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GULLY EROSION SUSCEPTIBILITY MAPPING IN IKWUANO LOCAL GOVERNMENT AREA OF ABIA STATE USING GIS TECHNIQUES

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ABSTRACT

This research work assessed the gully erosion susceptibility of Ikwuano Local Government Area of Abia State, Nigeria using the GIS-based multi-criteria evaluation approach. The objectives were to identify susceptible areas, examine and evaluate the causes as well as the impacts and recommend possible control measures. The multi-criteria evaluation approach of pairwise comparison by Analytical Hierarchy Process was used to calculate and assign criteria weights to the 5 erosion factors. The pairwise comparison matrix was tested using Saaty Consistency Ratio to ensure accuracy. The five erosion controlling factors were analyzed in the GIS environment and prioritized as rainfall erosivity (R factor, 36%), soil erodibility (K factor, 30%), slope (LS factor, 19%), vegetative cover (C factor, 9%) and conservation practice (P factor, 6%) in order of importance. The susceptibility map was produced and validated by ground truthing. Gully initiations are widespread in the study area. Dormant gullies at Umulu, Ihim and Amuro are well-vegetated with *bambusa vulgaris*. The active gullies at Elemaga-Ibere and Amaegbu-Ariam are within the moderate to high susceptible areas. The major anthropogenic causes of erosion in the study area include sand mining, bad farming practices, lumbering, poor drainage system and abandoned road constructions. The impacts included the destruction of roads and houses, isolation of communities, loss of farmlands and silting of streams. Tree planting and regrassing, engineering and structural designs to channel runoff, proper road design, improved farming practices and engaging in sensitization of all stakeholders targeted on early stage preventive measures were recommended. The GIS-based multi-criteria evaluation approach has proved both useful and effective in the mapping of gully erosion susceptibility in Ikwuano Local Government Area of Abia State, Nigeria.

KEYWORDS

Gully erosion, GIS, mapping, susceptibility, gullies .

1. INTRODUCTION

Gully erosion seems to be one of the critical environmental hazards of modern times. Most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased mostly by human activity. A gully is usually defined as a deep channel eroded by concentrated flow of water, removing upland soil and parent material that is too big to be obliterated by normal tillage operations [1].

In a study, researchers described gullies as only being intermittently occupied by water and are most likely to occur on unconsolidated slope deposits, weak shales and weathered soils [2]. They typically present a rectangular or V-shaped cross-section and a steep head cut which migrate upslope as a consequence of the erosion produced by overland flow, sub-surface piping and/or mass wasting processes [3-6].

A group researcher noted that in the last three decades, gully erosion has been an issue of concern in the south-east Nigeria [3]. In Abia State, described gully erosion as one of the major land degradation problems which still stands between the government, rural areas and the final victory against hunger [4]. United Nation Environmental Programme pointed out that the adoption of integrated resources uses, and management policies and rehabilitation programs are hampered by weak knowledge of the nature, extent and severity of erosion, and the inadequacy of tools and methods for assessment and monitoring of this phenomenon [5].

Gully erosion is one of the environmental problems facing the people of Ikwuano Local Government Area of Abia State [6-12]. It has become an issue of environmental concern. Several roads have been cut off and villages isolated. For example, in 2010, the emergence of Elemaga and Amuro gullies led to the isolation of 5 villages including Elemaga, Itunta, Obuoro, Nkalunta and Amuro. Also, in 2017, Amaegbu gully grew rapidly into disaster level leading to the cutting off of Ariam-Usaka ring road. Some vehicles are stuck on the road after heavy rainfall. As a result, harvested farm produce cannot be easily transported to market places due to the poor conditions of the road networks resulting from gully erosion. Loss of farmlands to erosion has striped the people their primary source of livelihood [13-15].

Human lives, houses, roads, electric poles, springs and streams (the people's source of drinking water) and even vegetated areas are under threat. Little or no attention has been given to this issue of environmental concern by the government in both local and state levels. The residents, under community efforts have in several occasions devised means of controlling gully erosion in the area [16-20]. These included conversion of erosion sites into refuse dump sites, sand-filling the sites, mining of sands along erosion channels to help contain surface run-off, periodic pouring of gravel and palm kernels on the roads, etc. These efforts have not only proved abortive but enhanced the accelerated rate of gullying in the area.

Numerous new gullies are emerging and many of old ones are growing rapidly to disaster level. As an issue of environmental concern, there is therefore need to identify areas susceptible to gully erosion and examine the possible control measures. The need to quantify the amount of erosion in a spatially distributed form has become essential in the implementation of conservation efforts [6]. In many situations, land managers and policy makers are more interested in the spatial distribution of soil erosion risk than in absolute values of soil erosion loss [7].

This global environmental issue has not been given serious authoritative control measures. There is therefore a pressing need for gully erosion assessment to evaluate its nature, extent and severity in the study area.

2. THE STUDY AREA

The study area is Ikwuano Local Government Area of Abia State, Nigeria. Figure 1 is the location map of study area. It has a total landmass of approximately 281km^2 and a population of about 137,993 (2006 census). The study area lies between latitudes 5^0 19′ N and 5^0 29’N and longitudes 7^0 32′E and 7^0 40′ E. The Local Government Area has 4 clans namely Ariam, Ibere, Oboro and Oloko; 44 autonomous communities and 52 villages. It is bounded by Bende L.G.A in the north, Umuahia L.G.A in the northwest, Isialangwa L.G.A in the southwest and Akwa Ibom State in the southeast [21].

The study area has high relative humidity values over 70%, and characterized by high temperature of about 29-31^{o}C. The area is part of the sub-equatorial belt with average annual rainfall of about 4000mm per annum. The wet season starts from Mid-April to October and dry season from November to Mid- April, and has double maxima rainfall peaks in July and September with a short dry season of about three weeks between the peaks locally known as the August break.

The area is endowed with natural springs and streams including Onu-Inyang River which flows from Bende (the northern boundary) through the study area in a south-westerly direction; while Iyinta-Ocha River flows from the central part (Isiala) through south-western part (Ogbuebule) into Akwa-Ibom State on the western flank [22-26]. The Akoo River, Ehie River and Iyi-Oba River flow southerly from the eastern part of the study area. On the other hand, Anya River traverses the entire western flank of Ikwuano and joins with Ahi (the westernmost counterpart). This confluence together with others is the main tributary of the great Kwa Ibo River of Akwa-Ibom and Cross River States of Nigeria.

