

Regression of Selected Erosion Susceptibility Factors to Gully Erosion In Orlu Zone, Imo State

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Abstract – Gully erosion issues are of paramount concern in Orlu Zone, Imo State. In recent decades, consequences of gully erosion are unimaginable ranging from land degradation, soil quality loss for agricultural activities, and environmental pollution through water quality contamination to disruption of the entire ecosystem and destruction of valuable properties. The aim of this study is to integrate Geographic Information System (GIS) and Statistical analysis in ascertaining the contributions of selected gully susceptibility factors to gullying in Orlu Zone. In this research, gully susceptibility factor maps were produced and overlaid with sample size gully erosion profile. The contributions of each erosion factor against each unit gully sample size location overlay were harnessed and copied to excel via SPSS software for further analyses. Statistical analyses such as Principle Component Analyses (PCA), Multiple Linear Regression (MLR), Analyses of Variance (ANOVA) and Stepwise Regression were carried to ascertain erosion susceptibility factors (slope, land use, variation in elevation, population density, soil characteristics, geology and drainage density) contribution to gullying and validation of assumptions to gully variability in Orlu Zone. The results of PCA showed a strong influence of the independent variable (erosion susceptibility factors) to the dependent variable (gully size location). MS of the MLR analyses showed that the seven selected susceptibility factors accounted for 90% of gullying in the study area. ANOVA showed that the predictors are able to account for a significant amount of variance in determining gully location and development. SR showed that five out of seven independent variables satisfied the criteria. This research showed the flexibilities and capability of GIS and Statistical tools in assessing and predicting contributions of erosion factors to gullying in a particular area.

Keywords: sample size gully erosion, susceptibility factors, PCA, MLA, GIS and SPSS

1. INTRODUCTION

Gully erosion is a serious environmental problem involving obvious sediment transport on stable channels through surface runoff as active driver from highland areas to valley floors. For 150years ago, according to Irin (2011) Southeastern Nigeria was covered by thick rainforest, however, in the past four decades, gully has emerged with serious threat to man and his environment (Nwilo, Olayika Uwadiegwu and Adzandeh; 2011). Human activities like land- clearing, and deforestation, overgrazing, as well as the creations of firewood tracks accelerate the natural rates of these processes with immediate site effect seen as loss of soil while the off-site effects include the yield of sediment on the river network, which results in declining water quality (Ogbonna, 2012).

In Orlu Zone of Imo State, gully erosion is a serious problem. Many communities have been displaced coupled with huge loss of farmland through the excessive removal of the topsoil and water pollution as a result of sediment deposit. In many communities, there are reports of roads, buildings, telecommunication and electric poles damages as a result of gully erosion. Survey by Newmap (2013 and 2014) revealed two prominent gully sites (Urualla gully in Ideato North LGA and Iyuzo gully in Orlu LGA) as one of the longest gully erosion in the South Eastern Region, measuring above 3km with numerous channels (fingers) cutting across many communities.

In order to assess soil susceptibility factors contributions to gully erosion, we identified and selected factors leading to the development of gully erosion. The parameters used are slope, variations in elevation, soil characteristics, drainage density, geology, population density and landuse.

This research used GIS as the basic analytical tool for gully erosion mapping and SPSS statistical tool for regression of susceptibility factors contribution to gullying. It presents an effective platform for spatial and database management and manipulation accounting for gullying in the study area.

1.1 Study Area (Orlu Zone, Imo State)

The study area (Orlu Zone) is located at a Geographic Coordinate of Long. 6.662E -7.121E and Lat. 5.274N - 5.949N (fig 1). It is a senatorial district in Imo state, South Eastern Nigeria occupying an estimated area of 2292.13sqkm and a 2017 projected population of 2,350,540 from 1,648,086 of the 2006 national census in the 12 Local Government Areas. According to NIMET, (2015), the study area is characterized by high annual rainfall (over 2000mm/yr), high relative humidity (90%) and temperatures (24 - 27°C). It experiences two major seasons – rainy season (March to October) and dry season (November to February). Orlu Zone geology 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. Bende-Ameki formation 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). The geology of the study area is characterized by five major geologic formations (fig 2). Orlu Zone is characterized by three main landform regions (fig3) A highland region ranging from 183 to 350m of elevation in major parts of Orlu, Nkwere, Nwangele, Ideato North and South Local Government Areas, Moderate region with an elevation ranging from 95 to 183m covering Orsu, Njaba, Isu and the low land region of 1 to 95m elevation covering the entire Oguta and Ohaji/Egbema Local Government Areas.

