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Effect of Rainfall on Gully Head Retreat Using GIS (University of Benin Gully as Case Study)

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Abstract

This paper investigated the impact of rainfall (precipitation) on gully head retreat at the University of Benin gully erosion site. The devastating effects of this environmental menace necessitated this study with a view to finding a lasting solution to the challenge. The catchment area was geo-referenced using hand held GPS receiver while ground survey data were obtained by the use of Total station and the data were downloaded into excel spread sheet before it was exported to Arc GIS 9.3 software used for environmental modeling. The shape files created for the elevation data were added and Triangulated Irregular Network (TIN) was created using Z coordinates. Goggle imagery was used to monitor the gully head retreat for a record period of ten (10) years. Rainfall data for Benin City (1960 – 2010) were obtained from Nigerian Meteorological Agency (NIMET) and the data was analyzed using three-years moving average method. Auger samples were obtained from different locations within the catchment to a maximum depth of 2m. Recovered samples were taken to the Laboratory for standard classification and analysis. The geotechnical results shows that the soil being predominantly silt with erodibilty index of 5.68 can hardly resist rainfall with kinetic energy of 63j; this factor predisposes it to high erosion during wet period. Analysis of rainfall data shows that precipitation has been on the increase (an annual average of 2,039mm) especially in the last decade (2000 – 2010). Within this period, gully head retreat was about 550m (average annual retreat of about 52.7m in the last decade) while over three hundred thousand cubic meters (300,000m^3) has been lost in the area. The graphical representation of the relationship between rainfall and gully head retreat has correlation coefficient, r^2 =0.953 and r = 0.97 while the model relating both parameters was given as Y =0.023x+1.685. The result shows that the pattern of the scattered plot is narrow and there is a strong linear relationship between rainfall and gully head retreat.

Keywords: Rainfall, Retreat, Gully Erosion, Annual, sediment

1.0 Introduction

Rainfall is the primary source of runoff generation over the land surface. Extreme precipitation (Rainfall) events with long duration and high frequency are not rare in most urban cities in Nigeria especially in the Niger Delta region. This is formed especially through convective processes followed by wet seasons. The occurrence of devastating flood in continuous years within urban cities and towns (like Benin City) has created the awareness of designing better urban storm water management/control system for the future. In a recent study [1], in urbanized catchment near Lumpur, the highest 5min intensity in the greatest storm events in 2003 was 222mm/hr and the rain lasted for about 1hour 54minutes. In this case, high volume of runoff is rapidly disposed from urban areas which inundates downstream and also degrade lands in most areas where control at source concept was not introduced into storm water management.

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Within Edo state, erosion gullies are formed primarily by surface runoff from high intensity events on the fine to fairly coarse grained sand of Benin formation. The process of gully formation yields a degraded terrain in which deep and wide gullies are formed. Within the region, gullies originate with a down slope orientation which undergoes progressive widening and deepening with successive rainfall events. Rainfall intensity exceeding designed drainage system discharge capacity results in surcharging in urban areas like Benin City and other settlements. Assessing soil erosion rate due to excessive runoff is essential for the development of adequate erosion prevention and management measures for sustainable management of scares land resources within the university [2].

Gully head retreat at the University of Benin has reached alarming stage in the last decades as the blocks of flats which accommodates university staff is under serious threat by the environmental hazard. This has in no small way affected the infrastructural development of the campus as the long awaited "Phase B" expansion project of the university is almost becoming a mirage. The gully has not only gulped over three hundred (300) hectares of land but it has also partitioned the campus into two thereby making communication between the university and the neighboring community a herculean task [3]. The modern world is being faced with major environmental problem of global warming thereby making long term rainfall forecasting difficult. On a general note, climate and rainfall are highly non linear phenomena in nature displaying what is otherwise known as 'Butterfly Effect". While some parts of the world are noticing a systematic decrease in annual rainfall, others experiences flooding and severe storms. This global phenomenon is always very complex and requires computer modeling and simulation to predict accurately [4].

One very valuable technological tool that has been developed for environmental impact modeling is Geographic Information Science (GIS). It can acquire data and process it anywhere in the globe at low cost. It has consistent data update potentials. Many images interpretation and analysis, data merging and other layers can be done in GIS. The technology integrates common data base operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. It has advanced features for data storage, management, processing, analysis and display. Apart from using it to acquire various topographic features, it can also be used to integrate various models. Data inputs are usually derived from the combination of hard copy maps, aerial photographs; remotely sensed images survey documents etc. today a lot of geographic data already exist in GIS compatible format. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public use especially in environmental science and Engineering [2, 5].