Geologically, the area is situated in the Eastern Niger Delta. The geology of the area falls within two out of eleven geologic units in Abia State. They are Bende-Ameki Formation and the Benin Formation [8].

The Bende-Ameki Formation was classified by some researcher into two lithological groups viz: the lower part which consists of fine to coarse grain sandstones and intercalations of calcareous shales and thin shelly limestone and upper part which comprise coarse, cross-bedded sandstone with bands of fine, grey-green sandstone and sandy fossiliferous clays [27]. The age of the formation has been given as early Eocene and early middle Eocene respectively [8,9]. The depositional environment of the Ameki Formation has been interpreted based on the faunal content. The depositional environment has been interpreted by various authors.

A group researcher interpreted it to be an open marine depositional system suggesting that the fish may probably have been washed into the Ameki sea from inland waters whereas interpreted it to be near-shore to intertidal/sub-tidal zones of the shelf environment suggesting that the environment that ranged from near-shore to intertidal and sub-tidal zones [8,9,28]. White interpreted an estuarine environment because of the presence of the fish species of known estuarine affinity [9]. The sandstones of the study area belong to the Ameki Formation (Eocene) which underlies the Imo shale (Paleocene) which conformably overlies the Nsukka Formation. The Ameki Formation consists predominantly of alternating shales, clayey sandstone and fine–grained fossiliferous sandstone with thin limestone bands [29].

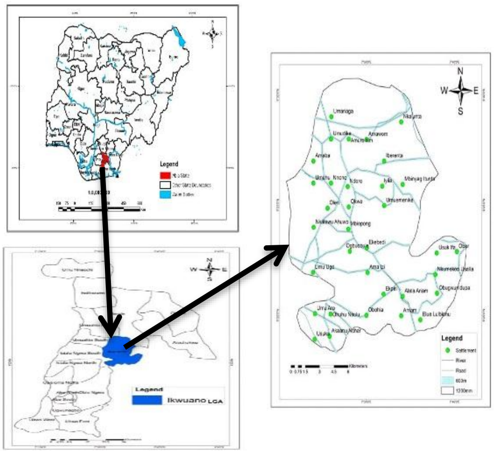

Figure 1: The Geographical Map of the Study Area

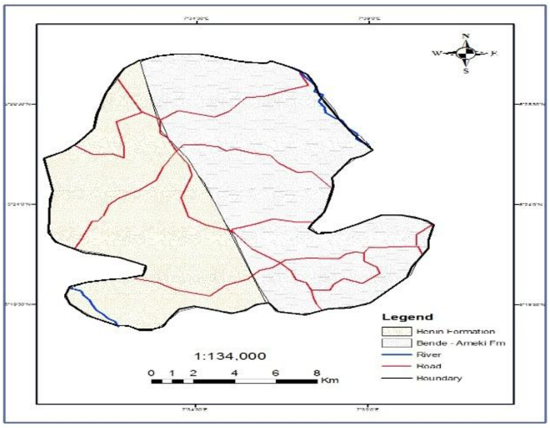

Figure 2: The Geological Map of the Study Area

3. METHODS OF STUDY

The field study was carried out in which the coordinates and the altitudes of the gully sites were obtained with the use of Global Positioning System, GPS (Table 1). The photographs of the gully sites were captured during ground truthing with a digital camera [30]. The dimensions of the gully sites- the length, width and depth were measured using a measuring tape. The data acquired both the primary and secondary was analyzed in the GIS environment using MS-Excel and ArcGIS 10.5 software. The selected factors of erosion were analyzed using the GIS-based Multi-Criteria Evaluation approach by Analytical Hierarchy Process.

Table 1: The Geographical Coordinates of Sampled Communities

S/N	Locality	Longitudes	Latitudes	Gully Type
1	Iyalu	N05^0 26′ 49.02″	E007^0 35′ 49.92″	Active
2	Elemaga	N05^0 26′ 20.52″	E007^0 36′ 48.18″	Very active
3	Itunta	N05^0 27′ 4.72″	E007^0 38′ 8.28″	--
5	Inyila	N05^0 26′ 2.4″	E007^0 36′ 28.86″	Initiation
6	Obuohia	N05^0 25′ 13.5″	E007^0 35′ 10.08″	Initiation
7	Elu-Elu Ariam	N05^0 20′ 36.66″	E007^0 37′ 23.4″	Under check
8	Ahaba Oloko	N05^0 22′ 51.6″	E007^0 32′ 22.26″	--
9	Ekwelu Ariam	N05^0 20′ 33.12″	E007^0 38′ 15.3″	Under check
10	Amaoba	N05^0 26′ 55,86″	E007^0 32′ 33.48″	Under check
11	Amawom	N05^0 28′ 10.02″	E007^0 33′ 52.32″	Active
12	Umuariaga	N05^0 28′ 51.06″	E007^0 32′ 46.26″	--
13	Ihim	N05^0 27′ 59.64″	E007^0 34′ 39.66″	Under check
14	Amuro	N05^0 27′ 53.4″	E007^0 35′ 7.32″	Under check

15	Umulu	N05⁰ 26′ 22.68″	E007⁰ 35′ 9.72″	Under check
16	Amaegbu	N05⁰ 21′ 34.26″	E007⁰ 38′ 10.08″	Very active
17	Iberenta	N05⁰ 26′ 35.4″	E007⁰ 36′ 24.96″	Active
19	Isiala Oboro	N05⁰ 24′ 19.14″	E007⁰ 34′ 14.34″	--

Table 2: Sources of Data

DATA	SOURCES	CLASS	PRINCIPAL PRODUCT
Rainfall	NIMET, Umudike	Secondary Data	Rainfall Erosivity Map
Soil	NRCRI, Umudike	Secondary Data	Soil Erodibility Map
Slope	Google Satellite Image	Secondary Data	Slope Factor
Land Use	SRTM	Secondary Data	Land Use Map
Conservation Practice	SRTM	Secondary Data	Conservation Practice Map
Coordinates	Ground truthing	Primary Data	Gully sites
Gully dimensions	Ground truthing	Primary Data	Gully size

4. DATA ANALYSIS

The watershed of the study area was computed from the meteorological samples collected including the different localities, their longitudes, latitudes, altitudes and rainfall amount. The base map was geo-referenced with the coordinates. The rainfall erosivity (R factor), soil erodibility (K factor), slope (LS factor), vegetative cover (C factor) and the conservation practice (P factor) maps were computed from the watershed (Figures 3, 4, 5, 6 and 7). The streams and basins, flow directions and accumulations were obtained.