2. MATERIALS AND METHODS

2.1 Gully Identification

Gullies in the study area were identified using remote sensing tools (Earth Explorer and Sas Planet) and distinguished from other open cavities through reconnaissance survey. Systematic Sampling technique was used to obtain sample size gully profile for further analysis in the study area.

2.2 Gully Susceptibility Factors Processing

Orlu Zone LGAs map which served as the study area was acquired from Imo State Ministry of Lands, processed and dissolved on the delineated map of Imo State LGAs in ArcGIS version 10.2.1 software environment (fig1).

Susceptibility factors chosen are; soil characteristics, geology, DEM (elevation, slope and drainage density), population density and land use/land cover. Randomly collected soil samples in the study area based on sub-basin of the old Imo Anambra River basin were analysed for various soil erodibilities and other characteristics (atterberg limit, gradation, permeability, structure, organic matter content and bulk density).

SRTM data procured from the Regional Centre for Training in Aerospace Survey (RECTAS) was integrated with recently downloaded SRTM data from Global Mapper software and analysed using ARCGIS surface analyst tool for elevation, slope and Arc Hydro extension tool for drainage density.

Landsat imagery downloaded from global land use facility website containing the land use land cover of Orlu Zone was classified into various regions of interests (paved surface, bared/cultivated land, wetland, water body, forested land and vegetated land) in ENVI remote sensing software and exported to ArcGIS software where erodibility values were assigned.

Population data collected from Nigerian Population Census (NPC) office, Federal Secretariat, Owerri for each Local Government Area was projected to recent population figure and exported to ArcGIS software where the population density was calculated.

Procured geologic map of Imo State was scanned, georeferenced and digitized into various geo-forms and assigned hierarchical erosion risk potential based on reviewed literature.

Thus, each of the erosion susceptibility factor maps were converted to raster of the same resolution, reclassified and overlaid with sample size gully erosion profile map of the study area, their corresponding values at unit gully interception was copied to excel via SPSS software to ascertain the amount of variance contributing to gully in the study area.

2.3 Multiple Linear Regressions

First, KMO and Bartlett’s Test were employed to measure the sampling adequacies and justify the data reduction procedure to adopt while measuring the statistical significance of the analysis. Scree plotting was carried out to ascertain the number of data reduction to adopt before multiple regression analysis.

For this research, Multiple Linear Regression was carried out to estimate the coefficients of the linear equation involving independent variables “Susceptibility factor” that predicts dependent variable “gully sizes location” so as to establish relationships between them in a concise manner and to understand generally how they influenced gully formation and development in the study area.

3. RESULTS AND DISCUSSION

3.1 Gully Population

91 gully erosion sites were identified in the study, out of which 80 were active, 40% of the active gully sites translated to 36 gullies were estimated as sampling size of the study using systematic sampling method (table 1)

3.2 Regression of Gully Susceptibility Factors

KMO test (table 2) result showed a strong positive correlation at (.685) signifying a strong adoption of Principal Component (PC) analysis over factor analysis while Bartlett’s test result showed a very high significance value of .000 at 21 degree of freedom. The result of screen plot (fig 4) below showed that two major factor component has an eigenvalue ≥ 1 .

There were strong loadings and correlations of variables on the two principal component variables in both the unrotated factor solution (table 3) and in oblique rotation (table 4 and 5) respectively excluding drainage density on pattern matrix table. Component loading gives information about the amount of variation in the variable explained by the components as shown in the total variance explained (table 6).