The aim of this study is to evaluate the effect of rainfall on gully head retreat at the University of Benin using GIS and rainfall data with a view to developing a storm water management plan for the catchment.

2.0 Study Area

The study area is university of Benin, Ugbowo campus (Fig. 1) which extends from Benin-Lagos road in the west to the Benin - Auchi road in the North east. The campus is divided into two (western and eastern) parts by large basin of Ikpoba River. It's between Latitude 05^0 44'N to 07^0 34'N and longitude of 05^0 04'E to 06^0 45'E. The western sector slopes at between 3-5% into Ikpoba River. On this same sector (western), the slope breaks just behind the capitol. From this point, run off due to change in the gradient accelerated into Ikpoba River [2, 6].

The elevation of the study area ranges from 44m to 88m above mean sea level. The average temperature in this area is approximately 27^0C and annual rainfall is between 1,500mm/yr to 3,000mm/yr. The rainy season spans from March to November with break in the month of August popularly known as August Break. Maximum rainfall is as high as 549mm (July/September) with minimum as 4.1mm (January/December). Humidity is about 80% most time and the area lies in the tropical rain forest zone while the soil at the location is predominantly fine grains with some traces of sand especially at the upper reach of the catchment (towards Ekosodin).

3.0 Materials and Methods

Field survey (reconnaissance and topographical) was undertaken to have a good knowledge of the area using surveying instruments. Geo-spatial data were collected by the use of GARMIN hand held GPS receiver; the coordinates were converted to Nigerian Transverse Mercator (NIM) by using INCA software. With the use of Total station, the gully bed was mapped out. The projects coordinates from the total station were down loaded into arc GIS software as an excel spread sheet for further processing. The shape files created for the elevation data were added and a Triangulated Irregular Network (TIN) was created using Z coordinates. From here, the Digital Elevation Model was then generated by converting the TIN into raster. Google earth was used to monitor the annual growth in gully head at the end of each rainy season (November) while the corresponding annual rainfall amount for that year was also obtained.

The main data needed for the study was rainfall data, though meteorological data (Rainfall, Temperature and Relative humidity) for Benin City from 1970-2010, was obtain from Nigerian Meteorological Agency (NIMET). The rainfall data was analyzed by using three years moving average method.

Precipitation process is essentially random in nature. Is difficult to predict in certainty what would be the rainfall for any given period in future. The rain fall magnitude can be estimated only with some probability attached to them. Therefore, the analysis of rain fall data obtained over a long period of time in the past would help to make reasonable probabilistic estimate of rainfall to be used for various designs. In order to ascertain the properties of the soil in the catchment area, hand auger samples were obtained from within and around the gully to a maximum depth of 2m. The recovered samples were taken to geotechnical laboratory for standard classification in accordance with BS 1377:85. The following tests were carried out; specific gravity, sieve analysis, atterberg limit test, compaction test, natural moisture test and shear box test.

3.1 Moving Average Curve

All other methods of representation of rainfall data (bar chart, chronological chart and ordinate graph) may not show any trend or cyclic pattern present in data. The moving main curve smoothens out the extreme mean variation and indicates the trend of cyclic pattern if any. The moving average curve is constructed with a moving period of m years, where m is generally taken to be 3 or 5 years. Let $x_1, x_2, .x_n$ be the sequence of given annual rainfall in the chronological order. Let y_i denote the ordinate of the moving average curve for the *ith* year. Then m=3, y_i is computed from:

$$y_1 = \frac{x_1 + x_2 + x_3}{3}$$

$$y_2 = \frac{x_2 + x_3 + x_4}{3}$$

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“ “

$$y_i = \frac{x_{i-1} + x_i + x_{i-1}}{3}$$

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$$y_{n-1} = \frac{x_{n-2} + x_{n-1} + x_n}{3} \qquad (1)$$

From equation (1) the computed value of y correspond in time to the middle value of the x’s being average and therefore its convenient to use odd value for m.

The normal rainfall of the study area (which is the arithmetic average of annual rainfall in the last 30 years) was also computed and plotted. If the observed rainfall in any year is less than the normal annual rainfall, it is called the deficient or the dry year and if otherwise, it’s called a surplus or wet year [7].