The meteorological samples were computed in the Excel. The data was imported to ArcGIS. This was converted to shape files. The erosivity values were inputted through the geostatical analyst [31]. The soil data was imported to GIS environment to generate the soil erodibility map. The DEM file of the watershed was used to obtain the field, flow accumulation and the slope of the DEM. This gave the slope factor. The DEM file of the watershed was used to extract the slope in raster algebra. The slope was reclassified. The conservation map was obtained as the final result from the reclassification of the slope.

The GIS-based multi-criteria evaluation approach of pairwise comparison matrix by analytical hierarchy process was used to assign and calculate the criteria weights of the five erosion parameters. The pairwise comparison matrix of the parameters was tested using Saaty Consistency Ratio (Table 6) to ensure accuracy [32-35]. The susceptibility map of the study area was produced (Figure 8). The susceptibility map was validated by comparing with ground truth data geolocated on the susceptibility map (Figure 9).

The Criteria weighting: Analytical Hierarchy Process, one of the most popular methods for calculating criteria weights in Multi-Criteria Evaluation approach through an expert pairwise matrix was used [10]. Two criteria were evaluated one at a time in terms of their relative importance (Table 3). The five criteria evaluated included rainfall erosivity (R), soil erodibility (K), slope (LS), vegetative cover (C) and conservation practice (P). Table 3 is the pairwise comparison matrix. The weights of the individual criteria were calculated (Table 4).The sum of the weights are always 1.

Table 3: Completion of Pairwise Comparison Matrix

S/N	Indicator/ Criteria	R Factor	K Factor	LS Factor	C Factor	P Factor
1	R Factor	**1**	3/1	2/1	4/1	5/1
2	K Factor	1/3	**1**	2/1	5/1	4/1
3	LS Factor	½	½	**1**	3/1	3/1
4	C Factor	¼	1/5	1/3	**1**	2/1
5	P Factor	1/5	¼	1/3	1/2	**1**

Table 4: Calculation of Criteria weights

	R Factor	K Factor	LS Factor	C Factor	P Factor	Sum of the Row	Average of the Row	Criteria Weights (w)	Weight (%)
R Factor	1.00	3.00	2.00	4.00	5.00	15.00	3.00	0.36	36
K Factor	0.33	1.00	2.00	5.00	4.00	12.33	2.466	0.30	30
LS Factor	0.50	0.50	1.00	3.00	3.00	8.00	1.60	0.19	19
C Factor	0.25	0.20	0.33	1.00	2.00	3.78	0.756	0.09	9
P Factor	0.20	0.25	0.33	0.50	1.00	2.28	0.456	0.06	6
Total	2.28	4.95	5.67	13.50	15.00	41.39	8.278	1.00	**100**

Criteria weight (%) = rank (sum of row)/total ranking (total sum of row) ×100

The Consistency Ratio (CR): A statistically reliable estimate of the consistency of the criteria weights was made in accordance with a study [10]. The Consistency Ratio (CR) is considered adequately consistent if the corresponding CR is less than 10% [11]. First, a normalized comparison matrix was created. The sum of a normalized is always 1. Table 4 is the normalized matrix.

Table 5: Estimating the value of λmax

	R	K	LS	C	P	Geometric mean (nth root)	SUM of column	Normalized value	Maximum eigenvalue
R	1.00	3.00	2.00	4.00	5.00	2.605	0.411	0.411	0.936
K	0.33	1.00	2.00	5.00	4.00	1.675	0.264	0.264	1.307
LS	0.50	0.50	1.00	3.00	3.00	1.176	0.185	0.185	1.051
C	0.25	0.20	0.33	1.00	2.00	0.505	0.080	0.080	1.075
P	0.20	0.25	0.33	0.50	1.00	0.383	0.060	0.060	0.906
Total	**2.28**	**4.95**	**5.67**	**13.50**	**15.0**	**6.344**	**1.00**	**1.000**	**λmax =5.275**

where Geometric Mean is the nth root of the product of n observations, that is,

$$G = \sqrt[n]{x_1 \times x_2 \times --- \times xn} \quad (1)$$

Normalized Value (NV) = nth root/summation of nth root
Maximum eigen value (λmax) = Normalized Value x Sum of Column
The Consistency Index, CI is first computed using

$$\text{CI} = \frac{(\lambda \max - n)}{n - 1} \quad (2)$$

where n = number of criteria and λmax = maximum eigenvalue. Table 5 shows how the maximum eigenvalue (λmax) was obtained.

CR is then computed using

$$\text{CR} = \frac{\text{CI}}{\text{RCI}} \quad (3)$$

where Random Consistency Index (RCI) in this study is the value for n = 5 (Table 6).

From equation (4),

$$\therefore \text{ CI} = \frac{(5.275 - 5)}{5 - 1} = \frac{0.275}{4} = 0.06875 \quad (4)$$

Table 6: Random Consistency Index (RCI) values for different values of n

N	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Source: Saaty (1999) [10]
From equation (5),

$$\text{CR} = \frac{0.06875}{1.12} = 0.06 \quad (5)$$

The Consistency Ratio (CR) is 6% (which is less than or equal to 10%). Therefore, the matrix is adequately consistent for the decision making process of producing an erosion susceptibility map.

5. RESULTS AND DISCUSSIONS

The gully sites are of three classes: initiations, dormant and active sites. The active sites are found within the areas with moderate to high susceptibility to soil erosion [36]. The dormant sites at Umulu, Ihim and Amuro communities are under check with *bambusa vulgaris*. The initiations are wide spread in the study area (Table 1). These are common along abandoned road constructions and places where sand mining and lumbering are going on. The active gullies are found in Elemaga, Amaegbu, Amawom, Iyalu and Iberenta. These fall within areas of high susceptibility [37].