Total Variance Explained (TVE on table 6) represented the extracted two major component factor solutions. The eigenvalue for the first PCA is 3.505 representing about 50.091% of the total variance while the second PCA has an eigenvalue of 1.107 making up for 15.815% of the total variance with a cumulative of 65.906%.

Thus, the rotated component of the eigenvalues gives a value of 3.031 for the first PCA representing 43.305% of total variance while the eigenvalue for the second PCA is 1.784 making up for 25.487% of the total variance with a cumulative of 68.792%.

Model Summary (MS) of the multiple regression (table 7) of independent/predictor variables against dependent variable showed a strong measure of relationship among the seven erosion factors with an R value of 95.90% and R square value of 92% which represents main variance in the independent or predictor variables as a group or set that accounted for the dependent variable. Though R square does not measure how much each independent variable accounted for but represents the coefficient of determinant or covariance in the proportion of variability in the dependent variable explained by the independent. In addition, the adjusted R square which represents a more reliable coefficient of variance explained by the predictor variable in a set based on the sample size was 90%.

Thus, slope, soil characteristics, geology, elevation, population density, drainage density and land use accounted for 90% of gullying in the study area.

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + \dots + etc \quad (1)$$

Where

- Y = Gully locations in Orlu Zone
- b_0/b_1 = constant/regression coefficient
- x_1 = soil characteristics
- x_2 = elevation
- x_3 = slope
- x_4 = drainage density

x ₅	=	population density
x ₆	=	land use
x ₇	=	geology

Multiple Regression Coefficients (MRC on table 8) represented the correlation of the seven independent variables against the dependent variable individually and assess its significant levels for uniqueness. The significant variables predictors signifies that they explained a unique amount of variance to the dependent variable, hence, explained what other variables did not account for in predicting dependent variable. However, the non significant shows that a portion of what it explains has been explained by a co predictor, indicating perfectly correlated variable that offers nothing uniquely to the dependent variable. Thus, MRC result on table 8 showed that soil characteristics, drainage density, geology and population density were significant while slope, elevation and land use were not significant in predicting gully location in the study area.

$$\text{Gully size} = 17.860 + (.17)\text{slope} + (.225)\text{drainage density} + (.066)\text{population density} - (6.44)\text{soil characteristics} - (.22)\text{elevation} - (.002)\text{land use} - (.179)\text{geology}$$

Analysis of variance (ANOVA) of the multiple linear regressions (table 9) significantly predicted the dependent variable. An F value of 45.776 was gotten with a p value of .000 showing a strong significance since it is less than 0.05, this means that R square value of 92% is significantly greater than zero and the predictors are able to account for a significant amount of variance in gully location.

The MS of Stepwise Regression (SR on table 10) showed that five out of the seven independent variables that entered the model satisfied the criteria. Soil characteristics initiated model entry at a strong correlation of 83.9% to the dependent variable with a coefficient of variance (R square) of 70.0% and (adjusted R square value of 67.1%) of all the variance that predicted gully location. At step 2, drainage density entered the model increasing the correlation to 90.5% (6.8% increase) and the total variance explained from 70.0% to 82.0% (12.0% increase), indicating that drainage density itself explained 12% of the variance accounted for the dependent variable (gully location), but since it was correlated with soil characteristics, a portion of what it could explain had already been explained by soil characteristics.

At step 3, slope entered the model at an increased correlation of 17% (90.5-92.2%) with an increased total R square variance of 3.1% (82 -85.1%) and adjusted R square variance of 2.8% (80.9-83.7%). At step 4, population density entered and increased correlation to 94% (an increase of 1.8%) with an R square variance of 88.3% (3.2% increase) and adjusted R square variance of 86.8% (3.1% increase). At step 5, geology entered and increased the correlation to 95.7% (1.7% increase) with R square and adjusted R square total variance of 91.5% and 90.1% respectively representing an increase by 3.2% and a decrease by 3.3%.

