugwu-Ukwu 1	27.78	1.33	49.81	16.45	12.34	4.11	0.8151	29.60
14	Enugwu-Ukwu 2	28.33	1.34	49.43	20.99	16.37	4.62	1.0313	33.08
15	Eziowelle 1	31.94	1.57	40.75	20.47	16.28	4.19	1.3112	46.34
16	Eziowelle 2	30.91	1.48	44.15	18.39	17.45	0.94	1.5288	44.47
17	Ideani 1	43.79	1.45	45.28	16.76	14.98	1.78	1.3072	42.67
18	Ideani 2	49.45	1.58	40.38	18.32	13.65	4.67	1.3985	39.66
19	Igbariam 1	12.88	1.56	41.13	20.39	17.69	2.7	0.6523	19.01
20	Igbariam 2	13.39	1.47	44.53	21.84	17.92	3.92	1.4204	23.66
21	Ihiala 1	15.66	1.32	50.19	18.53	13.71	4.82	1.5547	50.83
22	Ihiala 2	16.16	1.36	48.68	24.35	16.93	7.42	1.6139	48.43
23	Mgbakwu 1	45.08	1.53	42.26	24.47	17.31	7.16	1.3347	45.47
24	Mgbakwu 2	48.94	1.53	42.26	12.99	10.52	2.47	1.3919	48.54
25	Nando 1	42.22	1.49	43.77	11.07	9.67	1.4	1.1638	54.50
26	Nando 2	41.21	1.48	44.15	26.82	14.05	12.77	1.6122	47.22
27	Nibo 1	38.89	1.55	41.51	22.30	13.27	9.03	1.5212	38.66
28	Nibo 2	34.00	1.56	41.13	20.52	17.82	2.7	1.5772	36.09
29	Nimo 1	38.89	1.42	46.42	18.88	15.11	3.77	0.9276	28.99
30	Nimo 2	43.79	1.52	42.60	22.21	17.39	4.82	1.2542	30.79
31	Nise 1	32.83	1.47	44.53	24.10	20.64	3.46	0.9353	30.66
32	Nise 2	31.82	1.35	49.06	25.82	20.19	5.63	0.7721	25.59
33	Nkpologwu 1	21.21	1.49	43.77	18.14	14.74	3.4	1.3410	43.29
34	Nkpologwu 2	19.70	1.22	53.96	26.70	16.56	10.14	0.7976	31.12
35	Nnewi 1	18.55	1.63	38.49	23.19	21.79	1.4	1.1059	36.01
36	Nnewi 2	16.16	1.36	48.68	26.87	24.56	2.31	1.3860	39.05
37	Nsugbe 1	38.89	1.45	45.28	33.38	19.17	14.21	1.8695	34.83
38	Nsugbe 2	41.67	1.53	42.26	37.25	17.97	19.28	1.9308	36.22
39	Ojoto 1	46.36	1.55	41.51	18.31	14.39	3.92	0.8677	29.40
40	Ojoto 2	37.09	1.54	41.89	19.69	17.42	2.27	0.8872	25.27
41	Okija 1	26.26	1.45	45.68	24.90	21.66	3.24	1.6138	28.89
42	Okija 2	30.30	1.55	41.51	20.15	17.39	2.76	1.6396	33.21
43	Oko 1	15.66	1.41	46.79	33.57	12.69	20.88	0.6494	28.43
44	Oko 2	17.17	1.54	41.89	37.05	25.76	11.29	0.8875	30.86
45	Okpuno 1	44.30	1.36	48.68	19.54	17.42	2.12	0.7225	8.85
46	Okpuno 2	45.25	1..49	43.77	11.43	10.23	9.31	0.4965	9.55
47	Omor 1	9.60	1.26	52.45	31.93	26.74	5.19	0.3587	17.02
48	Omor 2	9.61	1.71	35.47	30.13	24.63	5.5	0.4782	13.18
49	Onitsha 1	31.42	1.41	46.79	23.74	17.49	6.25	1.8758	41.58
50	Onitsha 2	32.45	1.57	40.75	24.33	15.91	8.42	1.9635	32.65
51	Ozubulu 1	14.14	1.24	53.21	16.67	14.31	2.36	0.7224	22.78
52	Ozubulu 2	18.10	1.36	48.68	29.06	15.79	13.27	0.6265	19.49
53	Ukpor 1	23.74	1.45	45.28	23.88	11.78	12.10	1.2217	39.40
54	Ukpor 2	26.79	1.56	41.13	20.25	13.52	6.73	1.1063	38.88
55	Umueri 1	7.73	1.64	38.11	29.63	17.42	12.21	1.2245	32.47
56	Umueri 2	9.27	1.62	38.87	25.28	13.17	12.11	1.0799	28.23
57	Umueze-Anam 1	12.63	1.11	58.11	38.21	15.59	22.62	0.6320	39.13
58	Umueze-Anam 2	13.64	1.24	53.21	37.31	20.17	17.14	0.7714	39.21
59	Umumbo 1	9.09	1.28	51.70	33.07	17.43	15.64	1.2185	48.70
60	Umumbo 2	9.05	1.58	40.38	26.49	17.26	9.23	1.3939	51.24
	Average	**27.16**	**1.47**	**44.51**	**23.62**	**16.90**	**6.92**	**1.12**	**32.68**
	STDEV	**12.59**	**0.12**	**4.59**	**7.30**	**4.76**	**5.17**	**0.41**	**11.21**

Source: Laboratory Result Compiled by the Authors, (2020)

Table-2c. The Chemical Properties of Soils across Anambra State

S/N	**Location**	**pH_{H2O}**	**pH_{KCl}**	**OC (%)**	**OM (%)**	**CEC (Me/100 g)**
1	Aguleri 1	6.1	5.0	0.760	0.802	9.60
2	Aguleri 2	6.4	5.4	1.399	2.411	11.20
3	Agulu 1	6.7	5.5	0.693	1.194	7.60
4	Agulu 2	4.5	4.0	1.690	2.914	8.00
5	Akpo 1	6.8	6.2	1.810	3.120	10.80

6	Akpo 2	6.2	5.4	1.052	1.813	8.80
7	Anaku 1	5.9	4.8	1.279	2.205	16.00
8	Anaku 2	5.0	4.0	1.997	3.443	28.00
9	Awka 1	7.4	6.3	0.653	1.126	9.20
10	Awka 2	7.9	6.8	1.291	2.226	9.60
11	Ekwulobia 1	7.2	6.4	0.852	0.987	8.40
12	Ekwulobia 2	7.4	6.6	2.049	3.533	12.80
13	Enugwu-Ukwu 1	7.3	6.4	1.411	2.433	10.00
14	Enugwu-Ukwu 2	6.9	6.0	1.411	2.433	8.80
15	Eziowelle 1	5.5	4.5	1.810	3.120	9.60
16	Eziowelle 2	6.9	6.1	0.733	1.263	8.00
17	Ideani 1	6.4	5.4	1.212	2.089	9.20
18	Ideani 2	7.1	6.0	0.773	1.332	7.20
19	Igbariam 1	5.9	4.4	0.720	1.242	14.40
20	Igbariam 2	5.9	4.5	0.601	1.035	10.40
21	Ihiala 1	6.6	5.7	1.650	2.845	10.00
22	Ihiala 2	6.9	6.2	1.650	2.845	14.00
23	Mgbakwu 1	5.3	4.2	0.693	1.194	10.40
24	Mgbakwu 2	6.0	4.3	1.052	1.813	10.00
25	Nando 1	5.6	4.2	0.401	0.691	4.40
26	Nando 2	5.8	4.8	1.598	2.755	18.00
27	Nibo 1	7.3	6.4	1.890	3.258	12.40
28	Nibo 2	6.5	5.9	1.331	2.295	11.60
29	Nimo 1	6.6	6.1	1.770	3.052	12.00
30	Nimo 2	7.2	6.5	1.439	2.480	9.60
31	Nise 1	5.8	4.5	1.052	1.813	12.00
32	Nise 2	6.9	5.9	1.052	1.813	12.00
33	Nkpologwu 1	5.0	4.2	1.132	1.951	8.40
34	Nkpologwu 2	4.9	4.0	1.178	2.031	14.80
35	Nnewi 1	6.1	5.2	1.331	2.295	8.80
36	Nnewi 2	6.0	5.2	1.810	3.120	10.00
37	Nsugbe 1	5.6	4.1	0.321	0.554	16.40
38	Nsugbe 2	6.1	5.0	0.880	1.517	10.80
39	Ojoto 1	6.3	5.5	1.079	1.861	11.60
40	Ojoto 2	6.1	5.2	0.561	0.967	10.40
41	Okija 1	7.2	6.4	1.730	2.983	10.40
42	Okija 2	7.3	6.3	1.890	3.258	9.20
43	Oko 1	5.4	4.4	1.331	2.295	9.60
44	Oko 2	6.9	6.1	1.451	2.501	12.80
45	Okpuno 1	7.3	6.7	0.162	0.279	10.80
46	Okpuno 2	6.3	5.7	0.184	0.317	9.60
47	Omor 1	4.7	3.7	1.040	1.792	20.00
48	Omor 2	5.6	4.7	0.521	0.898	9.60
49	Onitsha 1	7.9	7.1	1.518	2.618	20.00
50	Onitsha 2	7.7	6.8	1.001	1.725	10.40
51	Ozubulu 1	6.8	6.1	1.571	2.708	10.80
52	Ozubulu 2	5.9	5.2	0.972	1.676	6.00
53	Ukpor 1	5.7	4.7	1.132	1.951	8.00
54	Ukpor 2	6.6	5.9	1.092	1.882	10.40
55	Umueri 1	5.8	4.7	1.040	1.792	4.40
56	Umueri 2	6.2	5.2	0.441	0.762	8.40
57	Umueze-Anam 1	5.3	4.0	1.598	2.755	36.40
58	Umueze-Anam 2	5.5	4.0	0.242	0.416	28.40
59	Umumbo 1	4.9	3.9	1.119	1.930	20.00
60	Umumbo 2	5.9	4.8	1.638	2.824	19.60
	Average	**6.28**	**5.32**	**1.16**	**1.99**	**12.00**
	STDEV	**0.83**	**0.93**	**0.49**	**0.86**	**5.64**

Source: Laboratory Result Compiled by the Authors, (2020)

3.3. Anthropogenic Activities as a Factor of LULCC and NDVI in Soil Erosion Occurrences

Land Use Land Cover Change (LULCC)

Satellite imagery of the study area was downloaded from USGS and processed with ArcGIS 10.2, and the resultant maps are land use/land cover as shown in figures 3(a), 3(b), 3(C), 3(d). The maps showed a sharp increase in land use and land cover variations in various settlements and in other areas attracting developmental projects in the study area. The change as detected in this study occurred from 1987 to 2017 due especially to anthropogenic activities of land users such as estate developers, farmers, among others.

