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Gully Erosion Monitoring at the University of Benin for Effective Remediation and Control

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Abstract

Gully erosion has become a serious environmental problem within the University of Benin as several hectares of land which would have been used for development of various infrastructure within the university is being lost to the ravaging effect of gully erosion. Already, many buildings both within the senior staff quarters and the block of flats are at risk if the effect of the gully erosion is not adequately monitored and appropriate control measures adopted. In this research, measurements were carried out in 2010 and 2012 using Global Positioning System (GPS) and Total Station instrument along with satellite image data to create Triangulated Irregular Network (TIN) and Raster Models.The rate of gully head erosion and the overall soil loss between the two measurement epochs weredetermined. The results of the study revealed that the total volume of soil loss increased from 228,048m^3 in 2010 to 253,767m^3 in 2012; long term gully erosion rate increased from 4.63 tons per hectare per year in 2010 to 5.32 tons per hectare per year in 2012. It can therefore be concluded that the rate of soil loss due to the effect of gully erosion within the University of Benin is high and appropriate control measures need to be adopted to prevent further soil loss and land degradation.

Keywords: Gully erosion, GPS, TIN model, Raster model, Land degradation

1.0 Introduction

Gully erosion is a serious environmental problem within the University of Benin. The factors that have been responsible for accelerated soil loss within the university include removal of vegetation cover, topography, soil condition and precipitation.

Gully erosion within the University has been traced to improper termination of drainage channels just around the blocks of flat area and the borrow pit site used for construction of a bridge across Ikpoba river which kept widening and elongating as a result of undercutting and steep slope towards Ikpoba river.

In order to plan for the control of the gully erosion ravaging the University land, it is necessary to determine the rate of gully development. Gully erosion is said to be very rapid during the period of initiation when morphological parameters are far from being stable [1,2].

In order to plan for gully erosion control, critical thresholds for their initiation, and development in terms of precipitation, topography, soil, land use and flow hydraulics need to be studied([3,4].There are in general two steps of gully development. These include [5] incision stage and stability infilling stage. The initiation stage of gully erosion is said to be the most critical stage, and the best period to control gully erosion. This is because once the gully has initiated and developed, it is difficult to control [6,7,8].

There is an increasing concern for the devastating impacts of gully erosion in the University of Benin. The gully has been growing rapidly and this has made effective control technically difficult and economically expensive.

The objective in this paper is to evaluate the result of recent studies carried out for the intention of controlling the gully erosion within the University of Benin. Gully erosion takes place when excessive runoff with high velocity detach and carry soil particles down slope and cut deep along its path [9,10]. This is the case with the gully erosion site behind the blocks of flat in the University of Benin.

2.0 Methodology

2.1 Site Description

The University of Benin is located between 06^{o}22’15’’N to 06^{o}24’25’’N and 05^{o}36’24’’E to 05^{o}41’49’’E.The campus is bounded by Lagos road to the West, upper mission road Benin Auchi road to the East, Federal Government Girls

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College/UBTH road to the south and Ekosodin and Orior villages to the North.The V-shaped campus is divided into Eastern and Western parts by the large basin of Ikpoba river (Fig 1). The western sector where the gullies are located slope at between 3º - 8º into Ikpoba river.

Fig 1: Layout map of the University of Benin.

The problem of soil erosion in the western campus originated from man's intervention. The problem is said to have started in the early 1990's when a contractor established a borrow pit in this area thus changing the gradient of some places and additionally removing vegetative cover and thus exposing the sandy Benin formation to direct rainfall impact. The borrow pit area started eroding in different directions thus creating rills which eventually transformed to gullies. The main gully which is threatening the senior staff quarters was about 25m long as at 1998 but has increased in both length and width to over 800m as a result of continuous head cut and slumping of head walls. This gully started as a result of uncontrolled runoff from Ekosodin, an adjourning village to the University, where no attention was paid to site anti erosion measures.