Pearson Correlation Matrix (PCM on table 11) showed that soil characteristics maintained strong correlation with elevation, geology and slope at .531, .504 and .669 respectively. Slope, elevation and geology showed positive correlations at .974, .518 respectively. Slope population density and geology showed strong positive correlation at .524. Thus, population density had weak positive correlation with soil, slope and land use at .378, .404 and .005 respectively.

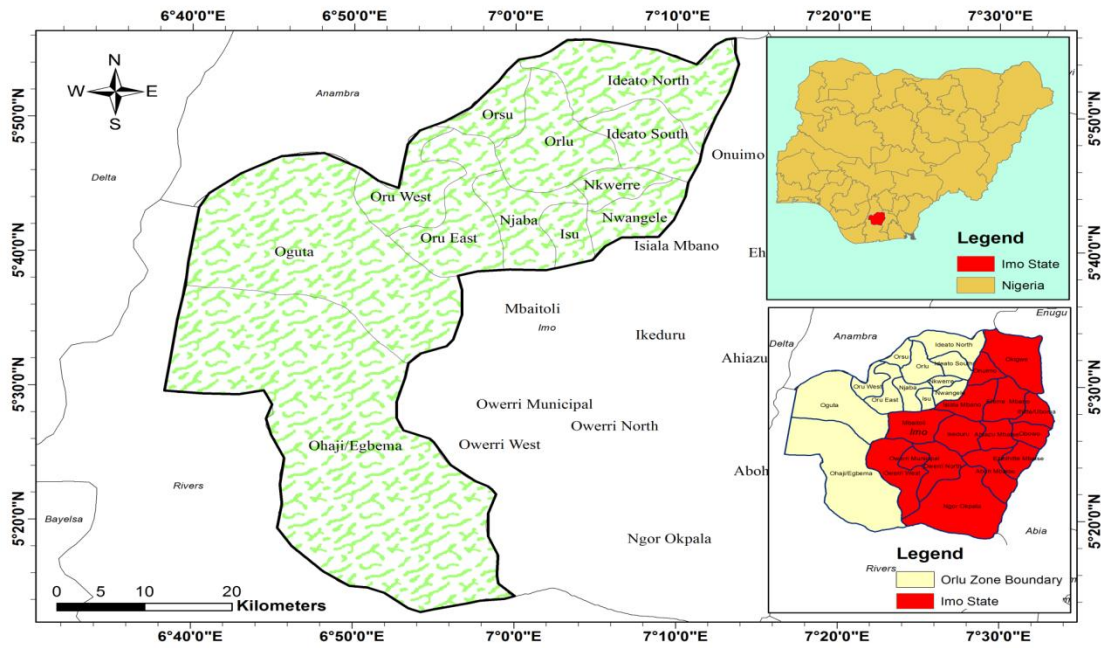


Fig1 study area map

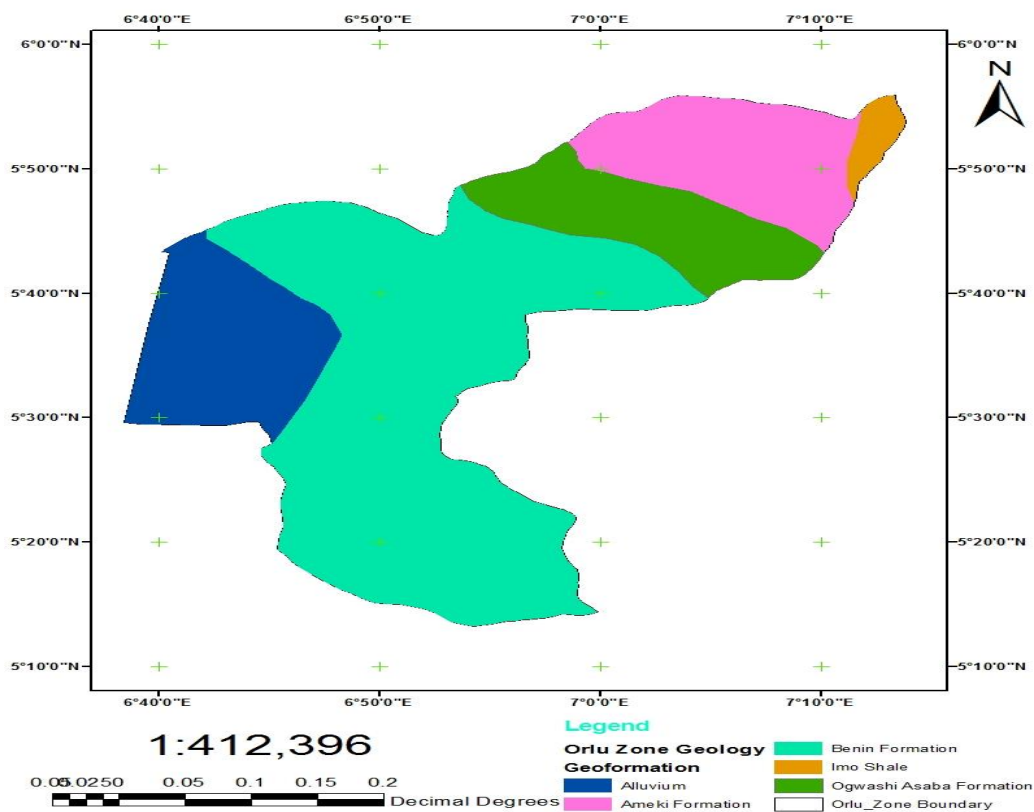


fig 2 geology of the study area

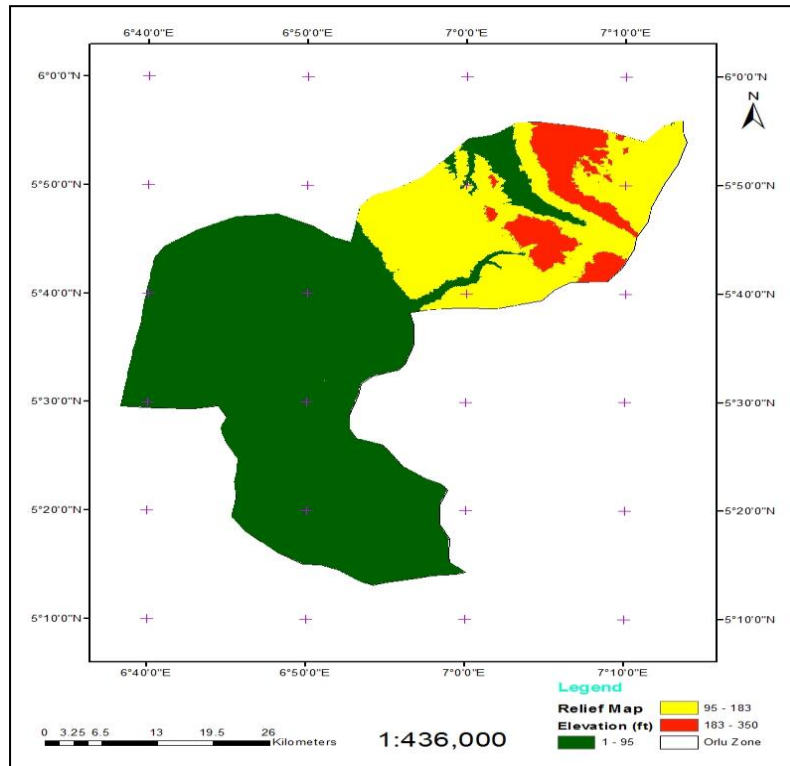


fig 3 relief of the study area

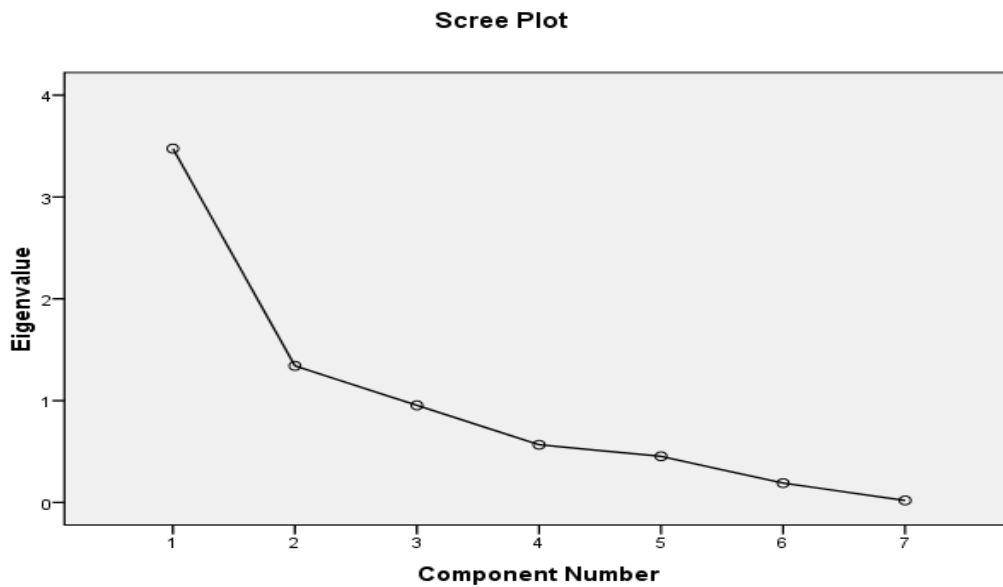


Fig 4: Screen plot eigenvalues component number

Table 1 Sample Size Gully Erosion Profile