Table-3. Areas and Percentages of Land Use Land Cover Change (LULCC)

Year	1987		1997		2007		2017		% Change
Name	Area (Km)²	Area %	Area (Km)²	Area %	Area (Km)²	Area %	Area (Km)²	Area %	
Vegetation	2579.91	53.26	2292.18	47.32	1541.85	31.83	1392.65	28.75	-24.51
Crop Land	1282.69	26.48	1340.33	27.67	1186.30	24.49	1211.97	25.02	-1.46
Bare Land	717.88	14.82	907.77	18.74	1085.54	22.41	1149.48	23.73	8.91
Settlements	227.18	4.69	222.82	4.6	926.66	19.13	993.50	20.51	15.82
Water Body	35.85	0.75	81.38	1.67	103.66	2.14	95.91	1.99	1.24

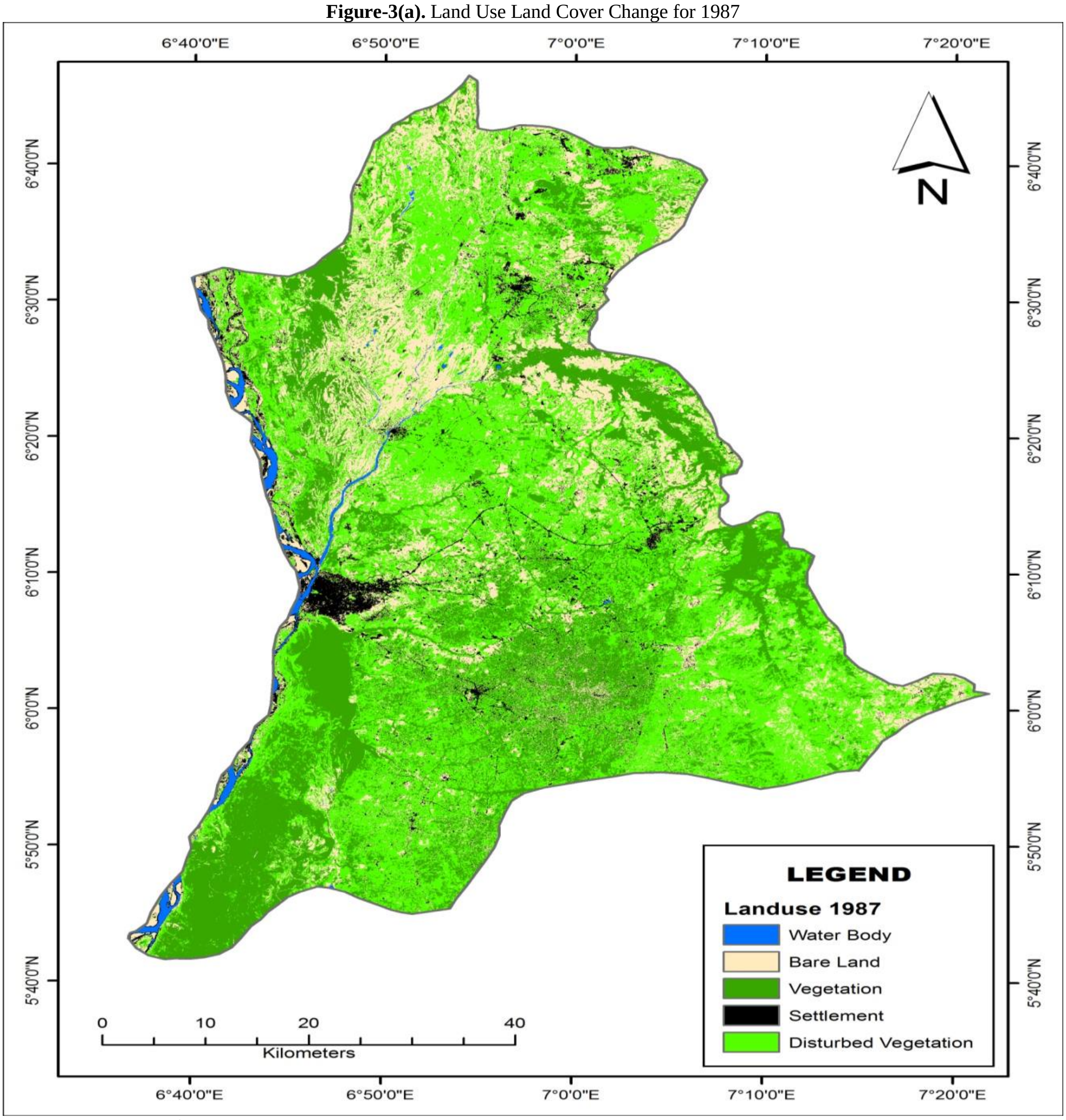
Source: Authors' Computation, (2021)

The table above shows the changes that occur in the study area from 1987 to 2017. The vegetated areas were reduced by 24.51 percent, while disturbed areas like farm lands were reduced by 1.46. Bare land, Settlement and water bodies were increased by 8.91, 15.82 and 1.24 percent respectively. It is worthy to note that there is a positive correlation between land use land cover change (LULCC) and normalized difference vegetation index (NDVI) that is, the more vegetated areas are converted to built-ups, (lower vegetation), the low the NDVI of the areas. The areas with low NDVI in the study area are built-up settlements like Onitsha, Nnewi, Awka, Ekwulobia, and Umunze, among others. One of the characteristics of these settlements is covered landscapes as a result of buildings, roads, cemented compounds, among others. These anthropogenic activities encourage runoffs which may have little effects in these settlements, but at their outskirts (Plates A - C).

Plate-A. Runoffs Along Ekwulobia Road with Little Effect on the Environment, B and C: Devastating Effect of Gully Erosion at the Outskirts of Awka Caused by Runoffs Generated from the City Center

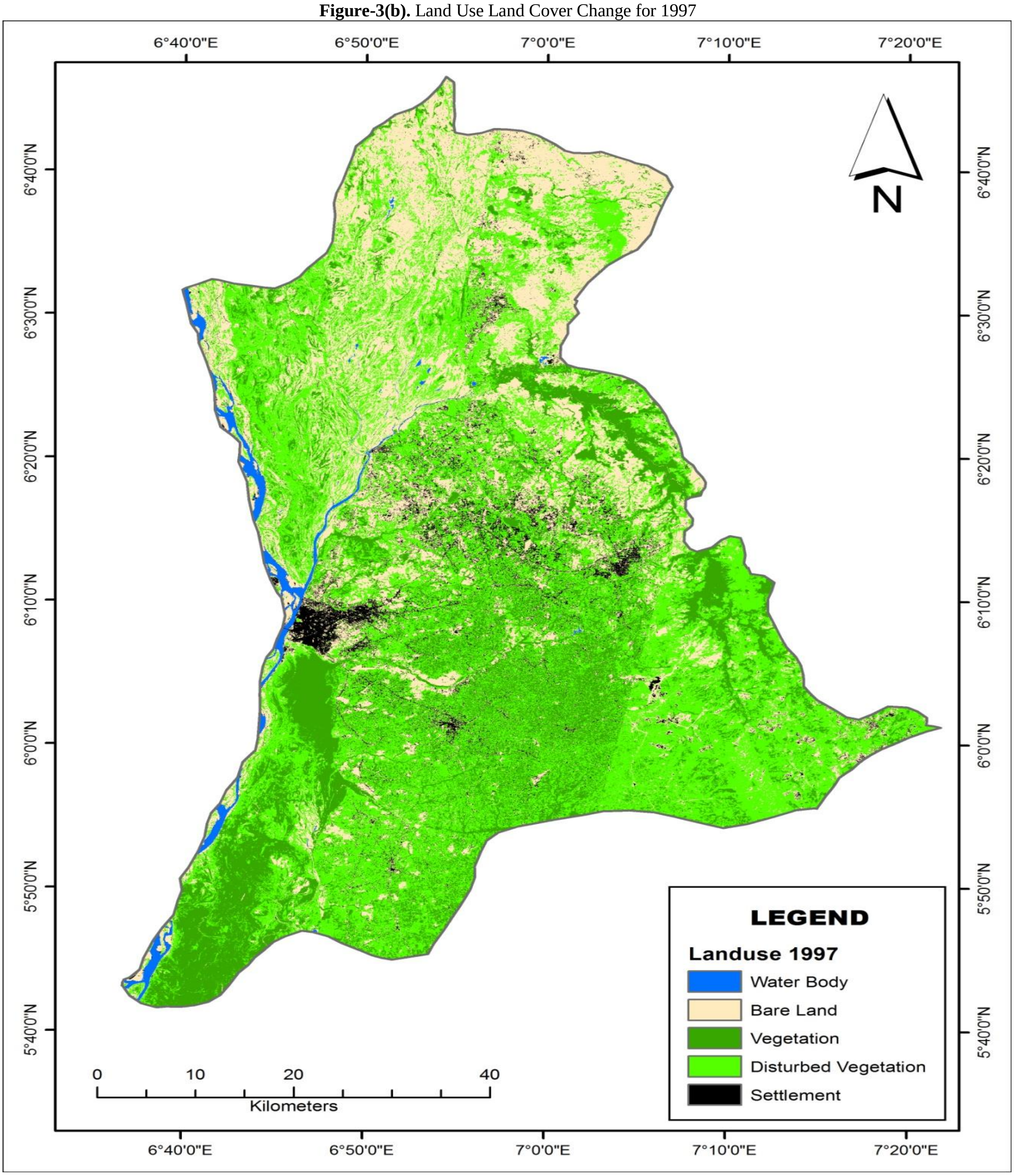
Source: Authors' Fieldwork, (2020)

Figure-3(a). Land Use Land Cover Change for 1987



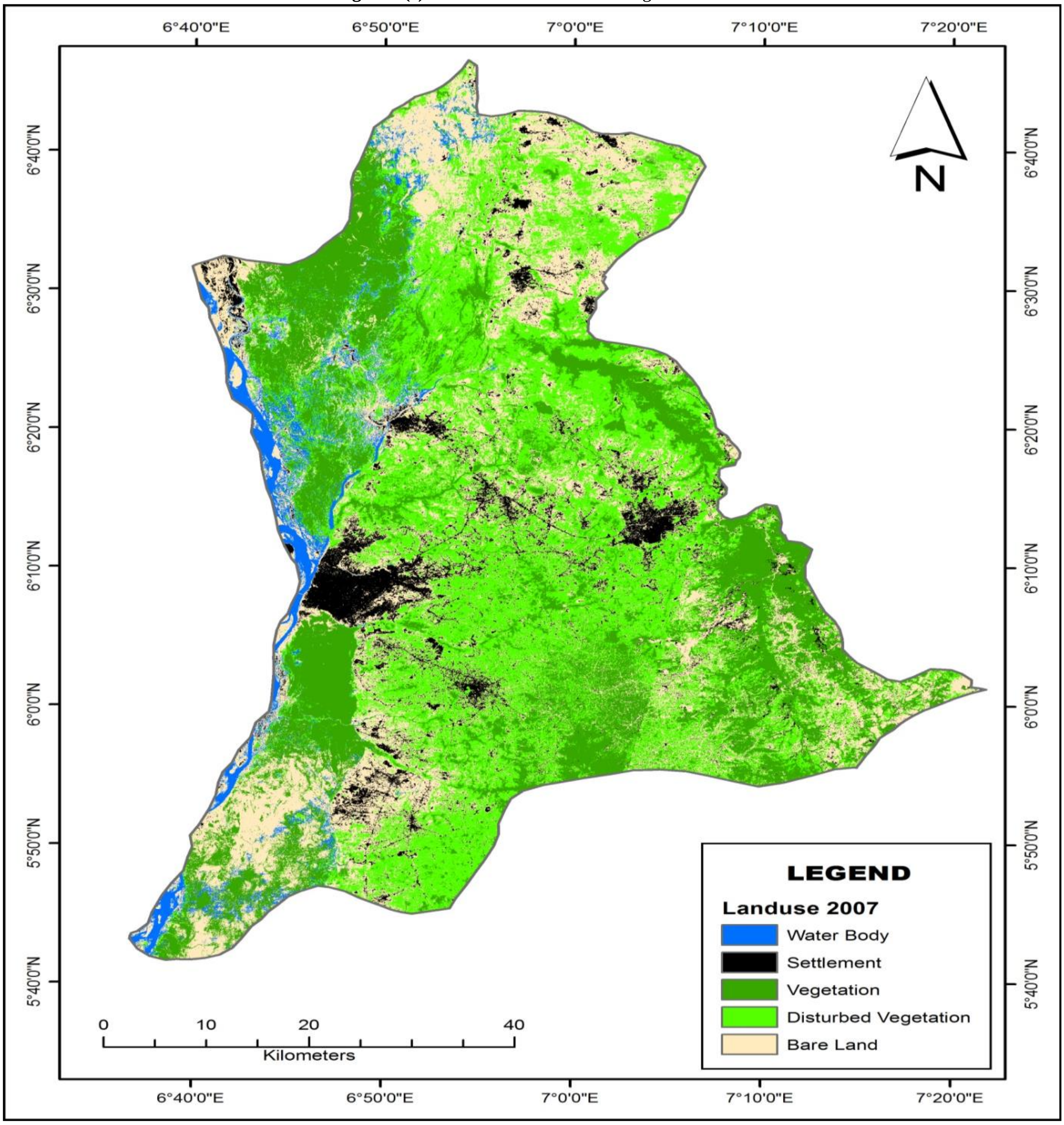
Source: USGS, Modified by the Authors, (2020)