2.2 Data Collection

The data collection involved field topographical surveys, geotechnical investigations as well as acquisition of meteorological data from Nigerian Meteorological (NIMET) agency office in Benin City.

2.2.1 Topographical Survey of the Site and Mapping

For proper mapping of the gully erosion sites in the University of Benin and its hazard in the erosion site, control points were established in the gully site using Differential Global Positioning System (DGPS) survey method. The world Geodetic System (WGS) 84 coordinates were converted to Universal Transverse Mercator (UTM) coordinate reference frame. During the topographical surveys, the average point's density in some areas such as the gully heads, gully edges and terraces were more intensive than in the other parts of the erosion site. The total station was tied to the GPS controls. Measurements were collected along the gully site. The gully cross sections along with topographic profiles running along the gully channels were recorded. The morphological parameters of the gully including depth, width, length and area of the gully were measured. The total station measurement were collected at centimetre level resolution to capture breaks in slope and other topographic features important for producing accurate Digital Elevation Models (DEM).

Detailed topographical survey of the erosion gullies was also made possible using Leica total station instrument, location and assessment of spatial coverage of the erosion sites from Google imagery. The easting, northings and elevation (XYZ coordinates) generated from the total station measurement were stored in Microsoft excel file format and were then imported to the ArcGIS environment using the add XY menu. The project coordinate system was then specified in (Nigeria West Belt) and then exported into personal Geo data base as shape files for the erosion sites. The shape files containing the elevation data were then added and Triangulated Irregular Network (TIN) created using the Z coordinates. The Digital Elevation Models(DEM) was generated by converting the TIN to Raster. Contour lines were generated using the created TIN to interpolate for the contour with the aid of 3D analyst extension. Arc-Scene was then used for the visualization of the 3D model generated from the TIN.

From the topographical survey data, various maps were plotted which includes the location maps, spot height, contoured map and 3-D model of the erosion sites using Arc GIS 9.3 software.

2.2.2 Geotechnical Investigation

This involved collection of soil from gully walls near the top and bottom and gully bank using hand auger to depth of 2-6m. The recovered samples were placed in cellophane bags and transported to the geotechnical engineering laboratory for tests and analysis.

2.3 Laboratory Test.

The laboratory tests carried out in the samples included natural moisture content, specific gravity, Atterberg limit test, compaction as well as soil shear strength and cohesion in undrained (saturated) state.

2.3.1 Acquisition of Meteorological Data

Meteorological data including rainfall, temperature and relative humidity for the period 1960-2010 were obtained from Nigeria Meteorological (NIMET)agency in Benin City. The obtained rainfall dada were analysed using 3-year moving average for the rainfall data while scatter plot and trend analysis was carried out in respect of the temperature.

2.4 Computation of Soil

Morphological parameter for the main gully site including length, breadth, depth, cross sectional area, volume of soil loss as well as the width to depth ratio were computed.
Volume of soil loss was computed using the equation

$$V_c = \frac{L}{2}(A_i + A_{i+1}) \tag{1}$$

Where V – volume of soil loss between cross section
L - Interval between sections
A_i - Cross sectional area of first section
A_{i+1} - Cross sectional area of next section

Cumulative volume = $\sum V = V_{1+}V_2 + V_3 \ldots + V_n$ (2)

Where $\sum V$ = Cumulative volume
$V_{1,}V_2, V_3 \ldots V_n$ = volume of soil loss between cross section from the beginning of the gully at head to the downstream end of the gully.

Long term gully erosion rate,E_L was computed using the estimated current volume (V), the bulk density of soil occurring in the contributing catchment (ρ), the time span of gully development (T), and the watershed area (A). The equation is given as [4,11]:

$$E_L = \frac{V\rho d}{TA} \tag{3}$$

Erosion per unit gully surface was estimated using the equation

$$E_p = \frac{V\rho d}{A_p} \tag{4}$$

Where A_p is plan area of gully inm^2

3.0 Results and Discussions

The location map for the gully erosion site is shown in Fig. 2, the contoured plan of the site is shown in Fig.3 while the Triangulated Irregular Network (TIN) model is shown in Fig.4.