S / N	Gully Location	Long	Lat	Elevation	Population Density	Drainage Density	Land use	Geology	Soil Characteristics	Slope	Scaled Gully Size location
4	Umuezumezu Umuturu Urualla	7 03 31.99	5 51 47.99	128	18.5	20.2	0.9	29.0	2.3	29.0	1
6	Umunkwukwua Obodoukwu	7 03 42.02	5 54 45.27	151	18.5	20.2	0.9	24.0	2.3	40.0	1
9	Umuago Ndada Urualla	7 04 16	5 51 13	153	18.5	20.2	0.7	29.0	2.2	43.0	1
11	Isiokpo	7 04 4.8	5 54 47.6	150	18.5	20.2	0.9	24.0	2.1	38.0	1
14	Osina-Umuobom Road	7 6 14.8	5 52 40.2	185	18.5	20.2	0.9	24.0	2.3	50.0	1
16	Umuchima Kizito Sch	7 04 13	5 49 51	111	24.5	20.2	0.7	29.0	2.2	20.0	2
19	Umuaghabe Unujisi Isiekenesi	7 07 53.9	5 47 27.8	160	24.5	20.2	0.7	29.0	2.2	48.0	2
21	Ntueke Mgbec road	7 04 24.28	5 49 16.55	97	24.5	20.2	0.9	29.0	2.3	16.0	2
24	Umuhu Ubierelem	6 59 26.35	5 51 08.9	78	24.5	20.2	0.9	29.0	2.3	14.7	3