Figure-3(b). Land Use Land Cover Change for 1997



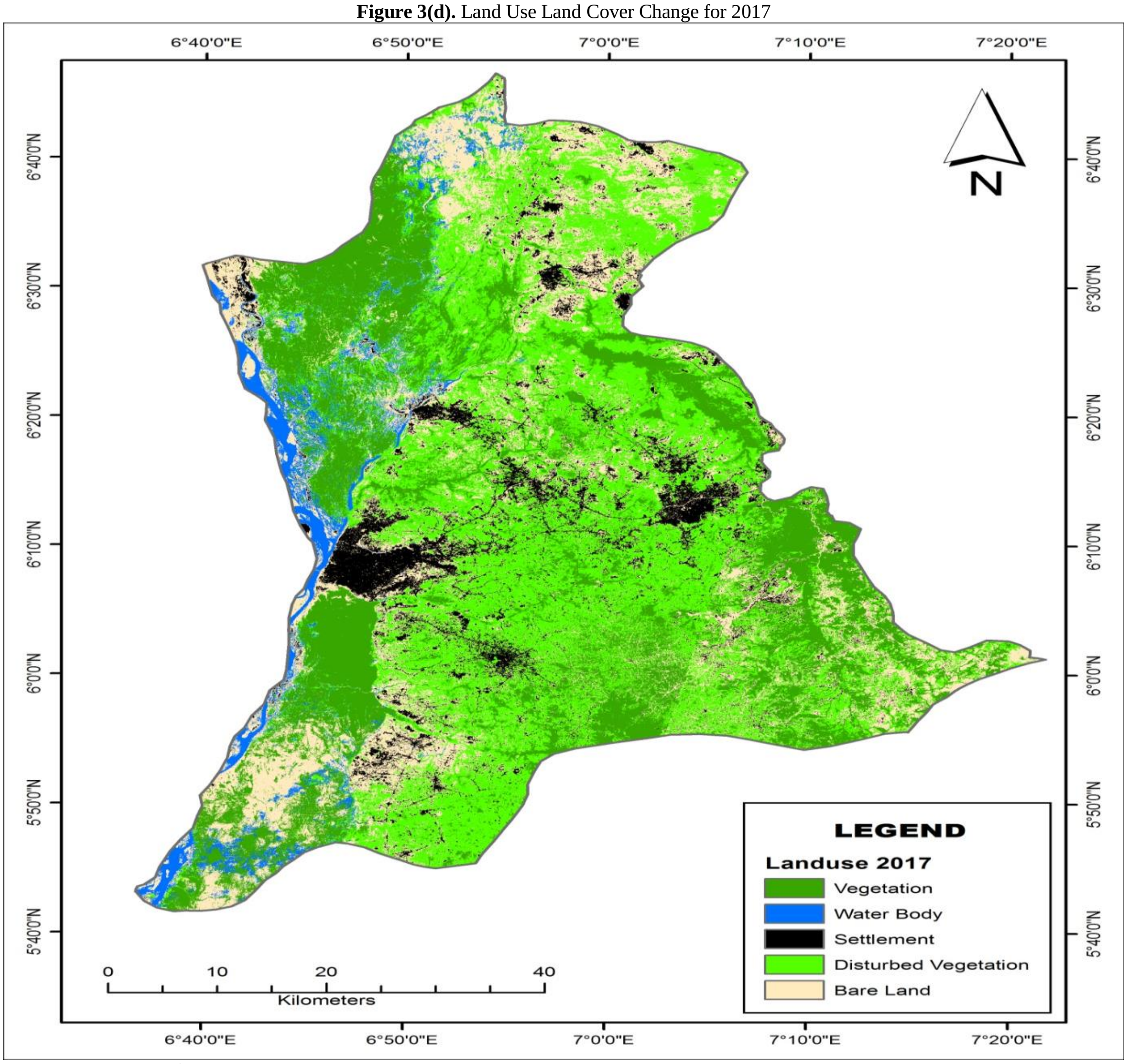
Source: USGS, Modified by the Authors, (2020)

Figure-3(c). Land Use Land Cover Change for 2007



Source: USGS, Modified by the Authors, (2020)

Figure 3(d). Land Use Land Cover Change for 2017



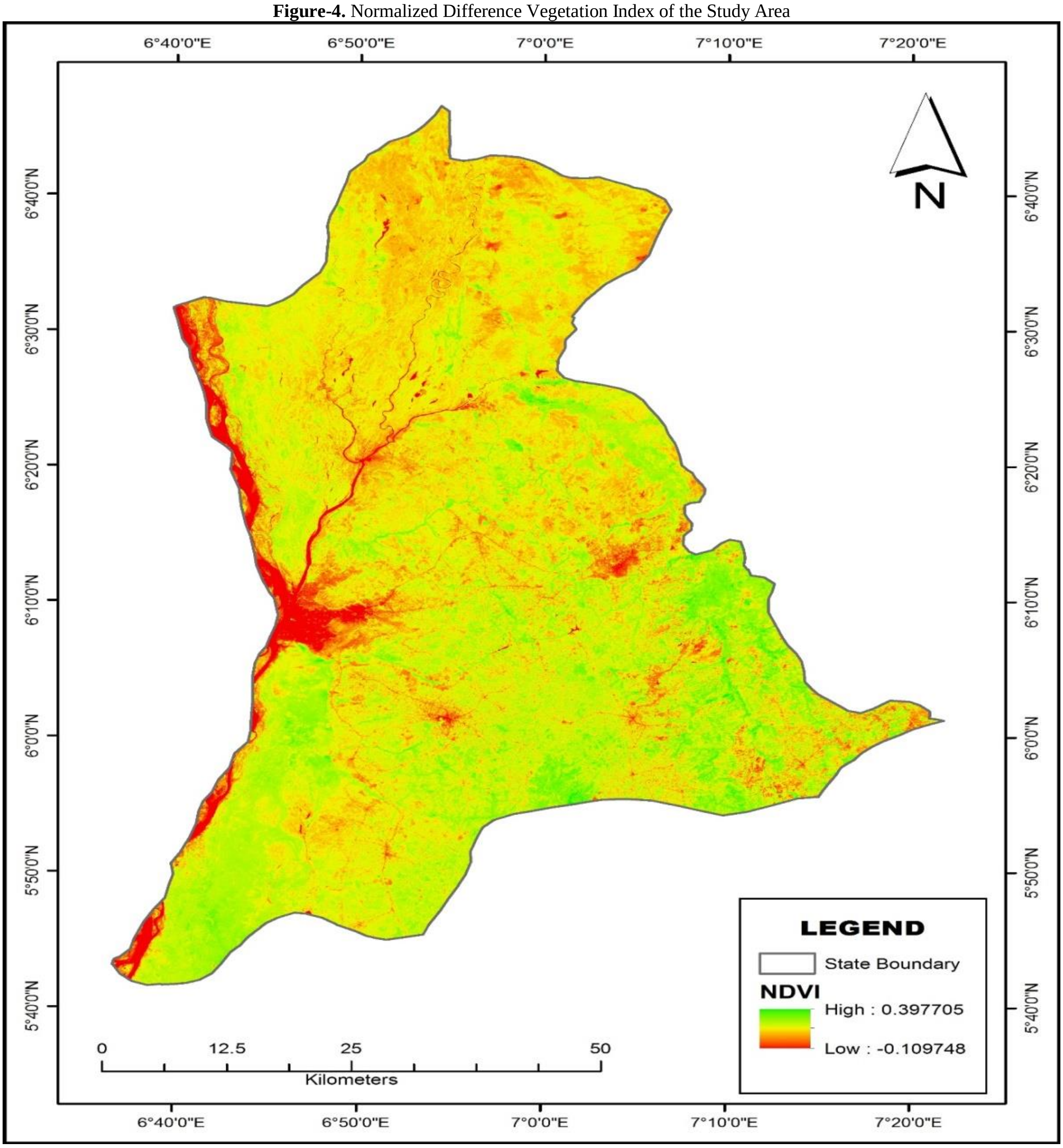
Source: USGS, Modified by the Authors, (2020)

In 1987 vegetation cover was about 53.27% of the study area and in 1997 it came down to 47.32%, in 2007 and 2017, it decreased to 31.83% and 28.75% respectively. These clearing of forests exposed the soils to erosion. Research work of Egbueri and Igwe [12] revealed that there is an increased land use activities in areas underlain by Nanka formations compared to areas underlain by Ogwashi and Benin formations due to high population. According to the researchers, population in those areas is inversely proportional to vegetation cover.

3.3.1. Normalized Difference Vegetation Index (NDVI)

NDVI is positively related to Land use Land cover [55]. The NDVI of the study area varied from 0.397705 to -0.109748 with an average of 0.1439785 and coefficient of variation of 22.02. NDVI map of the study area is shown in figure (8), with the erosion prone areas having lower NDVI as depicted in red with value of -0.109745 showing absence of vegetation and therefore exposed to erosion. This is possible especially in the cities of the study area and other vegetated areas were over grazing by Herders and incessant bush burning are reducing the areas to bare land which allow the generation of runoffs and subsequently initiating soil erosion. Areas with high NDVI are depicted in green with a value of 0.397705, showing full vegetation in the study area and restrict generation of runoffs, rather it encourages infiltration. This supports the fact that there is a relationship between low or negative value of NDVI (absence of vegetation), rainfall erosivity and soil susceptibility to erosion in the study area (Figure 4).

Figure-4. Normalized Difference Vegetation Index of the Study Area

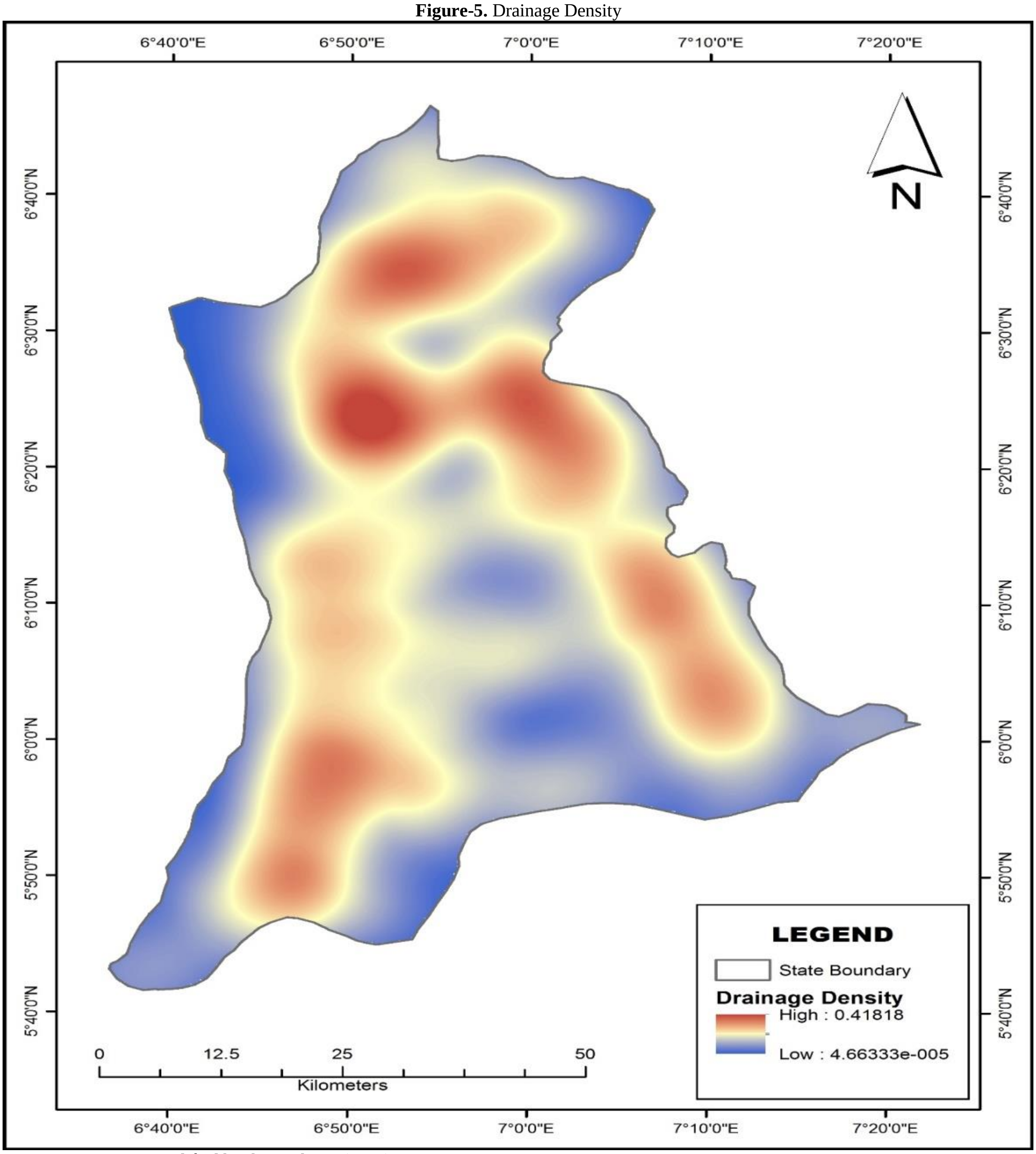


Source: USGS, Modified by the Authors, (2020)