3.2 Rain Drop Splash

The falling rain drop has certain kinetic energy and therefore results in land erosion of top soil. The splash action of a rain drop has certain physical characteristics such as size, shape, velocity of hitting land surface, kinetic energy and force. The following formula to express the terminal velocity of a rain drop after a compressive examination on the falling velocity of rain drop was given by [8].

$$v_m = \left[\left(38.9\frac{v}{d_{50}}\right)^2 + 2400gd_{50}\right]^{\frac{1}{2}} - 38.9\frac{v}{d_{50}} \qquad (2)$$

$$v_m = \frac{d_{50}}{0.113 + 0.0845d_{50}} \qquad (3)$$

Where v_m is the terminal velocity of rain drop; d_{50} is the median velocity; v is the kinematic viscosity of gas; g is acceleration due to gravity.

With Equation (3) which is a modification of Equation (2), the velocity of rain drop and kinetic energy of rain fall were computed.

Long term gully rates, E_L was computed for the gully using the estimated current volume (V) of the gully, the average bulk density of soils (ρ_d) occurring in the contributing catchment, the time span of gully development in years (T) and the water shed area in hectares (A). The equation is given as [2]

$$E_L = \frac{V\rho_d}{TA} \qquad (4)$$

Erosion per unit gully surface (tm^{-2}) E_p was estimated using the formula

$$E_p = \frac{V\rho_d}{A_p} \qquad (5)$$

Where A_p is plan area of gully in m^2, V is current volume of gully m^3

4.0 Presentation of Results

Precipitation data obtained from Nigerian Meteorological Agency, NIMET was arranged in decades taking cognizance of total annual, mean annual, maximum and minimum rainfall respectively. The arrangement of the precipitation data are presented in Table 1. Three (3) year moving average curve was used to analyzed rainfall data from 1981-2010. The chart of the three years moving average is presented in Figure 2

The normal monthly rainfall (i.e. arithmetic average of monthly rainfall in the past 30 years) was computed from the precipitation data obtained from Nigerian Meteorological Agency, NIMET and the results are presented in Table 2 while Table 1 is a summary of rainfall distribution in Benin City in the last thirty years.

The normal monthly rainfall computed was compared with the annual rainfall from 2006 – 2010. This was to ascertain the difference in monthly rainfall i.e. either deficient or surplus.

The annual head retreat as well as the corresponding total annual rainfall was recorded (2001 – 2010) and is presented in Table 4 while the graph showing the linear relationship between gully head retreat and rainfall is presented in Figure 4.

TOPOGRAPHIC RESULTS

Field (ground) surveys data were used to produce the catchment map and the Triangulated Irregular Network by using ARC GIS 9.3 software. The Triangulated Irregular Network (TIN) of the gully is presented in Figure 5.

5.0 Results and Discussion

The results presented in Figure 2 (computation by 3 year moving average) indicate that rain fall has been on a gradual increase in the last three decades, with 1995 being the height (2748mm). The moving average curve is obtained by plotting the values of y_i in column (5) against the corresponding year appearing in column (2). When the moving average curve was superimposed over the original rainfall series and the variation in the original data smoothened out to some extent, no apparent trend or cyclicity was visible in the curve. In Figure 2, what was well noticed is that in the last decade, rain fall has been on the increase which supports the meteorological proof that there is increase in climatic variation.

From Table 2, the normal monthly rainfall (arithmetic average of monthly rainfall in the past 30 years) in the study area was computed. The Table shows that rainfall was heaviest in the month of July (348.3mm rainfall) and September (326.9mm rainfall). The driest months were January (15.7mm of rain fall) and December (23.04mm of rainfall). February and November were also dry with arithmetic average of 42.31mm and 65mm of rainfall respectively.

Data from Table 2 (Normal Monthly Rain fall (1980-2010)) was compared with Table 3 (Annual Rainfall for years 2006 – 210).Table (3) shows an increase in rainfall from the period of 2006-2010 with the heaviest rain fall in 2010. The impulse of this is that, since the rain fall chart of 2006-2010 is higher than the normal rain fall (arithmetic average of rainfall data in the past 30 years 1981-2010), it therefore means that these years (2006-2010) were surplus rainfall years or wet years. Within these years under consideration (2006-2010) annual retreat in gully head ranged from 38.04m to 64.01m with the longest head retreat recorded in 2010. This was evidenced by the large volume of sediment deposit into Ikpoba River. Data from Table 4 was used to produce Figure 4 (graph of rainfall and gully head retreat) and correlation coefficient, r^2= 0.953 and r = 0.97 was obtained from the linear relationship of annual rainfall and gully head retreat. The value r = 0.97 show that the pattern of the scattered is narrow and there is a strong linear relationship between amount of rainfall and gully head retreat in the area.