26	Uhuala Ihittenansa	7 00 07.23	5 53 44.47	44	18.5	20.2	0.7	29.0	2.2	10.0	3
29	Amaike Obibi	7 04 13	5 46 50	194	24.5	30.3	0.7	29.0	2.1	60.0	4
31	Umudimuoke replot	7 02 54.36	5 44 48.47	176	33.7	30.3	0.7	29.0	2.0	52.0	4
34	Ubaha Ihitteowerri	7 01 05.11	5 50 01.5	147	24.5	20.2	0.7	29.0	2.0	38.0	4
36	Uhuala Obibiochasi	7 00 52.50	5 50 12.68	132	24.5	20.2	0.7	29.0	2.0	33.0	4
39	Ihioma Ancient Kingdom	6 59 56.85	5 50 54.17	140	24.5	20.2	0.7	29.0	2.2	36.0	4
41	Ihioma Ancient Kingdom3	7 00 31.01	5 51 17.92	99	24.5	20.2	0.9	29.0	2.0	16.2	4
44	Holy trinity cathedral Umuleke	7 03 26.3	5 47 41.1	170	24.5	30.3	0.9	29.0	2.1	48.0	41
46	Mgbec Ideato road	7 02 40.1	5 48 03.7	130	24.5	30.3	0.9	29.0	1.9	32.0	4
49	Amarju Amaigbo	7 05 53.6	5 41 33.23	135	33.6	17.9	10.9	29.0	1.8	35.0	5
51	Umuokwaraha Amaigbo	7 06 22.37	5 42 16.07	149	33.6	17.9	10.9	29.0	1.9	38.0	5