3.3.2. Drainage Density (DD)

This is the total length of streams per unit area of a watershed. The Drainage Density of 0.000047 to 0.41818, shows that there is an increment as indicated in the Satellite image of water body in 1987 with 34.19 sq km^2 which increased to 77.33 sq km^2 in 1997 as a result of human environment activities which exposed more water bodies to satellite camera but again it went down in 2017 as a result of sand filling as seen in Onitsha and other riverine areas like Nkpor, Obosi, Oba and along Idemili river. As DD showed positive relationship with NDVI, the implication is that NDVI with high values reduces runoff generation, surface flow, encourages infiltration rate and subsequent aquifer and stream recharge and flow with moderation. On the other hand, NDVI with low or negative value (absence of vegetation), reduces infiltration rate and subsequent aquifer and stream recharge, encourages runoff generation, surface flow which increases velocity of flow on the land surfaces and in water bodies, thereby increasing the erosive force on the watershed. Drainage Density map of the study area is shown below in figure 5. From the map it can be observed that riparian areas have higher drainage density then the erosion prone area because the Awka – Orlu upland which lacks drainage systems accounting for more erosion in that area. It corroborates with the fact that the low plains have more streams, rivulets and rivers.

Figure-5. Drainage Density

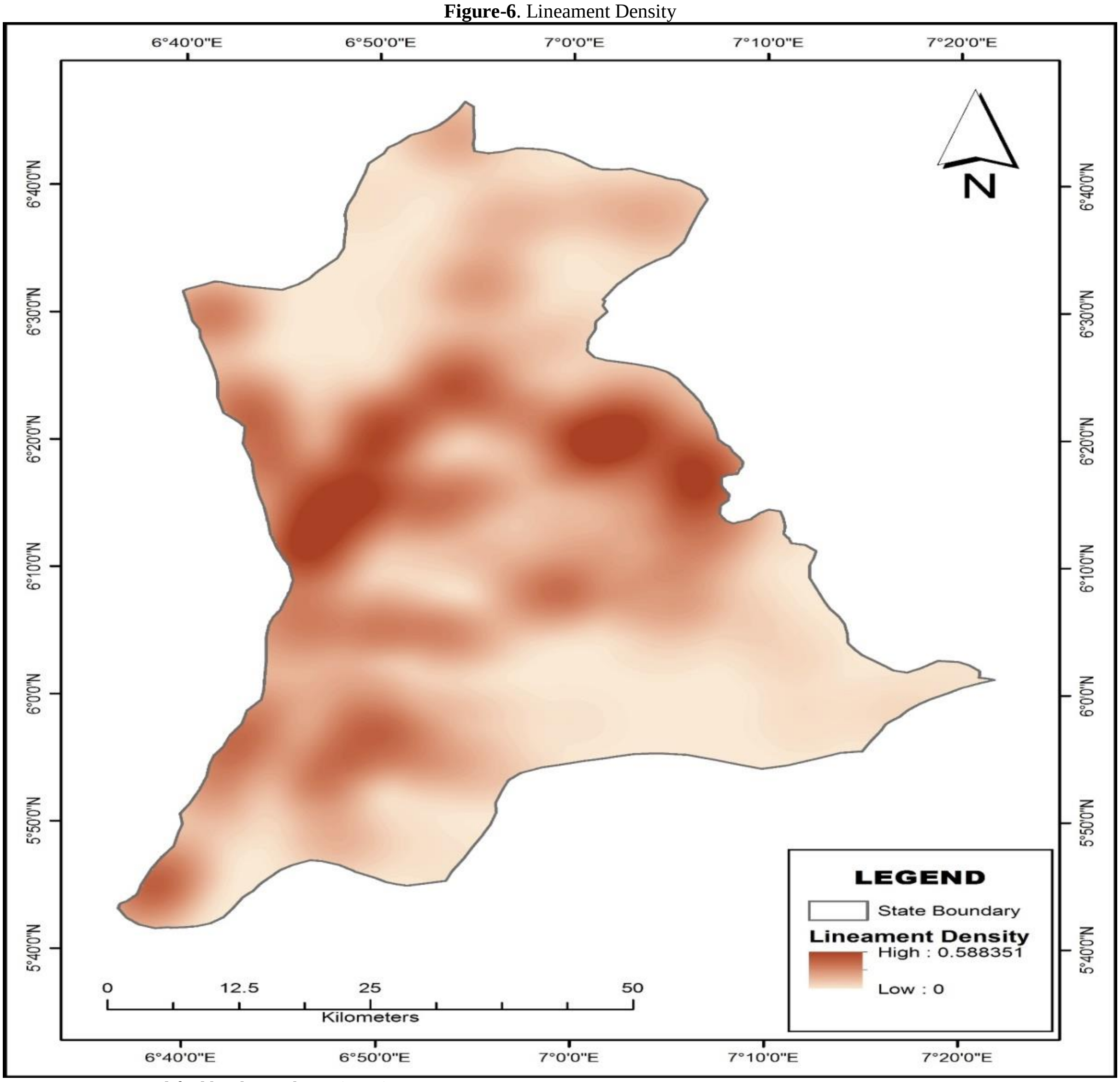


Source: USGS, Modified by the Authors, (2020)

3.3.3. Lineament Density (LD)

Lineament Density also showed a positive relationship with K-Factor by having values ranging from 0.000 to 0.58835 and a coefficient of variation of 66.71. Lineaments are fractures, joints or faults within the crust. These faults aid soil erosion as it allows more infiltration especially in parts of the study area that are low in clay content and lacks binding materials. Most soils as could be seen in the soil analysis are friable and collapse easily [7]. Lineament Density map of the study area is shown in figure 6. From the map, it could be observed that faults are more in the erosion devastated zones. These are areas with greater particle size and less in clay content. Igwe and Egbueri [10], had it that soil with lower percentage of fine sand has lower cohesion and high erodibility potentials. Because of the friability of these soils, it develops more fault lines which are later taken over by erosion as slope is high and generates tremendous runoff. Hong, *et al.* [56], pointed out that the shear strength of soil particles is closely related to their erodibility potentials. The fault lines are absent in some parts of Aguata and Orumba South LGAs, major parts of Anambra West and after the bluff in Ayamelum LGAs as shown in the map. Traces of faults are also observable in the south of Ozubulu (Ekwusigo LGA), Ihiala, Okija, Nnewi North, Nnewi South and Ogbaru LGAs. It is therefore observed that areas with higher Lineament Density correspond with areas of higher Erosion Density.

Figure-6. Lineament Density

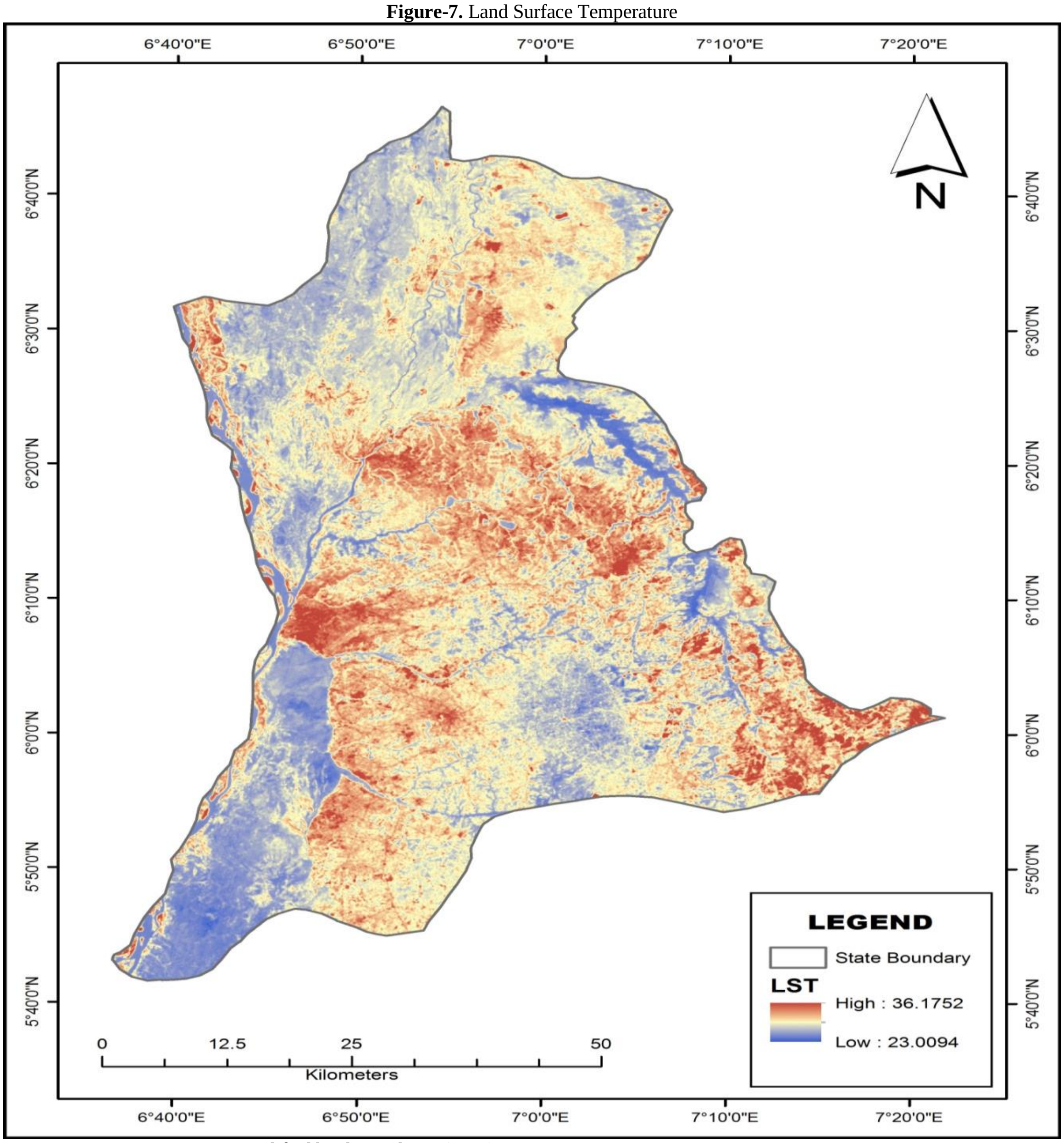


Source: USGS, Modified by the Authors, (2020)

3.3.4. Land Surface Temperature (LST)

This was evaluated to know its contribution to soil susceptibility to erosion in the study area and it revealed a sharp positive influence to soil erosion as it ranges from 23.009 to maximum of 36.1752. This causative factor is hardly considered as contributing to soil erosion. This was possible as land use land cover change (LULCC) changes induced by human or natural processes drive the biogeochemistry of the area influencing climate at regional scales. Drastic changes in the Land cover of the study area is positively correlated with NDVI. This is as a result of population explosion and unprecedented development. The study area as of 2016 had a projected population Census figure of five million, five hundred and twenty seven thousand eight hundred and nine (5,527,809) people and a population density of one thousand one hundred and seventy four (1174) persons per square/kilometer [57], and the results generated on LULCC/NDVI between 1987 and 2017 corroborated this. About 20.51% of the land surfaces in the study area presently are either covered, cemented or asphalted leading to low infiltration and greater runoff. An assessment of LST with a high of 40.71 and a low of 22.60, and K-factor (Erodibility) with a high of 0.176 and a low of 0.0007 reveals that there is a positive correlation between the two variables. The analysis showed the impact of land use change on LST. The changes of LST were related to many factors including changes in land use, land surface parameters, seasonal variations, climate variation and economic development. Most vegetation covers (24.51%) in the study area have given way to development as urbanization led to the migration of pixels from cool to hot surface condition. The soil particle size analysis revealed that saturated hydraulic conductivity (KSat) of Anam (Anambra East LGA), Umumbo, and Omor (Ayamelum LGA) were moderate because of high percentage of silt and clay which affects infiltration/permeability thereby causing high LST. In these communities, you cannot work bare footed in February - April without noticing the increase in LST, while reverse is the case in other months. These communities could have been susceptible to soil erosion except for the flat nature of the terrain. Land Surface Temperature map of the study area is shown in figure 7. From the map it can be observed that Ayamelum, Awka, Ihiala and Umunze areas have higher LST, this is attributed to the absence of vegetation and or vegetation types which is as a result of urban development and or high clay and silt contents of the soils found in the areas.