Using Equations (4) and (5) the erosion per unit surface and long term erosion rate of the gully were computed as 4.27 and 51.27 respectively. This shows that the rate of erosion is intense and about 300,000m^3 of soil have been lost in the area. The geotechnical investigation result shows that the soil in the area is predominantly silty soil with erodibility index of about 6.4 and with clay content of less than 18%. This predisposes the soil to erosion by runoff with high kinetic energy and velocity.

The slope of the land is about 0.022 and the watershed rocks are faulted. The processes of erosion by this kind of slope flow include the detachment of particles from soil, sediment transport, and deposition, which results from raindrop splash and surface runoff. In this condition, the eroding and carrying capacity of slope flow is determined by its hydraulic characteristics. The slope of failure in this case was parallel to the ground surface and the soil properties at identical depth were similar; this made the slope an infinite slope

The result portrays the fact that rainfall and topography plays major role in the retreat of the gully head in the last decade. In year 2011 which was accompanied by unprecedented rainfall and improper termination of drain into the gully i.e. no engineering structure was in place to reduce the velocity of the run-off, the gully head retreat was about 64m.

IPCC (2001) and Nigeria Environmental Study/Action Team (NEST, 2003) provided indicators that one could use to assess the evidence of climate change in the study area. These are increase in rainfall, increase in temperature, evaporation and transpiration among others [11, 12, 13]. The study has revealed that rain fall has not only increase but has also caused gully erosion which destroyed arable land especially at the University of Benin.

6.0 Conclusion

The study examined the effects of rainfall on gully head retreat at the University of Benin using GIS and precipitation data. From the study, the following conclusion has been drawn:

- The current investigation revealed in the paper shows precipitation has not only been on the increase but its impact on the soil has left much to be desired.
- Presently, the average depth, top width, bottom width and the length of the gully are; 10.2m, 18m, 14m and 1.1km respectively. Breadth-Depth ratio of the gully ranges from 0.4 to 4.89 while about 300,000 cubic meters of soil has been loss in the area since the initiation of the gully. This is an indication that the gully had gone beyond what the University management can handle and as such relevant agencies can be reached for assistance.
- Arc GIS, goggle historical imagery and ground survey data can be used for environmental modeling and other environmental hazards assessment.
- The university management should as a matter of urgency engage in cover cropping and soil conservation practice at the block of flats area.

7.0 Recommendation

It is commended that adequate human, materials and financial resources be set aside for the collection of meteorological data (rainfall, relative humidity, temperature, wind speed, wind direction and evapotranspiration) and other relevant information which will be useful in detecting climate changes and its impact on land and the environment at large.

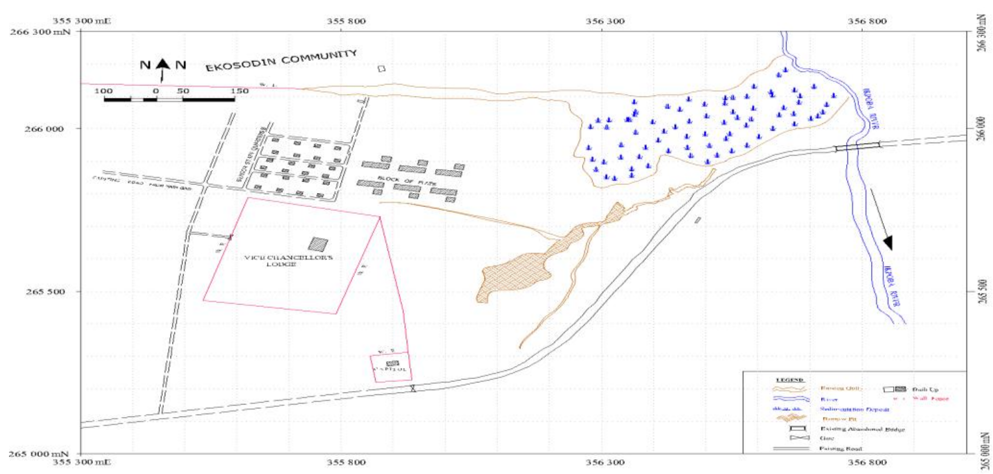

Fig 1: Location Plan of Study Area.