54	Umudioka Amucha	7 2 38.01	5 44 34.21	163	33.6	30.3	10.9	29.0	2.2	49.0	6
56	Umuzikabu Amucha	7 03 44	5 44 06	127	33.6	30.3	10.9	29.0	2.2	26.0	6
59	Uumuakaja Umuseke Okwudor 2	7 01 20.02	5 43 25.04	69	33.6	30.3	87.1	29.0	2.1	13.0	6
61	Ihebinaowerri Okwudor	7 00 40.89	5 43 00.68	100	33.6	30.3	87.1	29.0	2.1	14.7	6
64	Umuaka2	7 00 41.33	5 41 37.91	64	33.6	30.3	10.9	29.0	2.1	12.0	6
66	Umudurueze Amandugba	7 04 19.87	5 39 54.05	125	33.6	17.9	10.9	19.0	1.9	24.0	7
69	Obara Owerri	7 02 58.31	5 42 13.99	144	33.6	30.3	10.9	29.0	2.0	37.0	7
71	Isunjaba	7 03 53.54	5 43 44.91	156	33.6	30.3	0.7	29.0	2.2	44.0	7
74	Obibiezi Awommamma	6 59 10.56	5 31 12.63	76	18.5	30.3	10.9	19.0	1.9	14.0	8
76	Amiri	6 56 06	5 42 18	99	18.5	30.3	10.9	19.0	1.8	17.0	8
S / N	Gully Location	Long	Lat	Elevation	Population Density	Drainage Density	Land use	Geology	Soil Characteristics	Slope	Scaled Gully Size location
79	Mgbidi	6 53 20.8	5 43 31.95	58	18.5	30.3	0.7	19.0	1.8	7.0	9
81	Okwukwele Oguta	6 48 35.19	5 44 49.51	59	13.7	30.3	87.1	14.0	1.8	9.0	10
84	Mgbenle Gully1	6 51 0.36	5 40 47.1	60	13.7	30.3	10.9	19.0	1.7	10.2	10
86	Eziama-Egbe Izumbe	6 49 25.7	5 42 37.1	56	13.7	30.3	10.9	19.0	1.7	8.0	10
89	Obokofia Egbema2	6 47 42.69	5 31 47.47	45	9.6	30.3	0.4	19.0	1.7	6.0	11
91	Awara	6 45 53.91	5 21 03.86	46	13.7	31.5	10.9	19.0	1.7	5.0	11

Table 2: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	.685
Bartlett's Test of Sphericity	Approx. Chi-Square
	158.049
	Df
	21
	Sig.
	.000

Table 3: Component Matrix^a

	Component	
	1	2
Elevation	.868	-.090
Slope	.848	-.115
Geology	.787	.277
Soil Characteristics	.778	.150
Population density	.600	.524
Drainage density	-.529	.275
Landuse	-.412	.798

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

Table 4: Pattern Matrix^a

	Component	
	1	2
Geology	.843	.035
Population density	.815	.337
Soil characteristics	.765	-.087
Elevation	.712	-.352
Slope	.681	-.370
Landuse	.078	.915
Drainage density	-.313	.433

Extraction Method: Principal Component Analysis.