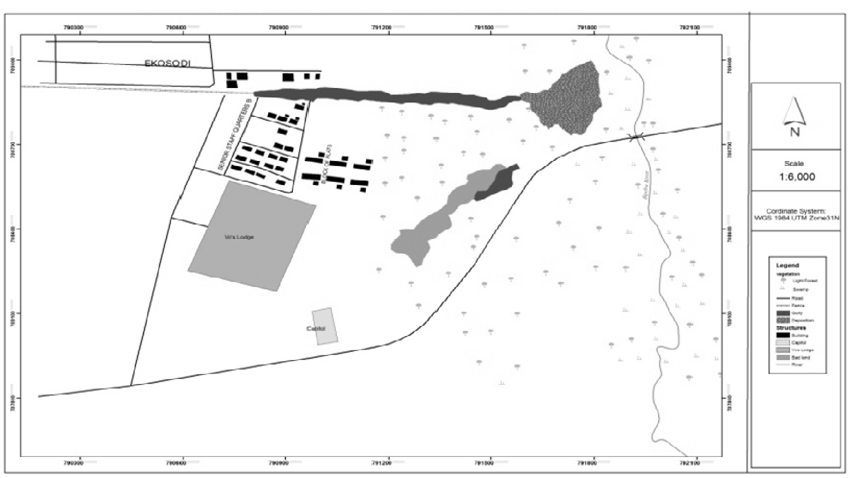

Fig.2: Location Map for University of Benin Gully Erosion and Bad Land Topography 2010

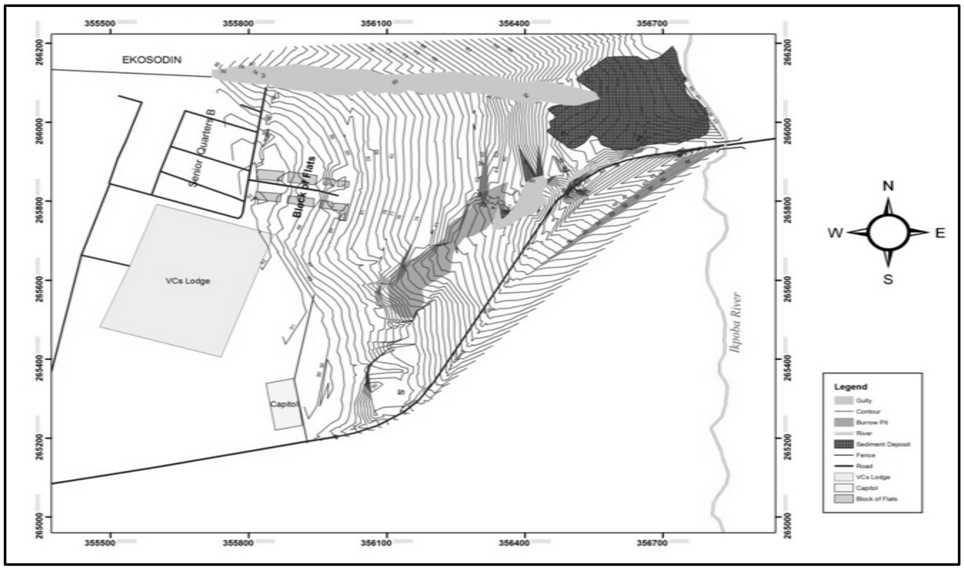

Fig.3: Contour Plan for University of Benin Gully Erosion and Bad Land Topography