TABLE 1: RAINFALL PARAMETERS IN BENIN CITY (1971-2010)

Decade	Total Annual Rainfall (mm)	Mean Annual Rainfall (mm)	Max Rainfall (mm)	Min Rainfall (mm)
1971-1980	2100-2585	175-215	482-539	3.2-10.4
1981-1990	1827-2461	152-205	394-615	00-19
1991-2000	2477-2239	187-206	556-414	00-4
2001-2010	1558-2618	130-182	274-437	0-3.2

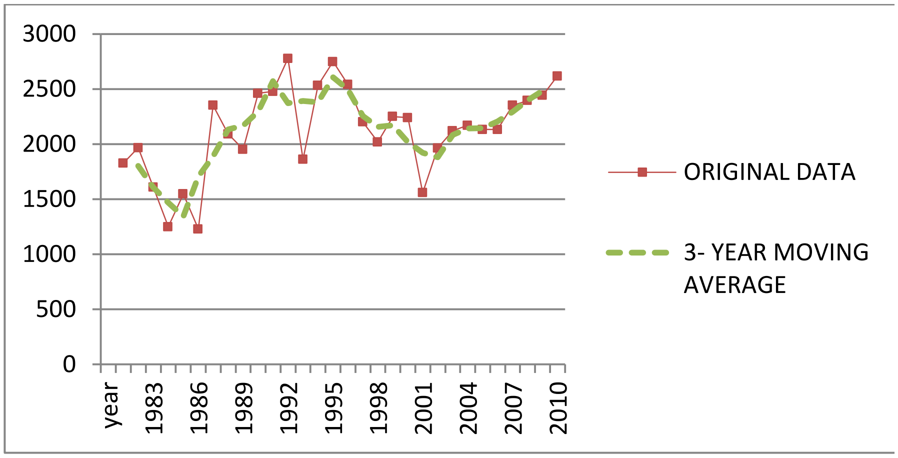

Fig 2: Three-year moving average of precipitation at the study area

Table 2: NORMAL MONTHLY RAINFALL COMPUTATION

S/N	Month	Normal Monthly Rain fall (mm)
1	Jan	15.72
2	Feb	42.31
3	Mar	105.22
4	Apr	175.51
5	May	221.85
6	Jun	258.58
7	Jul	348.26
8	Aug	294.15
9	Sept	326.91
10	Oct	239.62
11	Nov	65.74
12	Dec	23.04

Table 3: Normal Monthly Rainfall and Annual Rainfall Computation

S/N	Month	Normal Monthly Rain fall (mm) (1980-2010)	Annual Rainfall for 2006(mm)	Annual Rainfall for 2007 (mm)	Annual Rainfall for 2008 (mm)	Annual Rainfall for 2009 (mm)	Annual Rainfall for 2010 (mm)
1	Jan	15.72	12.8	7.5	0.0	5.6	3.2
2	Feb	42.31	49.4	51.1	38.9	40.6	37.7
3	Mar	105.22	157.5	108.9	42.4	148.2	109.4
4	Apr	175.51	136.5	259.7	211.4	106.3	386.3
5	May	221.85	137.7	298.3	182.4	178.4	368.3
6	Jun	258.58	352.7	351.7	385.3	250.2	277.7
7	Jul	348.26	569.2	445.3	434.8	174.3	506.1
8	Aug	294.15	127.1	82.4	275.3	722.4	257.1
9	Sept	326.91	393	402.8	410.7	369.1	336.7
10	Oct	239.62	150.3	292.2	384.2	291.7	138.4
11	Nov	65.74	23.3	39.9	29.8	154.8	102.1
12	Dec	23.04	22.8	11.5	0.0	1.1	91.3

Table 4: RAINFALL AND GULLY HEAD RETREAT

Year	Rainfall Amount(mm)	Gully Head Retreat (m)
2001	1558	38.4
2002	1962	48.01
2003	2120	51.9
2004	2170	52.1
2005	2132.1	50.11
2006	2132.3	51.73
2007	2351	52.77
2008	2395	57.89
2009	2442	60
2010	2618	64.01