Rotation Method: Oblimin with Kaiser Normalization.

a. Rotation converged in 11 iterations.

Table 5: Structure Matrix

	Component	
	1	2
Geology	.834	-.184
Elevation	.803	-.537
Soil characteristics	.788	-.286
Slope	.777	-.547
Population density	.727	.125
Landuse	-.160	.894
Drainage density	-.425	.514

Extraction Method: Principal Component Analysis.

Rotation Method: Oblimin with Kaiser Normalization.

Table 6: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings ^a
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	3.506	50.091	50.091	3.506	50.091	50.091	3.301
2	1.107	15.815	65.906	1.107	15.815	65.906	1.784
3	.982	14.026	79.931				
4	.593	8.476	88.407				
5	.522	7.451	95.858				
6	.268	3.827	99.684				
7	.022	.316	100.000				

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Table 7: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.959 ^a	.920	.900	.9578

a. Predictors: (Constant), Landuse, Population, Soil, Drainage, Slope, Geology, Elevation

Table 8: Multiple regression Coefficient

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	17.860	2.621		6.814	.000	12.491	23.229
	Soil characteristics	-6.444	1.116	-.461	-5.777	.000	-8.730	-4.159
	Elevation	-.022	.018	-.318	-1.233	.228	-.058	.014
	Slope	.017	.049	.090	.354	.726	-.082	.117
	Geology	-.179	.052	-.277	-3.427	.002	-.287	-.072
	Drainage density	.225	.037	.401	6.057	.000	.149	.301
	Population density	.066	.015	.294	4.438	.000	.036	.096
	Landuse	-.002	.008	-.013	-.212	.834	-.018	.015

a. Dependent Variable: gully size Location

Table 9: ANOVA^b for multiple regression equation

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	293.953	7	41.993	45.776	.000 ^a
	Residual	25.686	28	.917		
	Total	319.639	35			

a. Predictors: (Constant), Landuse, Population, Soil, Drainage, Slope, Geology, Elevation

b. Dependent Variable: Size Location

Table 10: Model Summary of Stepwise Regression coefficient

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.837 ^a	.700	.691	1.6791	.700	79.372	1	34	.000	
2	.905 ^b	.820	.809	1.3209	.120	21.940	1	33	.000	
3	.922 ^c	.851	.837	1.2207	.031	6.639	1	32	.015	
4	.940 ^d	.883	.868	1.0964	.033	8.668	1	31	.006	
5	.957 ^e	.915	.901	.9522	.031	11.102	1	30	.002	1.554

a. Predictors: (Constant), Soil

b. Predictors: (Constant), Soil, Drainage

c. Predictors: (Constant), Soil, Drainage, Slope

d. Predictors: (Constant), Soil, Drainage, Slope, Population

e. Predictors: (Constant), Soil, Drainage, Slope, Population, Geology

f. Dependent Variable:Size Location

Table 5.11: Correlation Matrix

	Soil	Elevation	Slope	Geology	Drainage	Population	Landuse
Correlation Soil	1.000	.531	.504	.669	-.449	.378	-.173
Elevation	.531	1.000	.974	.522	-.282	.404	-.322
Slope	.504	.974	1.000	.518	-.222	.367	-.344
Geology	.669	.522	.518	1.000	-.316	.524	-.191
Drainage	-.449	-.282	-.222	-.316	1.000	-.259	.338
Population	.378	.404	.367	.524	-.259	1.000	.005
Landuse	-.173	-.322	-.344	-.191	.338	.005	1.000

4. CONCLUSIONS

This research has shown the influence of selected susceptibility factors to gully development and soil erosion in general through integration of Multiple Linear Regression and Analysis of Variance. Result showed that predictors accounted for 90% of gully developments in the study area which authenticated the fact that significant relationships exist between landuse, slope, geologic formations, variation in elevations, soil characteristics, population density, drainage density and gully formation and development in the study area.

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