Figure-7. Land Surface Temperature

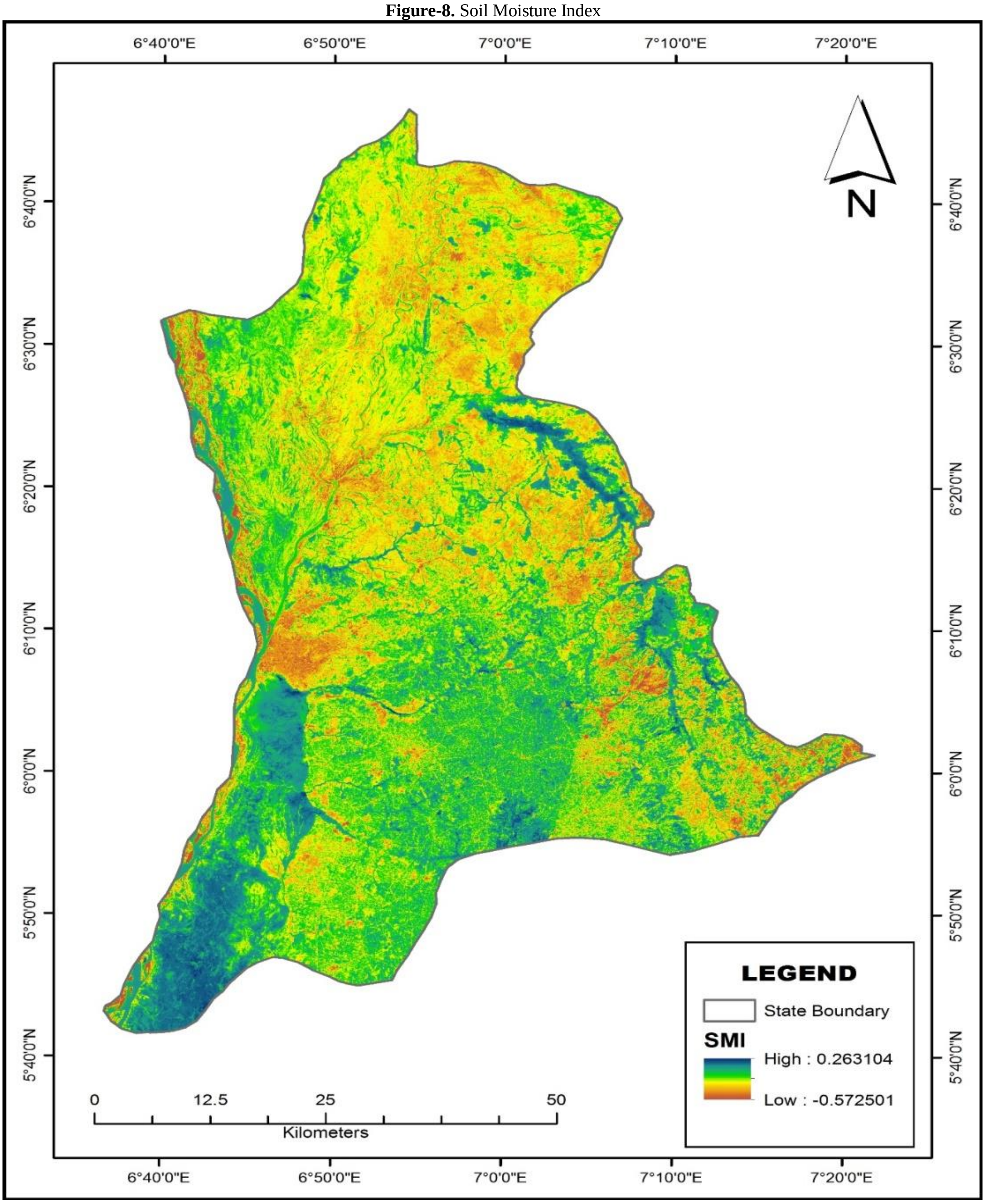


Source: USGS, Modified by the Authors, (2020)

3.3.5. Soil Moisture Index (SMI)

This showed a negative value of -0.5725 and maximum positive value of 0.26331 and coefficient of variation of 78.94. This causative factor depends on amount of surface recharge and available water holding capacity of the soil. From the soil analysis, Umueze Anam, Aguleri both of which are riparian communities, with large watersheds, rivulets and streams, and clay type of soil have high soil moisture content compared with the upland areas of Awka, Agulu and Enugu-Ukwu. These features ordinarily are enough to disintegrate and trigger soil erosion, but because of the low plain nature of the topography. The soils in these areas will easily get saturated and generate runoffs; however, their flat topography negates this. SMI Map of the study area is shown in figure 8. On the other hand the particle sizes of soils on Upland sections of the study area had more pore spaces with more infiltration rate but aggressive runoff due to high elevation. Hussein, *et al.* [58], reported that the higher the soil loss in a given pixel, the lower the amount of soil moisture available within the rooting depth. From the descriptive statistics, soil moisture index contribution to erosion was very insignificant where it had negative value, but varied to 0.93 with 78.94 coefficient of variation. The implication is that it contributes to soil susceptibility to erosion when more rains fall and urban development paved way for more infrastructure and destruction of vegetative covers. Again from the map which its imagery was taken in dry season precisely March, 2019; it could be observed that Ogbaru, parts of Anambra East – Aguleri specifically and Umueze Anam, parts of Awka North, and Orumba South L.G.As have high SMI. This is as a result of their proximity to rivers and other water bodies. Ayamelum L.G.A ordinarily should have moderate soil moisture index, but failed to do so as a result of the aforementioned clearing of over 5,000 hectares of forested land for an irrigated rice farm project. The River Niger banks in Ogbaru, the Confluence-area of Ezu and Omambala Rivers in Aguleri, the Ezu river banks of Ebenebe and Amansea all showed high SMI.

Figure-8. Soil Moisture Index

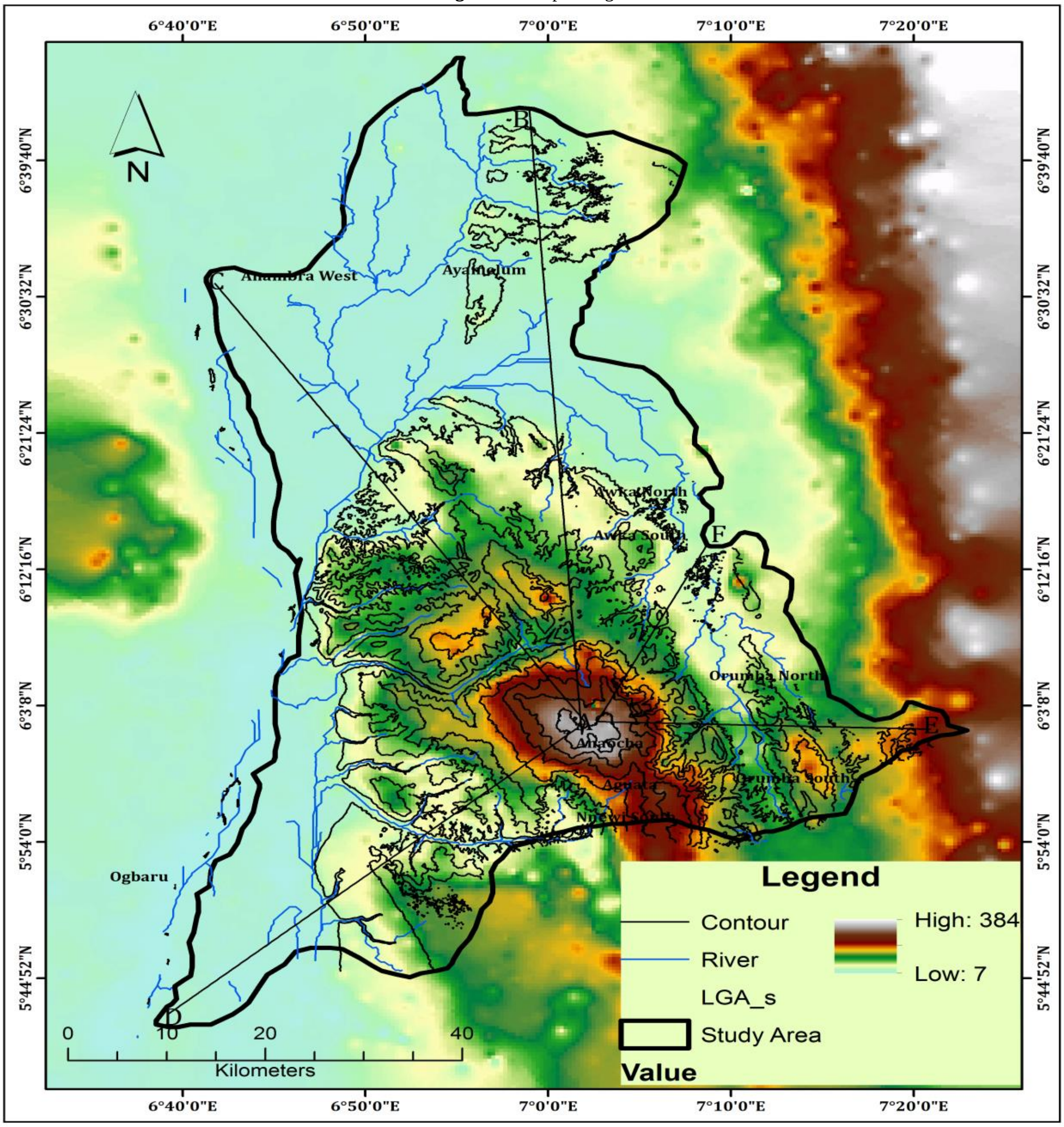


Source: USGS, Modified by the Authors, (2020)

3.3.6. Slope Length (LS)

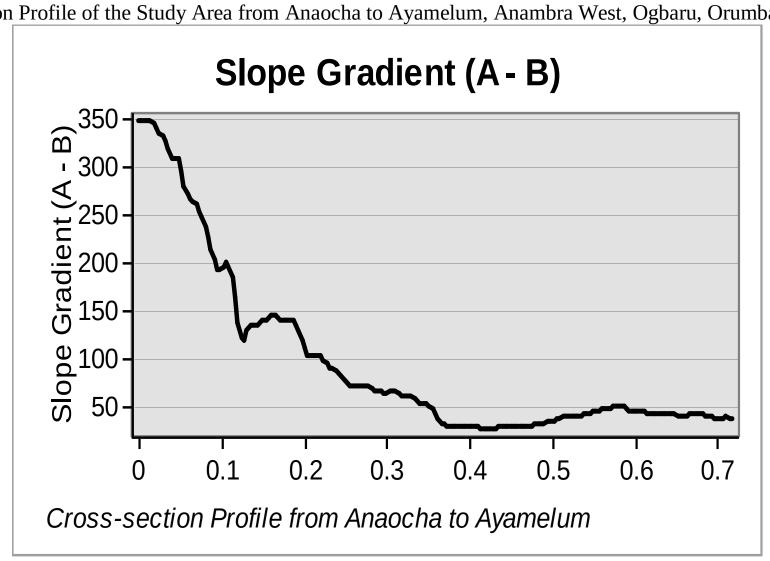
Slope length (LS) is one of the major soil erosion factors usually grouped under non-redundant causative factors. Slope length has a coefficient of variation of 0.000 to 1.1446. LS accounts for more runoffs especially on the higher grounds of Awka – Orlu upland with a slope angle of above 30^0 compared with the flood plains on the north-eastern fringes of the study area which is almost flat. A cross section profile of the study area is shown in figure 9b. The cross section shows the highest point in the study area, the nature of slope and their gradients up to the boundaries of the study area with other neighbouring States. It shows the trend of slope in the area and confirms the fact that slopes are major factor of soil erosion in higher grounds and generate runoffs that trigger soil erosion. From the cross section of the slope map, A – B shows that Anaocha L.G.A is over 350 m high compared to Ayamelum L.G.A. with height less than 40 m above mean sea level (Figure 9). A – C shows even gentler slope of less than 25^0. From the slope map, the red colour depicts the high ground of "Awka-Orlu upland" stretching across the borders of neighbouring States of Imo and Enugu (Figure 9a). A close look at the slope length map shows that Anaocha, Awka North, Awka South, Nnewi North and Nnewi South LGAs are seriously affected by soil erosion. Slope length and soil properties account more than any other factors to soil erosion as the slopes generate tremendous runoff during heavy rainfalls that disintegrate the soils, coupled with the weak and friable nature of soils in this parts of the study area. From this observation it could be said that slope length collaborates with areas consisting of weak and friable soils in the study area to cause soil erosion. Again, from the particle size analysis the aforementioned LGAs above are predominately sandy (57 – 89% sand) with low clay (8 – 23%), the soils are highly susceptible to erosion as they lack cohesion.