The factors of soil erosion including rainfall erosivity (R), soil erodibility (K), slope factor (LS), vegetation cover (C) and conservation practice (P) were analyzed. Figures 3, 4, 5, 6, 7, and 8 are the results [38]. Most parts of the study area fall within the areas with moderate to high susceptibility to soil erosion. This is against the finding in which the whole area was identified as low to moderate with respect to gully erosion susceptibility [3]. This is not far from the findings of researchers in which it was observed that intensified rainfall and human activities where natural rate of erosion has been significantly increased by human activities such as incessant lumbering, sand mining and bad farming practices in the area would have been the cause for this deviation [12-14,39].

The two major gully sites are Amaegbu-Ariam gully along Ariam-Usaka ring road (Plate 1) and Elemaga-Ibere gully along Ndoro-Itunta road (Plate 2) The gullies have led to the cutting off of some villages from the adjoining ones including Ariam Ala-Ala, Ugwuegbu, Amaegbu and Usaka (by Amaegbu gully site) and Elemaga, Itunta and Obuoro (by Elemaga gully site) [40]. The contributing factors were analyzed and prioritized as rainfall erosivity (R factor), soil erodibility (K factor), slope (LS factor), vegetative cover (C factor) and conservation practice (P factor) in that order with the criteria weights of 36%, 30%, 19%, 9% and 6% respectively (Figure 8).

Rainfall erosivity has the highest criteria weight (36%, Figure 3). This corresponds with the expert opinion of the Erosion Control Unit of Abia State Ministry of Environment in which rainfall's influence on the susceptibility of gully erosion in the study area was ranked the highest. Rainfall is an important erosion factor as reported by some researchers [3,4, 41]. The northern part of the watershed has low erosive potential with erosivity value of 127 whereas the central and southern parts have high erosive potential with erosivity value of 339. Figure 10 is the drainage pattern of Ikwuano Local Government Area.

Soil erodibility with the criteria weight of 30% (Figure 2) plays an important role in causing soil erosion in the study area. This is in agreement with the NEWMAP report which observed that soils in the southeastern Nigeria are friable and highly susceptible to erosion [15]. The friability of the soil reflects the ease with which the soil is detached by splash during rainfall and/or by surface flow. The southern and western parts of the watershed have high erodibility value of >0.3 whereas the eastern part has low erodibility value of 0.03. Figure 11 is the soil map of the study area [42-46].
Slope factor is a contributing factor to soil erosion in the study area with criteria weight of 19% (Figure 5). The gully erosion is widespread within the areas with steep slope. Some researchers observed that the steepness factor represented by S reflects the influence of slope steepness on erosion [16, 47-50]. Most of the watershed area has low to moderate slope value whereas a small portion within the central part has high slope value up to 7.48. Figures 12 and 13 are the slope map and the Digital Elevation Model (DEM) of the area [51-53].

Vegetative cover exerts influence on the soil erosion with criteria weight of 9% (Figure 6). This factor has been affected by the bad agricultural practices generally in place and the incessant lumbering activities going on within the northeastern part of the study area. The northern, eastern and southern parts of the watershed show bare soils [54]. This could be attributed to the incessant lumbering of trees and poor agricultural practices. The vegetative cover is the factor which is mostly readily changed by human activities [17].

The vegetative cover is influenced by conservation support practices. Pressure for settlements, farming and other activities which depend on both land and existing vegetation have given little or no room for soil and water conservation practices. Little contour farming and terracing are carried out in few areas [55,56]. This contributes 6% to soil erosion in the study area (Figure 7). The conservation support practices carried out in almost all the parts of the watershed have only 27% ability to reduce soil erosion with P-value of 0.73. Only a smaller portion within the central part of the watershed has conservation support practice which can reduce soil erosion by 45%, with P-value of 0.55.

6. CONCLUSIONS

The GIS-based multi-criteria evaluation approach for the assessment of the susceptibility of gully erosion has proved both useful and effective in the mapping of gully erosion susceptibility in Ikwuano Local Government Area of Abia State, Nigeria. The final result of the research which is the gully erosion susceptibility map (Figure 8) has shown the spatial distribution of gully sites in the study area. This has enabled the study to point out the major gully sites in the area which are found at Elemaga-Ibere and Amaegbu-Ariam communities.

The leading factors contributing to soil erosion in the study area were analyzed and prioritized as follows: rainfall erosivity, R (36%), soil erodibility, K (30%), slope factor, LS (19%), vegetation cover management, C (9%) and conservation practices, P (6%). The first four factors are natural causes of soil erosion. The R factor has erosivity values ranging from 127 (low erosive potential) to 339 (high erosive potential). The K factor has values ranging from 0.03956 (low erodibility) to 0.329579 (high erodibility). The LS factor has values ranging from 0 to 7.48. The P values are 0.55 (45%) and 0.73 (27%). The rate of erosion is accelerated by anthropogenic activities. These included sand excavation, bad farming practices, lumbering activities, abandoned road construction and poor drainage system.

The impacts of gully erosion in the study area were found to include the following: the destruction of houses and road, isolation of villages, loss of farmlands, vehicles stuck on the road and the siltation of streams and springs. The control measures recommended by the study include the following: regrassing (using lemon and vetiver grasses) and planting of trees such as *bambusa vulgaris* and gmelina tree; improved farming practices, proper road constructions, improved engineering/structural designs to channel runoff, engaging in early stage preventive measures; and carrying out enlightenment campaign.