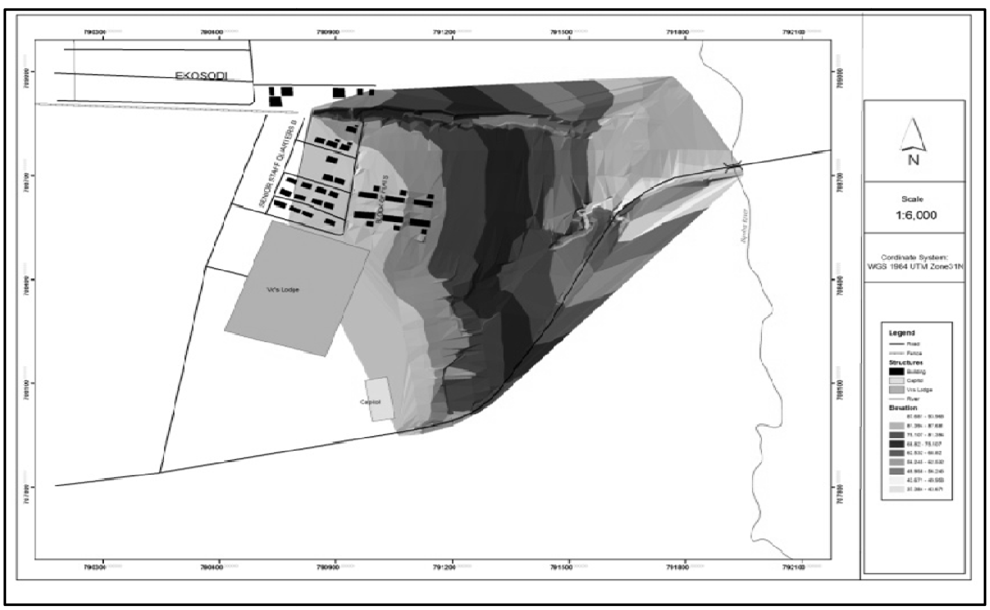

Fig.4: Triangulated Irregular Network (TIN) for University of Benin Gully Erosion and Bad Land Topography

3.1 Morphological Parameters and Volume Of Soil Loss

The computed morphological parameters for the University of Benin main gully erosion site including the cross sectional area and cumulative volume of soil loss from the gully head to the outlet (CH0+00 to CH 0+740) obtained from the 2012 and 2010 survey data, are shown in Table 1 below. The gully cross sectional areas including variations in gully head growth for the two years data, are shown in Fig. 5.

The long term gully erosion rates (E_L) and erosion per unit gully surface (tm^{-2}) E_p were computed in $tons\ per\ hectare\ per\ year, tha^{-1}yr^{-1}$ and tons per metre square,tm^{-2} respectively.The results are presented in Table 2.

Table 1: University Of Benin Main Gully Mophological Parameters including Cross Sectional Areas and Volume of Soil Loss in 2010 and 2012 Monitoring Periods