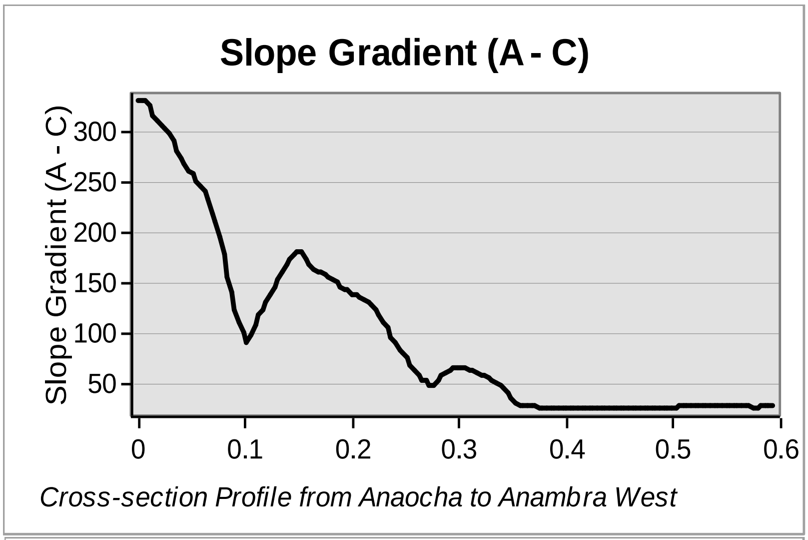
Figure-9a. Slope Length

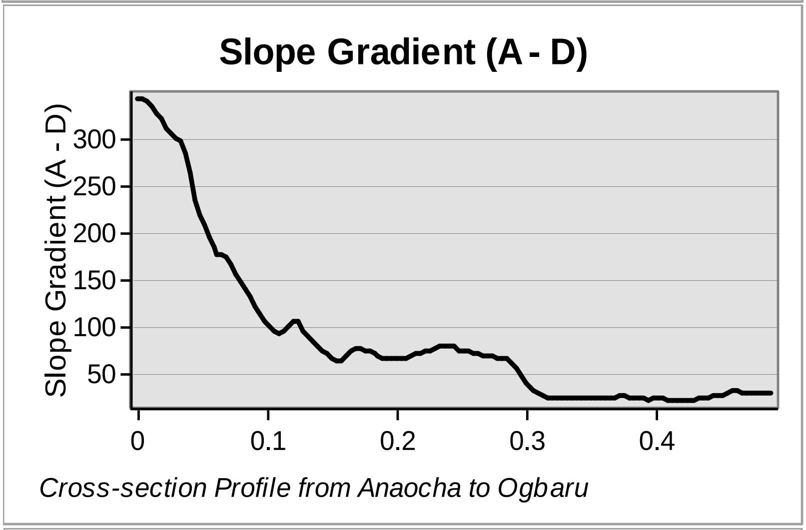


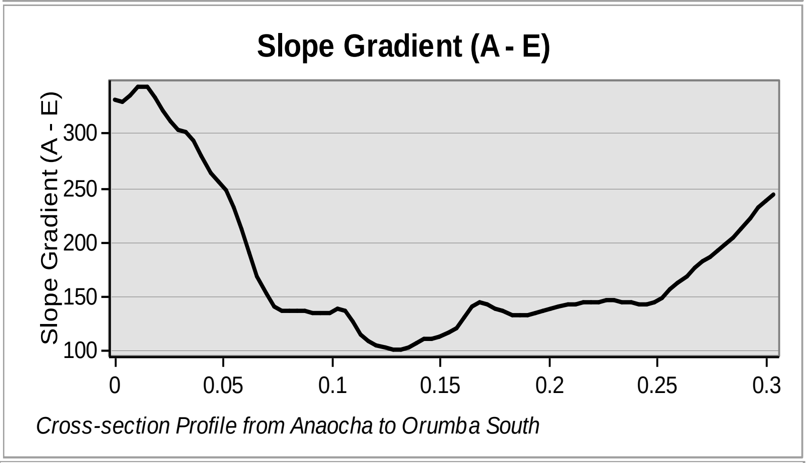
Source: USGS, Modified by the Authors, (2020)

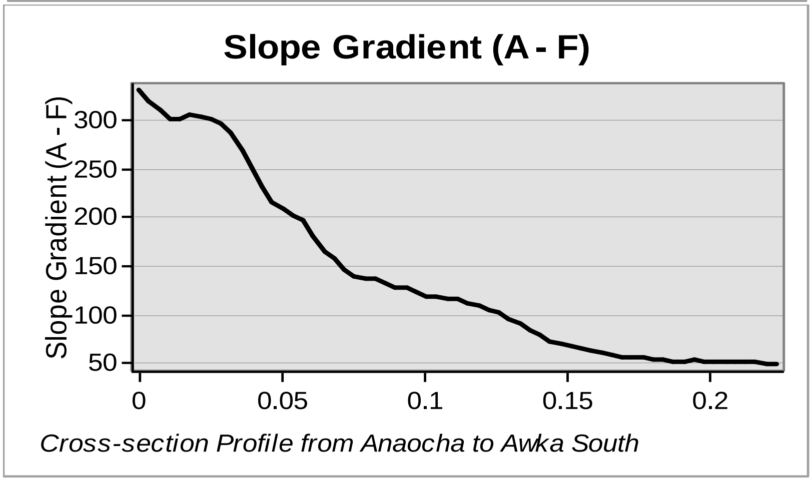
Figure-9b. Cross-section Profile of the Study Area from Anaocha to Ayamelum, Anambra West, Ogbaru, Orumba South and Awka South









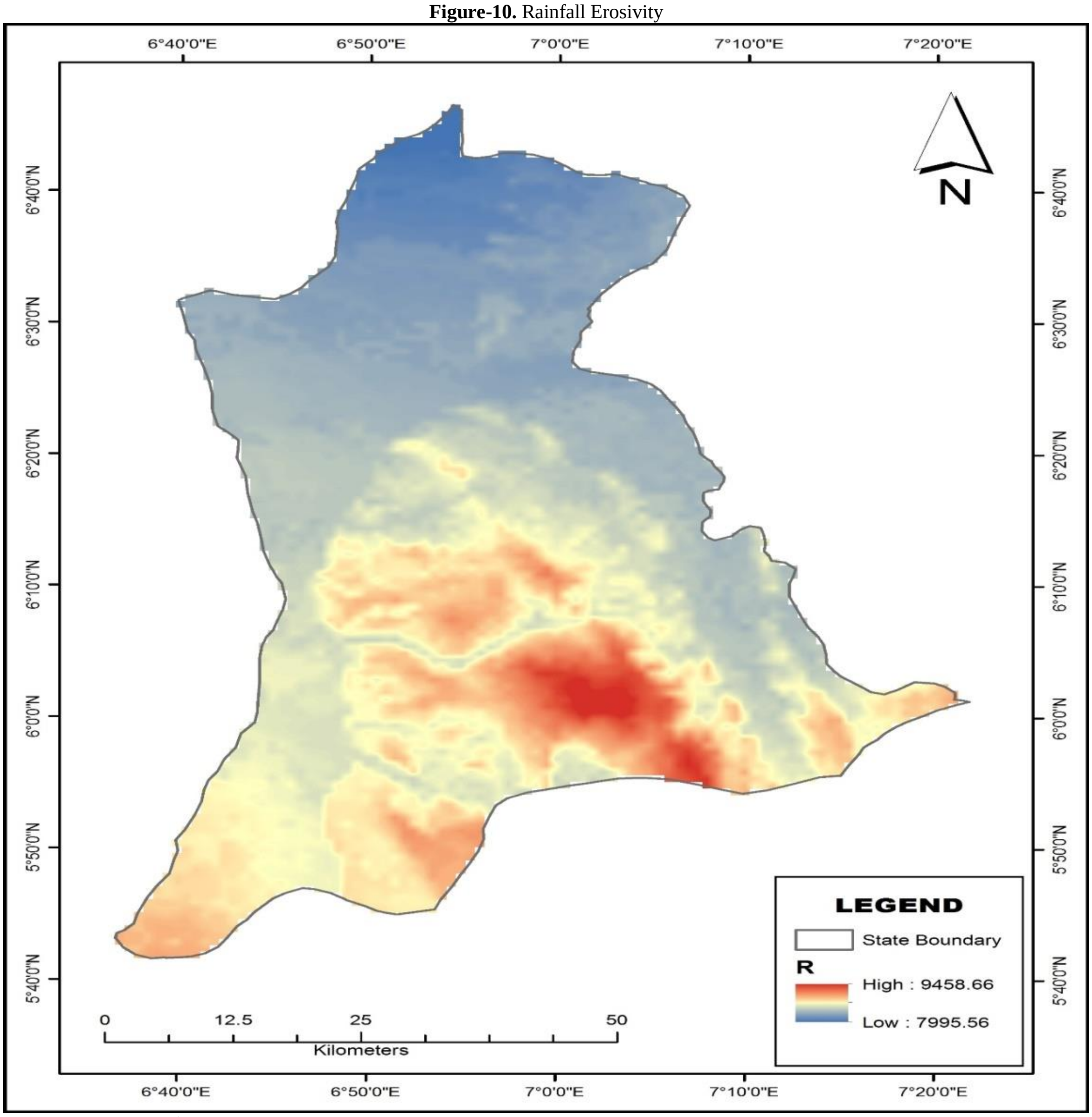


Source: USGS, Modified by the Authors, (2020)

3.3.7. Rainfall (R)

Rainfall varied from 7995.56 to 9458.11 with an average value of 1462.55 and coefficient of variation of 3.08. Rainfall is more in the southern part of the study and generates more runoff in higher ground geomorphologically than the plains. Figure 10 shows Rainfall map of the study area. From the map, rainfall is more in the southern part especially the erosion prone zones and generate more runoffs. Rainfall in the entire northern fringes of the study area is low. The entire Anambra East, Anambra West, Ayamelum, Oyi, parts of Orumba North, parts of Ogbaru LGAs have low rainfall compared with Aguata, Anaocha, Idemili North , Idemili South, Nnewi North, Nnewi South, Ihiala, Njikoka and parts of Orumba South LGAs. The later LGAs are where erosion is more pronounced and experiences average annual rainfall of over 2062 mm [59]. It therefore, suggests that areas of higher rainfall correspond with area of high erosion menace in the study area.