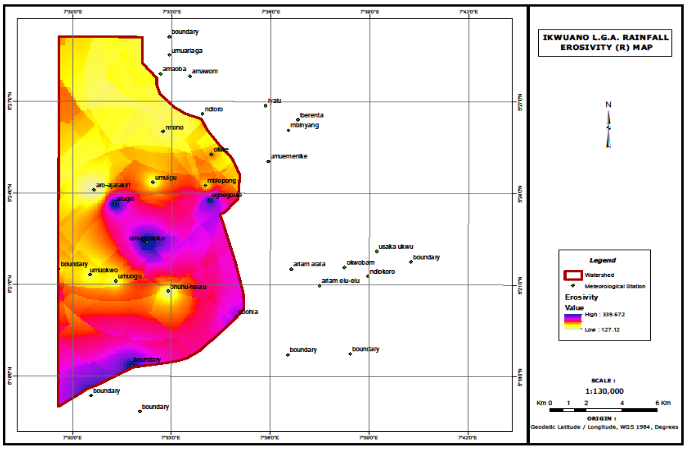

Figure 3: Rainfall Erosivity (R factor) Map

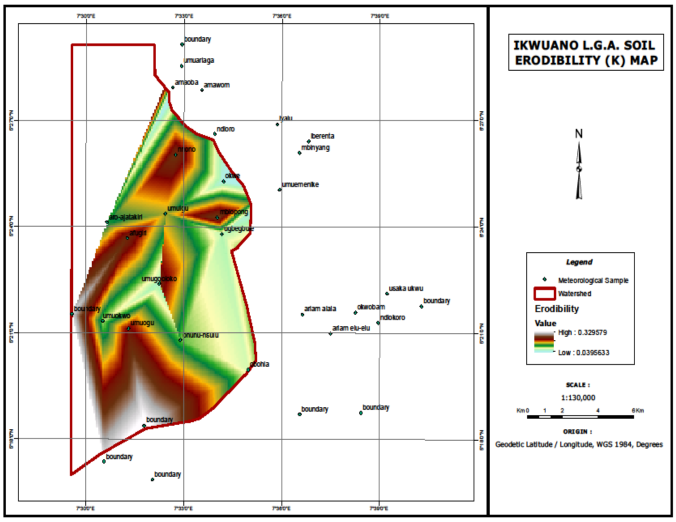

Figure 4: Soil Erodibility (K factor) Map

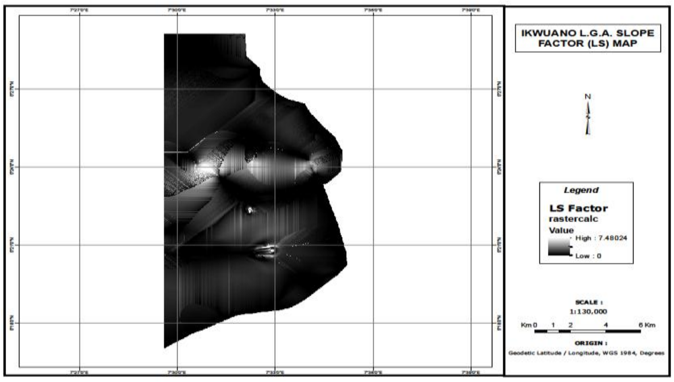

Figure 5: Slope (LS factor) Map

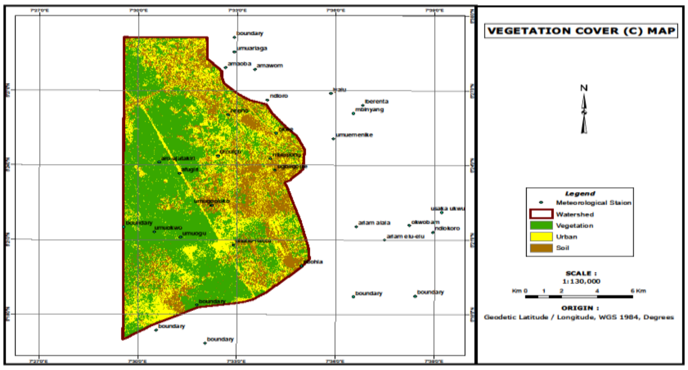

Figure 6: Vegetation Cover (C factor) Map

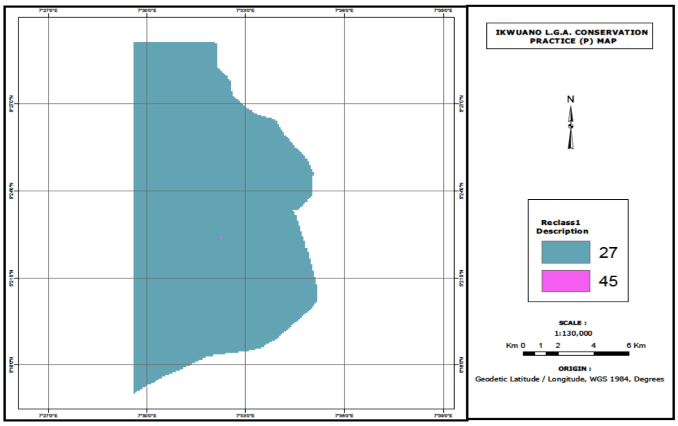

Figure 7: Conservation Practice (P factor) Map

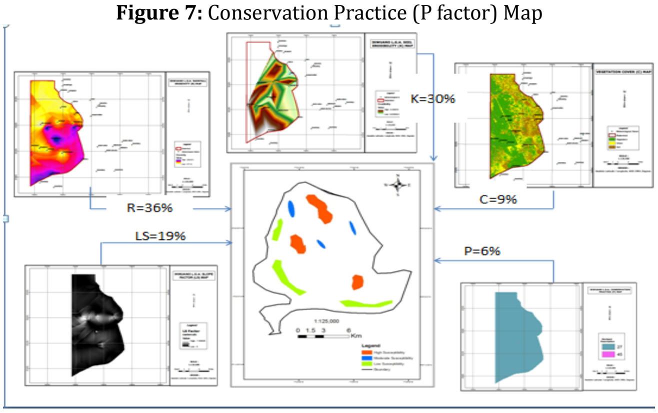

Figure 8: Gully Erosion Susceptibility Map of Ikwuano L.G.A

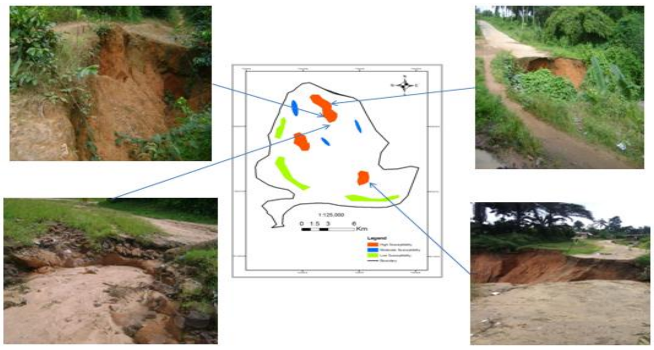

Figure 9: Gully Erosion Validation Map of Ikwuano L.G.A

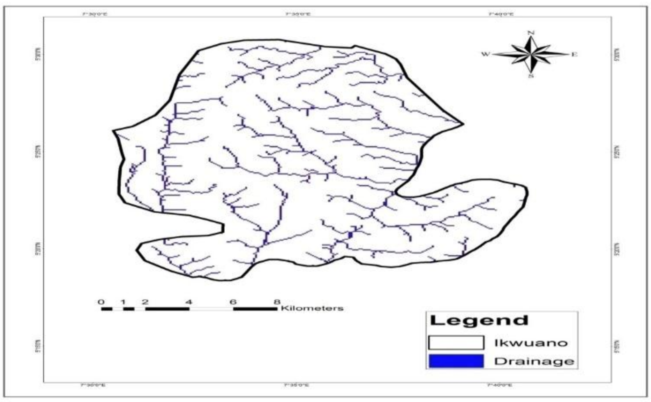