S/N	CH	TOP WIDTH			BOTTOM WIDTH			MAX. DEPTH			CROSS SECTIONAL AREA			VOLUME			CUMMULATIVE VOLUME		
		2010	2012	Δ	2010	2012	Δ	2010	2012	Δ	2010	2012	Δ	2010	2012	Δ	2010	2012	Δ
1	0+000	18.73	54.711	35.98	8.773	36.024	27.25	13.3	16.5	3.166	168.7	698.3	529.5	0	0	0	0	0	0
2	0+020	21.14	43.208	22.07	8.811	27.338	18.53	13.5	15.14	1.685	193.3	542.2	348.9	3620.7	12404.7	8783.98	3620.7	12404.7	8783.98
3	0+040	22.4	36.183	13.78	11.141	20	8.859	13	13.49	0.455	217.4	393.1	175.7	4107.1	9352.95	5245.85	7727.8	21757.6	14029.8
4	0+060	23.02	34.018	11	13.396	22.3	8.904	12.6	11.33	-1.247	218.7	307.5	88.8	4360.26	7005.64	2645.38	12088.1	28763.3	16675.2
5	0+080	24.98	36.935	11.95	13.989	16.423	2.434	13.6	12.53	-1.077	249.7	337.6	87.93	4683.65	6450.98	1767.33	16771.7	35214.3	18442.5
6	0+100	31.14	38.622	7.483	16.743	25	8.257	13.2	13.39	0.234	273.5	415.9	142.5	5231.9	7535.82	2303.92	22003.6	42750.1	20746.5
7	0+120	37.86	37.858	0	23.389	23.389	0	13	12.97	0	381	381	0	6544.95	7969.58	1424.63	28548.6	50719.7	22171.1
8	0+140	36.17	36.166	0	21.182	21.182	0	12.4	12.41	0	362.5	362.5	0	7434.92	7434.92	0	35983.5	58154.6	22171.1
9	0+160	37.11	37.111	0	23.636	23.636	0	12.2	12.18	0	358.8	358.8	0	7212.92	7212.92	0	43196.4	65367.5	22171.1
10	0+180	41.54	41.538	0	22.733	22.733	0	9.76	9.756	0	391.1	391.1	0	7499.08	7499.08	0	50695.5	72866.6	22171.1
11	0+200	41.8	41.801	0	24.667	24.667	0	11.5	11.51	0	391.1	391.1	0	7821.78	7821.78	0	58517.3	80688.4	22171.1
12	0+220	40	40	0	22.596	22.596	0	12.5	12.54	0	407	407	0	7980.66	7980.66	0	66497.9	88669	22171.1
13	0+240	47.33	47.33	0	32.117	32.117	0	13.9	13.88	0	407	407	0	8139.79	8139.79	0	74637.7	96808.8	22171.1
14	0+260	46.05	46.053	0	28.435	28.435	0	12.8	12.82	0	544.1	544.1	0	9511.49	9511.49	0	84149.2	106320	22171.1
15	0+280	46.05	46.053	0	26.437	26.437	0	13.1	13.06	0	466.8	466.8	0	10109.41	10109.4	0	94258.6	116430	22171.1
16	0+300	50	50	0	27.457	27.457	0	14.4	14.4	0	522.3	522.3	0	9891.41	9891.41	0	104150	126321	22171.1
17	0+320	38.63	38.633	0	20	20	0	13.6	13.62	0	397.9	397.9	0	9202.58	9202.58	0	113353	135524	22171.1
18	0+340	37.83	37.829	0	19.268	19.268	0	12.1	12.14	0	338.2	338.2	0	7361.16	7361.16	0	120714	142885	22171.1
19	0+360	34.45	34.447	0	20.001	20.001	0	11.3	11.33	0	325.4	325.4	0	6636.01	6636.01	0	127350	149521	22171.1
20	0+380	34.64	34.643	0	11.257	11.257	0	12.1	12.1	0	311.5	311.5	0	6369.06	6369.06	0	133719	155890	22171.1
21	0+400	39.28	39.28	0	24.269	24.269	0	13.9	13.93	0	424.8	424.8	0	7362.93	7362.93	0	141082	163253	22171.1
22	0+420	36.85	36.849	0	16.353	16.353	0	11.5	11.48	0	339	339	0	7637.45	7637.45	0	148719	170890	22171.1
23	0+440	38.72	38.717	0	17.583	17.583	0	12.4	12.45	0	357	357	0	6959.69	6959.69	0	155679	177850	22171.1
24	0+460	34.46	34.456	0	14.203	14.203	0	11.3	11.35	0	278.9	278.9	0	6358.97	6358.97	0	162038	184209	22171.1
25	0+480	37.31	37.305	0	18.423	18.423	0	10.9	10.91	0	292.8	292.8	0	5717.08	5717.08	0	167755	189926	22171.1
26	0+500	42.62	42.62	0	25.511	25.511	0	11.7	11.73	0	379.8	379.8	0	6725.7	6725.7	0	174481	196652	22171.1
27	0+520	38.11	38.11	0	23.301	23.301	0	11.1	11.11	0	346.6	346.6	0	7263.28	7263.28	0	181744	203915	22171.1
28	0+540	35.24	35.235	0	16.298	16.298	0	10.1	10.09	0	305.4	305.4	0	6519.44	6519.44	0	188263	210434	22171.1
29	0+560	37.08	37.081	0	21.981	21.981	0	9.3	9.295	0	259.7	259.7	0	5650.94	5650.94	0	193914	216085	22171.1
30	0+580	32.98	32.976	0	19.804	19.804	0	10.6	10.55	0	271.5	271.5	0	5311.99	5311.99	0	199226	221397	22171.1
31	0+600	38.29	38.292	0	22.931	22.931	0	9.76	9.758	0	296.2	296.2	0	5676.75	5676.75	0	204903	227074	22171.1
32	0+620	41.48	41.479	0	27.942	27.942	0	8.03	8.025	0	265.9	265.9	0	5621.31	5621.31	0	210524	232695	22171.1
33	0+640	36.03	36.033	0	15.575	15.575	0	9.43	9.426	0	239.5	239.5	0	5054.71	5054.71	0	215579	237750	22171.1
34	0+660	38.62	38.62	0	19.868	19.868	0	9.1	9.1	0	250.2	250.2	0	4896.98	4896.98	0	220476	242647	22171.1
35	0+680	32.75	32.751	0	16.966	16.966	0	7.06	7.063	0	177.3	177.3	0	4274.89	4274.89	0	224751	246922	22171.1
36	0+700	31.03	31.026	0	15	15	0	6.94	6.939	0	152.3	152.3	0	3296.67	3296.67	0	228048	250219	22171.1
37	0+720		19.975	19.98		12.59	12.59		5.347	5.347		91.92	91.92		2442.54	2442.54		252661	252661
38	0+740		22.753	22.75		13.524	13.52		1.304	1.304		18.65	18.65		1105.7	1105.7		253767	253767