Figure-10. Rainfall Erosivity

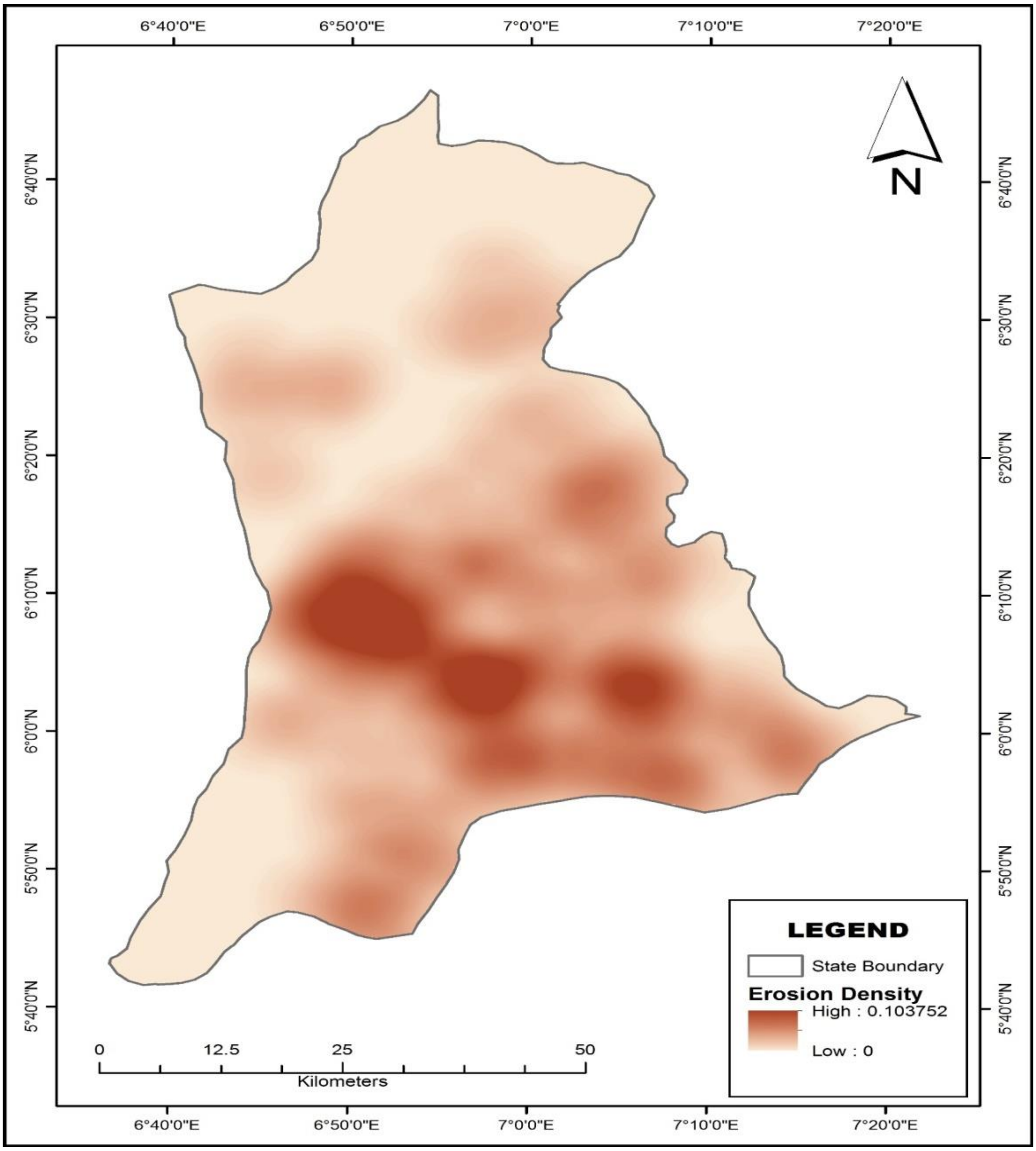


Source: USGS, Modified by the Authors, (2020)

3.3.8. Erosivity Density (ED)

This causative factor varied from 0.000 to 0.103752. This implies that where there is high erosion density, there is low drainage density. From Erosivity Density map (Figure 11), it is observed that areas around Awka – Orlu upland of the study area have high Erosion Density and this corresponds with areas of high Lineament Density and friable soils. A close look at the Erosivity Density map (Figure 11) shows that the entire plains in the study area have low ED. The whole of Ayamelum, Anambra East, Anambra West, Ogbaru, and pocket of areas in Awka North LGAs fall in this category. Erosion is high in Awka, Onitsha North, Anaocha, Ihiala, Nnewi North, Nnewi South and Aguata LGAs. These are areas of high Lineament Density, the implication is that areas with high Erosivity Density correspond with areas of high Lineament Density. Ramli, *et al.* [60], reported a positive relationship between Lineament Density and Erosivity Density where they studied lineament mapping and applications in landslide hazards assessment.

Figure-11. Erosivity Density

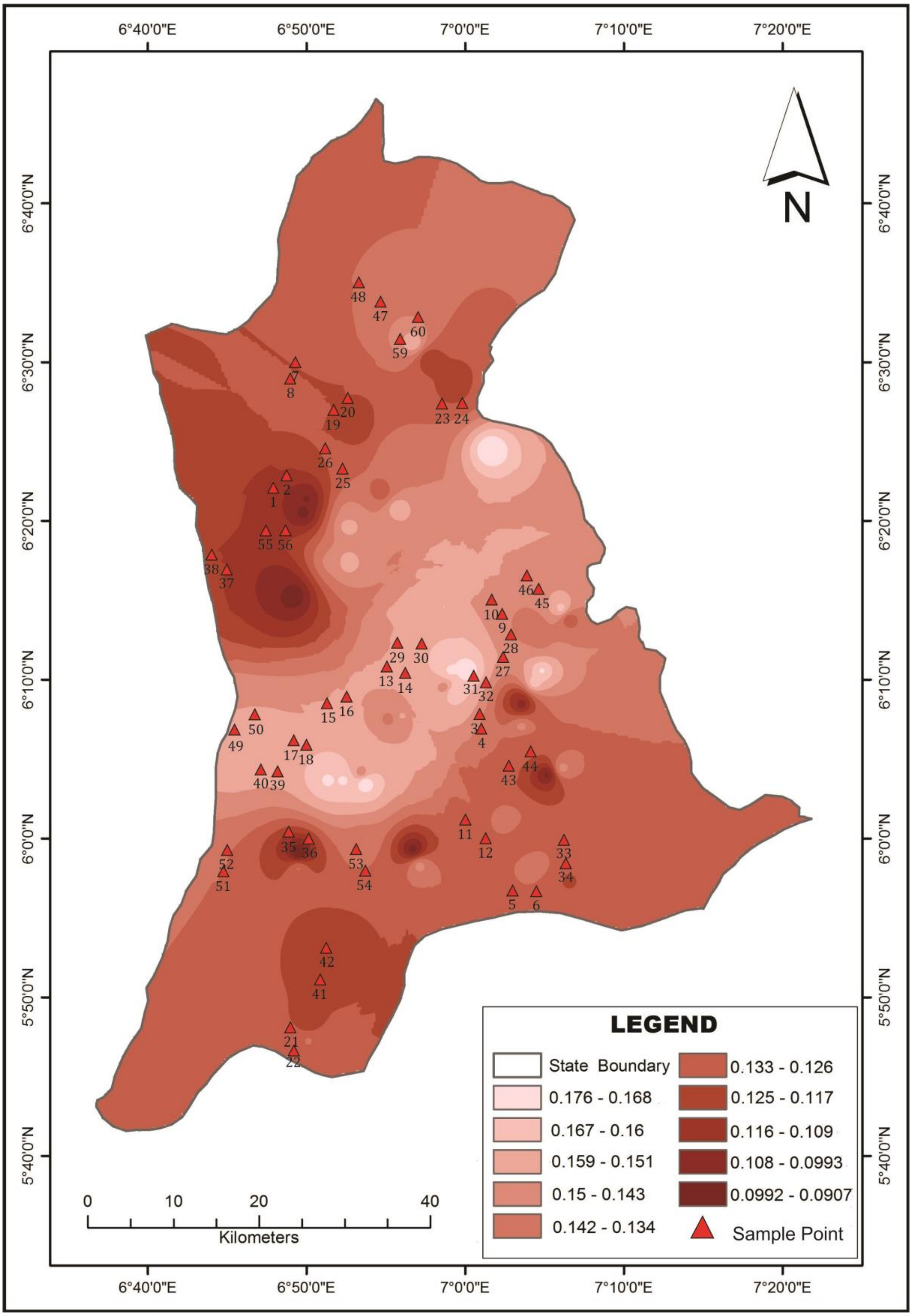


Source: USGS, Modified by the Authors, (2020)

3.3.9. Erodibility (K-Factor)

K-Factor varied from 0.09072 to 0.17523 with average value of 0.12978 and coefficient of variation of 18.05. Figure 12 shows the susceptibility and erodibility map of the study area. With this map, susceptibility level of any tract of land in the study area can be ascertained and precaution taken before embarking on any project therein. Other causative factors have positive relationship with soil erodibility based on findings of this research. From the erodibility map, areas with greater chances and levels of erodibility are shown with grades indicated on the legend. It is observed that the central parts of the study area have more values of K-factor and the areas consist of Anaocha, Orumba North, Aguata, Idemili North, Idemili South, Awka North, Awka South, parts of Ihiala, Onitsha North and Onitsha South LGAs. These areas are located on Nanka geological formation where the soils are friable and lack ionic bonding and or cohesive properties. Incidentally, majority of these LGAs are the most densely populated on the Awka-Orlu upland of the study area. The communities threatened by soil erosion include Agulu, Nanka, Ekwulobia, Nnewi, Awka, Okpuno, Ojoto, Omagba in Onitsha, and Awgbu among others.

Figure-12. Erodibility (K-Factor)



Source: USGS, Modified by the Authors, (2020)

4. Conclusion

The map analyses show that areas with high Drainage Density, Lineament Density, Erosion Density, Land Surface Temperature and Slope Length are erosion prone areas. Areas within and around Awka – Orlu upland, that is Awka, Awgbu, Nanka and Ekwulobia, Nnewi, Onitsha, Obosi, and Ojoto have high soil erosion tendencies; Ozubulu, Ihiala, and Okija have moderate soil erosion tendencies; while Ogbaru, Ayamelum, Anambra East and Anambra West LGAs have low soil erosion tendencies and or susceptibilities to erosion. The Erodibility Map shows the spatial variability in soil loss as a result of the combination of the various causative factors.

Remote sensing and GIS analysis present the effects of the causative factors on the occurrence of soil erosion. These causative factors were mostly not considered while treating the soil erosion factors. These causative factors especially LST, SMI, R and NDVI contributed to the loss of 8.91 ton/ha/yr; 9.1288 ton/ha/yr; 1,1134.7 ton/ha/yr and 0.245 ton/ha/yr respectively to soil erosion in the study area.

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Conflict of Interest

The authors declared that there is no conflict of interest

Data Availability Statement

All data used in this research are with the Corresponding Author and will be made available upon request.

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References

[1] Tang, K. L., 2004. *Soil and water conservation in China*. Beijing: Science Press. p. 845.

[2] Wang, B., Zheng, F., Romkens, M. J. M., and Darboux, F., 2013. "Soil erodibility for water erosion: A perspective and chinese experiences." *Geomorphology,* vol. 187, pp. 1-10. Available: https://doi.org/10.1016/j.geomorph.2013.01.018

[3] Abdulkadir, T. S., Muhammad, R. M., Yusof, K. W., and Ahmad, M. H., 2017. "Geostatistical based susceptibility mapping of soil erosion and optimization of its causative factors: A conceptual framework." *Journal of Engineering Science and Technology,* vol. 12, pp. 2880-2895.

[4] Lal, R., 1991. "Tillage and agricultural sustainability." *Soil and Tillage Research,* vol. 20, pp. 133-146. Available: https://doi.org/10.1016/0167-1987(91)90036-W

[5] Okorafor, O. O., Akinbile, C. O., and Adeyemo, A. J., 2017. "Soil erosion in south eastern Nigeria." *A Review. Scientific Research Journal (SCIRJ),* vol. V, pp. 30–37.

[6] Abdulkadir, T. S., Muhammad, R. M., Yusof, K. W., and Ahmad, M. H., 2019. "Quantitative analysis of soil erosion causative factors for susceptibility assessment in a complex watershed." *Cogent Engineering,* vol. 6, Available: https://doi.org/10.1080/23311916.2019.1594506

[7] Okoyeh, E. I., Akpan, A. E., Egboka, B. C. E., and Okeke, H. I., 2014. *An assessment of the influences of surface and subsurface water level dynamics in the development of gullies in Anambra State*. Southeastern Nigeria, Earth Interactions.