Figure 10: Drainage Map of Ikwuano L.G.A

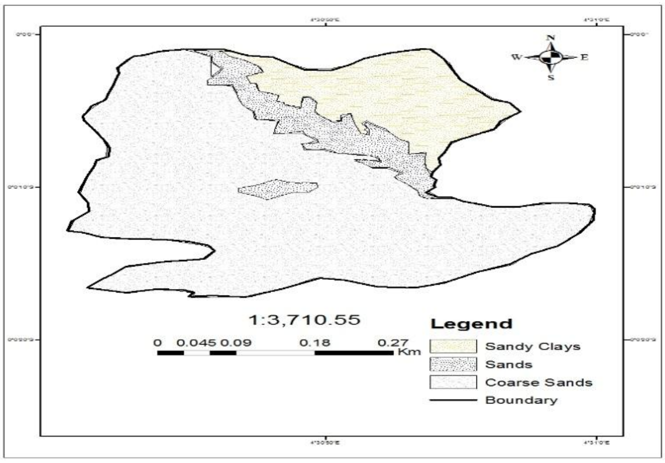

Figure 11: Soil Map of the Study Area

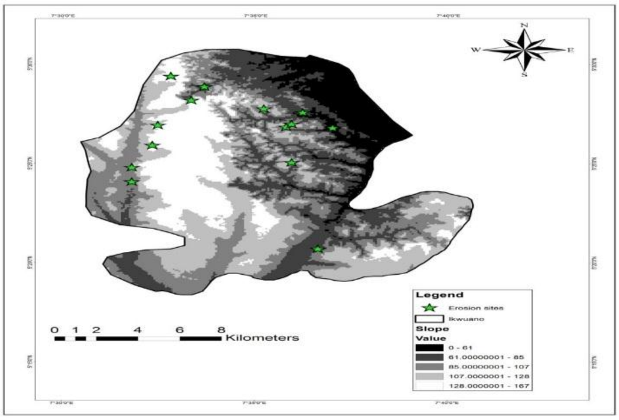

Figure 12: Slope map of Ikwuano L.G.A obtained from SRTM

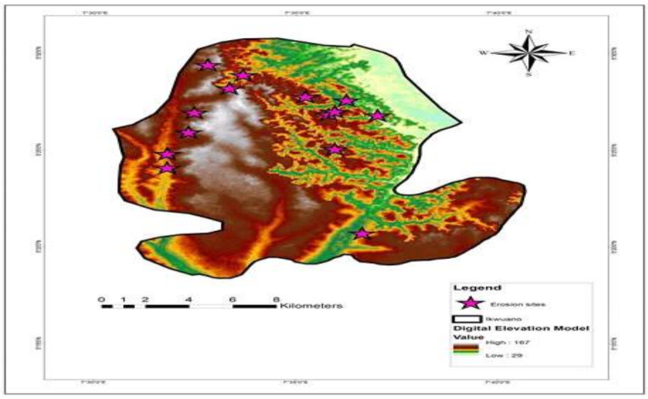

Figure 13: Digital elevation Model (DEM) of Ikwuano L.G.A

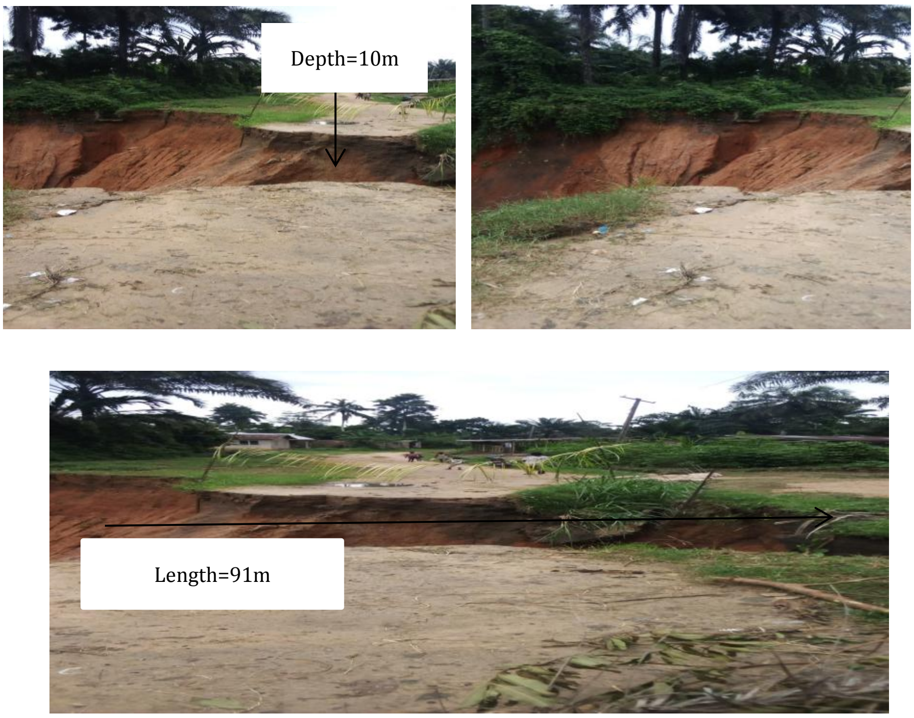

Plate 1: Amaegbu gully site (Ariam-Usaka ring road) N05^0 21′ 34.26″ & E007^0 38′ 10.08″

Plate 2: Elemaga gully site (Ndoro-Itunta road) N05^0 26′ 49.02″ & E007^0 36′ 48.18″

REFERENCES

[1] USDA. 1966. United States Department for Agriculture, Soil Conservation Service (USDA-SCS).