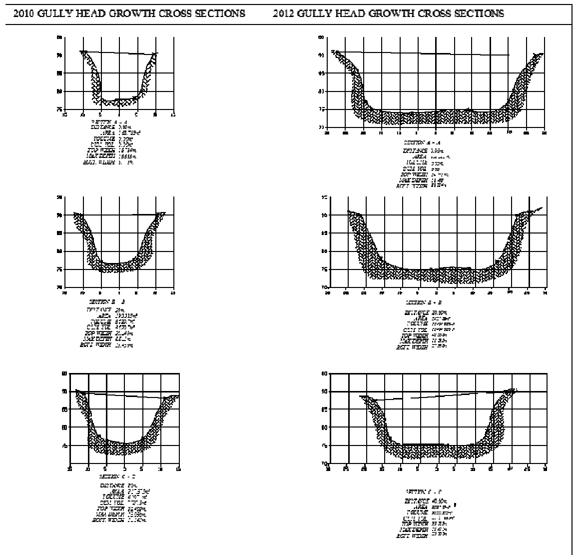

Figure 5:Typical Gully Cross Sections for the Monitoring Years.

3.2 Volumetric Estimate of Soil Loss

The volume of soil loss, V in $m^3$was computed in year 2010 and 2012. Long term gully rates E_L, erosion per unit gully surface Ep and Volume of soil loss over gully surface area $V(m^3)$ / $A(m^2)$ for the monitoring years were also determined and the results are presented in Table 2.

Table 2: Volumetric estimate of soil loss for the university of Benin main gully site

S/N	Monitoring Years	V (m^3)	Bulk density(g/cm^3)	E_L($tha^{-1}yr^{-1}$)	E_p (tm^{-2})	$V(m^3)/A(m^2)$
1	2010	228047.61	1.85	4.63	15.407	8.33
2	2012	253766.91	1.91	5.32	16.063	8.41
DIFFERENCE		25719.33	0.06	0.69	0.656	0.08

Erosion per unit gully surface Ep in (tm^{-2}) shows a difference of 0.656 within the monitoring years with 15.407 for the previous year and 16.063 for the recent year. The volume of soil loss over the monitoring years for the main gully area V (m^3) computed gave difference of 25719.33 with an annual rainfall of 12859.665mm. These results show that the annual rate of soil loss over these years is very high in the gullies.