[8] Ofomata, G. E. K., 1985. *Soil erosion in nigeria. The views of a geomorphologist. University of nigeria inaugural lecture series no. 7*. Nigeria: University of Nigeria Press Nsukka.

[9] Chikwelu, E. E. and Ogbuagu, F. U., 2014. "Geotechnical investigation of soil around mbaukwu gully erosion sites, south-eastern part of Nigeria." *Jour. Appld. Geol. Geophys.,* vol. 2, pp. 6–17.

[10] Igwe and Egbueri, J. C., 2018. "The characteristics and the erodibility potentials of soils from different geologic formations in anambra state, southeastern Nigeria " *Journal of the Geological Society of India,* vol. 92, pp. 471-478. Available: https://doi.org/10.1007/s12594-018-1044-1

[11] Emeh, C. and Igwe, O., 2018. "Effect of environmental pollution on susceptibility of sesquioxide-rich soils to water erosion." *Geology, Ecology, and Landscape,* vol. 2, pp. 115-126.

[12] Egbueri, J. C. and Igwe, O., 2020. "The impact of hydrogeomorphological characteristics on gullying processes in erosion-prone geological units in parts of southeast Nigeria." *Geol. Ecol. Landsc.,* Available: https://doi.org/10.1080/24749508.2020.1711637

[13] Ofomata, G. E. K., 1965. "Factors of soil erosion in enugu area of Nigeria." *Nigerian Geographical Journal,* vol. 8, pp. 45-59.

[14] Farauta, B. K., Egbule, C. L., Agwu, A. E., Idrisa, Y. L., and Onyekuru, N. A., 2012. "Farmers' adaptation initiatives to the impact of climate change on agriculture in northern nigeria." *Journal of Agricultural Extension,* vol. 16, Available: http://dx.doi.org/10.4314/jae.v16i1.13

[15] Ayadiuno, R. U. and Ndulue, D. C., 2021. "An Investigation into some Soil Indices as Indicators of High Soil Erodibility in Anambra State Southeastern." *Nigeria; International Journal of Modern Agriculture,* vol. 10, pp. 3451–3464.

[16] Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., and Yoder, D. C., 1997. *Predicting soil erosion by water. A guide to conservation planning with the revised universal soil loss equation (rusle). Agriculture handbook*. Washington, DC: US Department of Agriculture. pp. 1-251.

[17] Horton, R. E., 1945. "Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology." *Geological Society of America Bulletin*, vol. 56, pp. 275-370. Available: http://dx.doi.org/10.1130/0016-7606

[18] Kinnell, P. I. A., 2010. "Event soil loss, runoff and the universal soil loss equation family of models." *A Review; J. Hydrol.*, pp. 385384–397.

[19] Edet, A. E., Teme, S. C., Okereke, C. S., and Esu, E. O., 1998. "Application of remote-sensing data to groundwater exploration: A case study of the cross river state, Southeastern." *Nigeria. Hydrogeol. J.*, vol. 6, pp. 394-404. Available: https://doi.org/10.1007/s100400050162

[20] McCool, D. K., Brown, L. C. and Foster, G. R., (1987). , 1987. "Revised slope steepness sactor for the universal soil soss equation." *Transactions of the American Society of Agricultural Engineers*, vol. 30, pp. 1387-1396.

[21] Weng, Q., Lu, D., and Schubring, J., 2004. "Estimation of land surface temperature-vegetation abundance relationship for urban heat island studies." *Remote Sensing of Environment*, vol. 89, pp. 467–483.

[22] Weier, J. and Herring, D., 2000. *Measuring vegetation (NDVI and EVI)*. Washington DC: NASA Earth Observatory.

[23] Stone, R. P. and Hilborn, D., 2012. *Universal soil loss equation (USLE) factsheet*. Ontario: Ministry of Agriculture, Food and Rural Affairs.

[24] Saha, A., Patil, M., Goyal, V. C., and Rathore, D. S., 2018. "Assessment and impact of soil moisture index in agricultural drought estimation using remote sensing and gis techniques." In *Proceedings of the 3rd International Electronic Conference on Water Sciences (ECWS-3), 15–30, MDPI.*Basel, Switzerland.

[25] Kulimushi, L. C., Choudhari, P., Mubalama, L. K., and Banswe, G. T., 2021. "GIS and remote sensing-based assessment of soil erosion risk using rusle model in south-kivu province, eastern, democratic republic of congo, geomatics." *Natural Hazards and Risk*, vol. 12, pp. 961-987.

[26] Shainberg, I., Goldstein, D., and Levy, G. J., 1996. "Rill erosion dependence on soil water content, aging and temperature." *Soil Sci. Soc. Am. J.*, vol. 60, pp. 916– 922.

[27] Larionov, G. A., Bushueva, O. G., Dobrovol'skaya, N. G., Kiryukhina, Z. P., Krasnov, S. F., and Litvin, L. F., 2014. "Effect of the water temperature and soil moisture on the erodibility of chernozem samples: A model experiment." *Eurasian Soil Sc.*, vol. 47, pp. 734-739. Available: https://doi.org/10.1134/S1064229314070096

[28] Grissinger, E., 1996. *Rill and gullies erosion. In: Soil erosion conservation and rehabilitation, feoli, e., d. Pottier and w. Zerihun (eds.)*. New York: Marcel Dekker. pp. 153-167.

[29] Hanson, G. J. and Cook, K. R., 1999. "Procedure to Estimate Soil Erodibility for Water Management Purposes. ASAE Paper No. 992133. ASABE, St. Joseph, MI." Available: https://doi.org/10.1111/j.1365-2389.1975.tb01953.x

[30] Kemper, W. D., Trout, T. J., Brown, M. J., and Rosenau, R. C., 1985. "Furrow erosion and water and soil management." *Trans. Am. Soc. Agric, Eng.*, vol. 28, pp. 1564-1572.

[31] Igwe and Udegbunam, O. N., 2008. "Soil properties influencing water-dispersible clay and silt in an ultisol in southern Nigeria." *Int. Agrophysics*, vol. 22, pp. 319-325.

[32] Igwe, 2003. "Erodibility of soils of the upper rainforest zone, southeastern Nigeria." *Land Degradation and Development*, vol. 14, pp. 323-334.

[33] Middleton, H. E., 1930. *'Properties of soils which influence soil erosion*. USDA Technical Bulletins, p. 178.

[34] Zeleke, T. B. and Si, C., 2005. "Scaling relationship between saturated hydraulic conductivity and soil physical properties." *Soil Science Society of America Journal*, vol. 69, pp. 1691-1702.

[35] Evrendilek, F., Celic, I., and Kilic, S., 2004. "Changes in Soil organic carbon and other physical soil properties along adjacent mediterranen forest, Grassland, and cropland ecosystems in Turkey." *Journal of Arid Environments*, vol. 59, pp. 743-752.

[36] Lima, C. G. R., Marques, S. M., Lollo, J. A., Costa, N. R., and Carvalho, M. P., 2019. "Inter-relationships among erodibility, soil tolerance and physical-chemical attributes in northwestern of são paulo state." *Journal of Urban and Environmental Engineering*, vol. 13, pp. 102-114.

[37] Reddy, K., 1999. *Engineering properties of soils based on laboratory*. UIC.

[38] Zhuang, Y. T., Huang, Y. H., Lin, J. S., Jiang, F. S., Zheng, Y., Sun, S. X., Ding, Z. Q., and Yang, Y., 2014. "Study on liquid limit and plastic limit characteristics and factors of benggang in red soil layer." *Res. Soil Water Conserv*, vol. 21, pp. 208–216.

[39] Deng, Y., Cai, C., Xia, D., Shuwen, D. S., Chen, J., and Wang, T., 2017. "Soil atterberg limits of different weathering profiles of the collapsing gullies in the hilly granitic region of Southern China." *Solid Earth*, vol. 8, pp. 499-513. Available: www.solid-earth.net/8/499/2017/

[40] National Academies of Sciences Engineering, a. M.-N., 2019. *Relationship between erodibility and properties of soils*. Washington, DC: The National Academies Press.

[41] Le Bissonnais, Y., Cerdan, O., Lecomte, V., Benkhadra, H., Souchère, V., and Martin, P., 2005. "Variability of soil surface characteristics influencing runoff and inter-rill erosion." *Catena*, vol. 62, pp. 111-124.

[42] Troeh, F. R., Hobbs, J., and Donahue, R., 1980. *Soil and water conservation for productivity and environmental protection*. Englewood Cliffs, N.J. 07632.USA: Prentice-Hall, Inc.

[43] Parwada, C. and Van Tol, J., 2016. "Soil properties influencing erodibility of soils in the ntabelanga area, eastern cape province, south africa, acta agriculturae scandinavica, section B — soil and plant science."

[44] Toy, T. J., Foster, G. R., and Renard, K. G., 2002. *Soil erosion; processes, prediction, measurement, and control*. New York: John Wiley and Sons, Inc.

[45] Singh, M. J. and Khera, K. L., 2008. "Soil erodibility indices under different land uses in lower shiwaliks." *Tropical Ecology,* vol. 49, pp. 113-119.

[46] Hudson, N. W., 1995. *Soil conservation*. 3rd ed. ed. Ames: Iowa State University Press. p. 391.

[47] Morgan, R. P. C., 1996. *Soil erosion and conservation*. Addison Wesley Longman Limited, UK.

[48] Amezketa, E., Aragués, R., Carranza, R., and Urgel, B., 2003. "Chemical, spontaneous and mechanical dispersion of clays in arid-zone soils." *Spanish Journal of Agricultural Research,* vol. 1, pp. 95–107.

[49] Wischmeier, W. H. and Mannering, J. V., 1969. "Relation of soil properties to its erodibility." *Soil Sci. Soc. Amer. Proc.,* vol. 33, pp. 131-137.

[50] Evans, R., 1980. *Mechanics of water erosion and their spatial and temporal controls: An empirical viewpoint: In soil erosion. Ed. by Kirkby, M.J. and Morgan, R.P.C.* John Wiley and Sons, pp. 116-122.

[51] Brady, N. C. and Weil, R. R., 2002. *The nature and properties of soil*. 13th Ed. ed. Upper Saddle River, New Jersey: Prentice Hall.

[52] Kemper, W. D. and Koch, E. J., 1966. *Aggregate stability of soils from western USA and Canada*. Washington DC: USDA Technical Bulletin No. 1355, US Government Printing Office.

[53] Greenland, D. J., Rimmer, D., and Payne, D., 1975. "Determination of the structural stability class of english and welsh soils, using a water coherence test." *Journal of Soil Science,* vol. 26, pp. 294-303.

[54] Dimoyiannis, D. G., Valmis, S., and Vyrlas, P., 2001. "A rainfall simulation study of erosion of some calcareous soils." *Global Nest Journal,* vol. 3, pp. 179-183.

[55] Ihinegbu, C. and Ogunwumi, T., 2021. "Multi-criteria modeling of drought: A study of brandenburg federal state, Germany." *Modeling Earth Systems and Environment,* Available: https://doi.org/10.1007/s40808-021-01197-2

[56] Hong, S. Y., Noh, Y., and Dudhia, J., 2006. "A new vertical diffusion package with an explicit treatment of entrainment processes." *Mon. Weather Rev.,* vol. 134, pp. 2318- 2341.

[57] NBS, 2017. "Demographic statistics bulletin." Available: https://nigerianstat.gov.ng

[58] Hussein, H., Ibrahim, S. F., Kandeel, K., and Moawad, H., 2004. "Biosorption of heavy metals from waste water using Pseudomonas sp." *Electronic Journal of Biotechnology,* vol. 7, pp. 30-37. Available: http://www.scielo.cl/scielo.php?script=sci_arttext&pid=S0717-34582004000100006&lng=es&tlng=en.

[59] Ifeka, A. and Akinbobola, A., 2015. "Trend analysis of precipitation in some selected stations in anambra state." *1-12,* vol. 5, pp. 1-12. Available: https://doi.org/10.4236/acs.2015.51001

[60] Ramli, M. F., Yusof, N., Yusoff, M. K., Juahir, H., and M., S. H. Z., 2010. "Lineament mapping and its application in landslide hazard assessment: A review." *Bulletin of Engineering Geology and the Environment,* vol. 69, pp. 215–233.