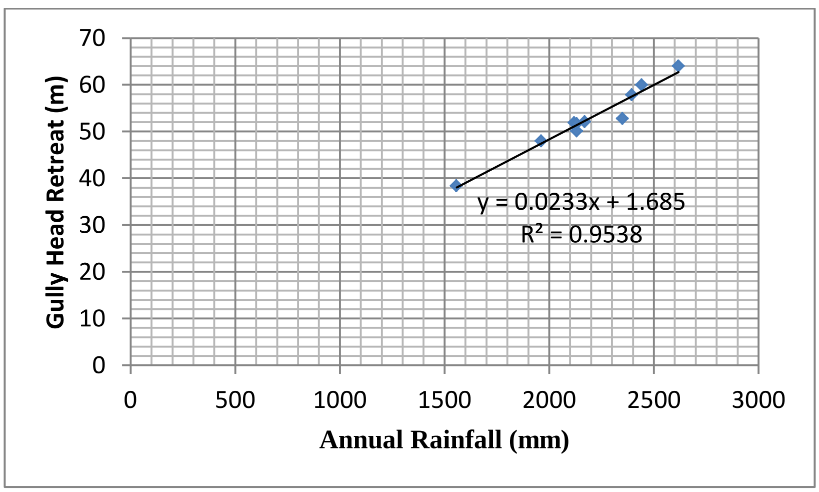

Fig 4: Graph of Annual Rainfall and Gully Head Retreat

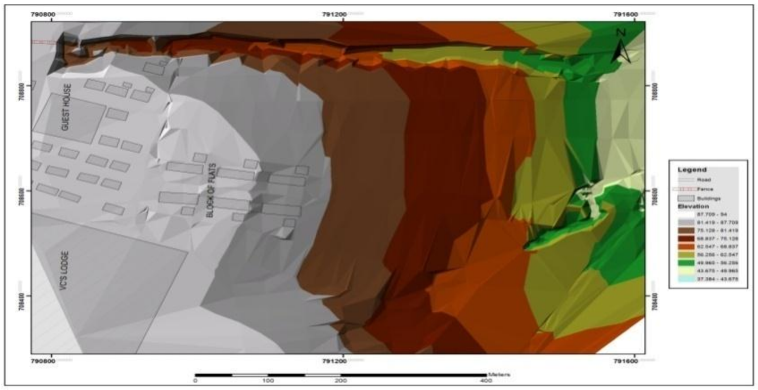

Fig 5: Triangulated Irregular Network of University of Benin Gully Erosion Site

Reference

[1] **Desa, E.S., Maurya, P., Madhan, R., Navelkar, G., (2005):** "Environmental Monitoring of the Coastal Zone by Robot Platform (2005). Proceedings of the IARP International Workshop on Underwater Robotics (IWUR 2005), Genoa, Italy, pp. 225-232.

[2] **Ehiorobo, J.O. and Audu, H. A .P. (2012);** "Monitoring Soil Loss from Erosion Using Geoinformatics and Geotechnical Engineering Methods". Journal of Civil Engineering and Architecture Vol 7, pp 48-53

[3] **Okonofua, S.E and Uwadia, N.O (2013):** "Evaluating Factors Responsible for Gully Development at the University of Benin, JETEAS 4(5): 707 -713

[4] **Abraham A, Philip N. S and Joseph K B (2001):** "Will we have a Wet Summer? Soft Computing Models for Long-term Rainfall Forecasting," In Proceedings of 15th European Simulation Conference ESM 2001, Prague, June 2001. Page 48 – 53.

[5] **Uwadia, N.O (2013)**:" Geo-Environmental Assessment of Gully Erosion in Ugbowo Campus, University of Benin, using Geoinformation" MSc. Project proposal submitted to Geology department, University of Benin.

[6] **Ehiorobo, J. O. (2010);** "Flood and Erosion Control in Edo State". Inception report submitted to NDDC on flood and erosion control in Niger Delta States.

[7] **Reddy, J.A (2006);** 'A textbook on hydrology'. Publishers, New Delhi, India

[8] **Yao, C (1987):** "Institute of Water Resources and Hydropower Research Publication" Beijing, China.

[9] **Intergovernmental panel on climate change, IPCC, (2001)**: "Impacts, adaptation and vulnerability, A summary for policy makers", A Report of working group 11, Geneva, Switzerland.

[10] **Nigeria Environmental Study/Action Term, NEST (2003):** "Impacts, adaptation and vulnerability, A summary for policy makers", A Report of working group 11, Geneva, Switzerland.

[11] **Odjugo, V.Y. (2010);** "Evaluating cost implication of environmental degradation in the face of climatic change" Trans ASAE Vol 66, pp 109-125.

[12] **Ahmad, Q.K and Ahmed, A. U (2000): "**Social sustainability, indicators and climate change." Proceedings of IPCC Experts meetings held in Colombo, Sri Lanka, 27 -29, April, 1999.

[13] **Suresh, R. (2006);** "Soil and Water Conservation Engineering Standard" Publishers, New Delhi, India.