[2] Conoscenti, C., Angileri, S., Cappadonia, C., Rotigliano, E., Agnesi, V., Marker, M. 2014. Gully Erosion Susceptibility assessment by means of GIS-based Logistic Regression: a case of Sicily (Italy). Journal of Geomorphology, 204, 399-411. Journal homepage: www.elsevier.com/locate/geomorph

[3] Nwilo, P.C., Olayinka, D.N., Uwadiegwu, I., Adzandeh, A.E. 2011. An Assessment and Mapping of Gully Erosion Hazards in Abia State: A GIS Approach. Journal of Sustainable Development, 4 (5), 196-211. Published by Canadian Center of Science and Education. Available online: www, ccsenet.org/jsd

[4] Akpokodje, E.G., Tse, A.C., Ekeocha, N. 2010. Gully Erosion Geohazards in Southeastern Nigeria and Management Implications. Sciencia Africana, 9 (1), 20-36.

[5] UNEP. 2002. Africa Environmental Outlook: GEO-4 United Nations Environmental Programme, Nairobi.

[6] Fernandez, C., Wu, J., McCool, D., Stockle, C. 2003. Estimating Water Erosion and Sediment Yield with GIS, RUSLE, and SEDD. Journal of Soil and Water Conservation, 58 (3), 128-136.

[7] Lu, D., Li, G., Valladares, G.S., Batistella, M. 2004. Mapping Soil Erosion Risk in Rondo-nia, Brazilian Amazonia: using RUSLE, Remote Sensing and GIS. Land Degradation and Development, 15 (5), 499–512.

[8] Uhegbu, A., Igboekwe, M.U., Chukwu, G.U., Okengwu, K.O., Eke, K.T. 2013. Aquifer characteristics and Groundwater Quality Assessment in Ikwuano Area of Southeastern Nigeria. Journal of Scientific Research and Reports, 3 (2), 366-383.

[9] Obasi, P.N., Okoro, A.U., Igwe, E.O., Edene, E.N. 2015. Petrological Characteristics and Paleo-depositional Environment of the Sandstones of the Ameki Group (Eocene) in Bende and Isimkpu Areas, Southeastern Nigeria. Journal of Applied Geology and Geophysics (IOSR-JAGG), 3 (5), 09-15.

[10] Saaty, T.L. 1999. Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World, Pittsburgh, RWS Publications.

[11] Saaty, T. 1980. The Analytic Hierarchy Process, New York, McGraw-Hill, pp. 287.

[12] Stone, R.P., Hilborn, D. 2000. Universal Soil Loss Equation (USLE), Agricultural and Rural Ministry of Agriculture, Food and Rural Affairs, Ontario, Canada.

[13] Amangabara, G.T. 2014. Understanding Effective Gully Control Measures in Imo State, Nigeria. Canadian Open Soil and Erosion Journal, 1 (1), 1-9. Available online at http://crpub.com/journal.php

[14] Abdulfatai, I.A., Okunlola, I.A., Akande, W.G., Momoh, L.O., Ibrahim, K.O. 2013. Review of Guly Erosion in Nigeria: Causes, Impacts and Possible Solutions. Journal of Geoscience and Geomatics, 2 (3), 125-129. Science and Education Publishing.

[15] Anda, A.Y. 2017. Sustainable catchment management and gully erosion control in Nigeria: The NEWMAP approach. Paper presented at the 2nd International Workshop on IWRM: A tool for sustainable climate change, flood and erosion control organized by the Institute of Erosion studies, FUTO, 13th Feb.

[16] George, A., Eric, F., Prosper, L., Raymond, A. 2013. Modeling Soil Erosion using RUSLE and GIS tools. International Journal of Remote Sensing and Geoscience (IJRSG), 2 (4), 07-17.

[17] Karaburun, A. 2010. Estimation of C Factor for Soil Erosion Modeling Using NDVI in Buyukcekmece Watershed. Ozean Journal of Applied Sciences, 3 (1), 77- 85.

[18] Bettis III, E.A. 1983. Gully Ereosion of Western Iowa. The Iowa Department of Natural Resources, Iowa Geological and Water Survey, 7 (2), 70-72.

[19] Brice, J.C. 1966. Erosion and Deposition in the thin Loess-Mantled great plain, medicine Creek Drainage Basin, Nebraska (Washington Dept. of the Interior Geolopgical Survey Professional Papers, 352-H)

[20] Chukwu, G.O. 2013. Soil Survey and Classification of Ikwuano Abia State Nigeria. Journal of Environmental science and Water Resources, 2 (5), 150-156.

[21] Danladi, A., Ray, H.H. 2014. Socio-economic effect of gully erosion on land use in Gombe Metropolis, Gombe State, Nigeria. Journal of Geography and Regional Planning, 7 (5), 97-105. July 2014. Available on http: llwww.academicjournals.org/ JGRP

[22] Dumas, P., Printemps, J. 2010. Assessment of Soil Erosion Using USLE Model and GIS for Integrated Watershed and Coastal Zone Management in the South Pacific Islands. Proceedings, International Symposium in Pacific Rim, 856-866.

[23] Eastman, J.R., Kyem, P.A.K., Toledano, J., Jin, W 1993. GIS and decision Making (Geneva: UNITAR). Multicriteria Analysis for Land-Use Management, 33-42.

[24] Efe, R., Ekinci, D., Curebal, I. 2008. Erosion Analysis of Sahin Creek

Watershed (NW of Turkey) using GIS Based on RUSLE (3d) Method. Journal of Applied Science, 8 (1), 49-58.

[25] El-Swaify, S.A., Dangler, E.W., Armstrong, C.L. 1982. Soil Erosion by Water in the Tropics, University of Hawaii/HITAHR-CTAHR Research and Extension Series 24, 173.

[26] Ezechi, J.I., Okagbue, C.A. 1989. Genetic Classification of Gullies in eastern Nigeria and its Implication on Control Measures. Journal of African Earth Science, 9 (3-4), 711-718.

[27] Federal Ministry of Environment. 2005. National Erosion and Flood Control Policy

[28] Gitas, I.Z., Douros, K., Minakou, C., Silleos, G.N., Karydas, C.G. 2009. Multi-Temporal Soil Erosion Risk Assessment. In N. Chalkidiki using a Modified USLE Raster Model. Earsel proceedings, 8 (1), 40-52.

[29] Graf, W.L. 1983. The Arroyo problem-palaehydrology and palaehydraulics in the short term, in K.J. Gregory (ed). Background to palaehyddrrology: A perspective (Chihester, Wiley), 279-302.

[30] Ionus, O., Boengiu, S., Licurici, M., Popescu, L., Simulescu, D. 2013. Mapping Soil Erosion Susceptibility Using GIS Techniques with the Danube Floodplain, the Calafat-Turnu Magulere Sector (Romania). International Conference MNatural Hazards-Link between Science and Practice.

[31] Jankowski, P., Richard, L. 1994. Integration of GIS-based suitability analysis and multi criteria evaluation in a spatial decision support system for route selection. Environment and Planning B, 21 (3), 326-339.

[32] Kirkby, M.J., Bracken, L.I. 2009. Gully processes and gully dynamics. Earth Surface Processes and Landforms, 34 (14), 1841-1851.

[33] Malczewski, J. 1999. GIS and Multi-criteria Decision Analysis, New York: John Wiley and sons, ISBN 0-471-32944-4.

[34] Mbaya, L.A. 2013. A study of inter-relations among gully variables in Gombe town, Gombe State, Nigeria. Wudpecker Journal of Geography and Regional Planning, 1 (1), 001-006.

[35] Monkhouse, F.J., Small, J. 1987. A Dictionary of the Natural Environment, London: Arnold.

[36] Moore, W., Bunch, M. 1986. Off–site costs of Soil Erosion; A case study in the Willamette Valley. Western Journal of Agricultural Economics, 12 (1), 42 – 49.

[37] Morgan, R. 1986. Soil Erosion and Conservation. Co published in the United States with John Wiley and Sons. New York.

[38] Moussa, R., Voltz, M., Andrieux, P. 2002. Effects of the spatial organization of agricultural management on the hydrological behaviour of a farmed catchment during flood events. Hydrology Process, 16 (2), 393-412.

[39] Nuga, B.O., Akimbola, G.E. 2011. Characteristics and Classification of Soils Developed over Coastal Plain Sand and Shale Parent Material in Abia State Nigeria. Journal of Technology and Education in Nigeria (JOTEN), 16 (1).

[40] Onyeagocha, A.C. 1980. Petrography and Depositional Environment of the Benin Formation. Nig. J. Min. Geology, 17 (2), 147-151.

[41] Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C. 2003. Gully erosion and environmental change. Importance and research needs Catena, 50, 91–133.

[42] Rahman, T.U., Skupin, A., Falcke, M., Taylor, C.W. 2009. Clustering of InsP3 receptors by InsP3retunes their regulation by InsP3 and Ca2+. Nature, 458 (7238), 655–659.

[43] Renard, K., Foster, R., Weesies, G., McCool, K., Yoder, C. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation. U.S Government Printing Office, Washington DC.

[44] Rojas-González, A.M. 2008. Soil Erosion Calculation using Remote Sensing and GIS in Río Grande de Are-cibo Watershed, Puerto Rico. Proceedings ASPRS 2008 Annual Bridging the Horizons: New Frontiers in Geospatial Collaboration, Portland, Ore-gon, April 28th– May 2nd, 6p.

[45] Roszkowska, E. 2013. Rank Ordering Criteria Weighting Methods- A Comparative Overview. Optimum Studia Ekonomiczne NR 5 (65), 14-33.

[46] Saaty, T.L. 1977. Scaling method for priorities in hierarchical structures. Journal of Mathematical Psycchology, 15 (3), 234-281.

[47] Short, K.C., Stauble, A.J. 1967. Outline of the Geology of the Niger Delta. AAPG Bull. 51 (5), 761-769.

[48] Sidorchuk, A. 2001. GULTEM – The Model to predict Gully Thermo erosion and Erosion (Theoretical Framework). In Stott, D.E., Mohtar, R.H., Steinhardt, G.C (eds) Sustaining the Global Farm. Selected Papers from the 10th International Soil Conservation Organization Meeting held May 24 - 29, 1999 at the Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

[49] Smith, 1976. Predicting Rainfall Erosion Losses; A guide to Conservation Planning, 3 (1), 9-21.

[50] Souchere, V.O., Cerdan, N., Dubreuil, Y., Bissonnais, L., King, C. 2005. Modeling the impact of agri-environmental scenarios on overland flow in a cultivated catchment (Normandy, France). Catena, 61 (2), 229-240.

[51] Surjit, S., Ravinder, J., Kaushik, S. 2015. Vulnerability Assessment of Soil Erosion Using Geospatial Techniques. A Pilot Study of Upper Catchment of Markanda River. International Journal of Advancement in Remote Sensing, GIS and Geography, IJARSGG, 3 (1), 9-21.

[52] Svoray, T., Michailov, E., Cohen, A., Rokah, L., Sturm, A. 2011. Predicting gully initiation: Comparing data mining techniques, analytical hierarchy process and the topographic threshold. Earth Surface Processes and Landforms, 37 (6), 607-6619.

[53] Umudu, M. 2008. Residents flee as erosion eats up Anambra community. The Nation. Monday, Oct 20, Vintage Press Ltd, Lagos.

[54] Wischmeier, W.H., Johnson, C.B., Cross. B.V. 1971. Soil Credibility Nomograph for Farmland and Construction Sites. Journal of Soil and Water Conservation, 26, 189-193.

[55] Wischmeier, W.H., Smith, D.D. 1978. Predicting rainfall erosion losses - a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook, 537, 58.

[56] Wenfu, P.B., Jieming, Z., Zhengwei, H., Cun-jian, Y. 2008. Integrated Use of Remote Sensing and Gis for Predicting Soil Erosion Process. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B4. Beijing.