3.3 Geotechnical Characteristics of the Gully Area

Attribute table along with location of sampling points for the University of Benin gully site are shown in Fig 6. The attribute table presents the results of the geotechnical characteristics for the gully site.

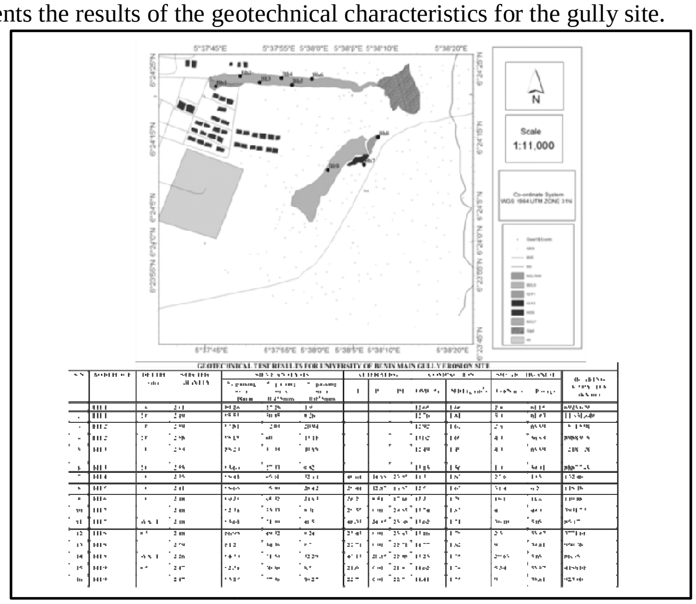

Fig 6: Attribute table of geotechnical properties along with location of sampling points for University of Benin Gully Site

From the results,

a) The specific gravity of the soil samples tested ranges from 2.18-2.61 indicating that the soils are of normal specific gravity (normal specific gravity of soils ranges from 2.35-2.99 [12]).

b) The sieve analysis test carried out shows that percentage of soil particles passing through sieve 1.18mm ranges from 81.21% - 99.25%, the percentage passing through sieve 0.425mm ranges from 27.28% to 72.08% while the percentage passing through sieve 0.075mm ranges from 0.24% -41.50%. On the average, the percentage passing through sieve 0.075mm is less than 35%, this indicates that the soil samples is predominantly of granular composition.

c) The Atterberg Limit test shows that the Liquid limit of the soil ranges from 21.0% - 48.33%, the Plastic Limit ranges from 0.00% - 24.95% while the plastic index ranges from 16.57% - 29.55%. This indicates that the plastic Limit of the soil is fairly low.since the Plasticity Index below 35% are regarded as low [13]. The soil therefore lacks enough binding or cementing properties.

d) The result of the compaction tests shows that the value of Maximum Dry Density of the soil ranges from $1.49g/cm^3$ – $1.87g/cm^3$ while the values for the Optimum Moisture Content range from 11.3% - 14.77%.

e) The shear box test obtained for the soil samples shows that the values for Angle of Internal friction ranges from 5.05° - 67.57° and the value of cohesion ranges from $1kN/m^2$ – $30.10kN/m^2$ for the various samples collected. These values were used to compute the bearing capacity of the soils.

f) The bearing capacity obtained from the soil samples ranges from $6923.68kN/m^2$ to $11,631.65kN/m^2$ for the coarse samples and $85.171kN/m^2$ to $132.48kN/m^2$ for cohesive soil sample. It is to be noted that shear strength and cohesion in undrained (saturated) soil condition causes instability of slopes embankment hence given the high rainfall in Benin City and permeability of the soils these tests become necessary in Gully erosion control in order to provide necessary embankment protection works.

4.0 Conclusion

This paper examines the development and devastating effect of gully erosion in the University of Benin. Measurements carried out in 2010 and 2012 were analysed and the result used to evaluate the rate of soil loss in the erosion gully from the results of the study, it was observed that the volume of soil loss increased from $228,047m^3$ in 2010 to $253,767m^3$ in 2012. Long term gully erosion rate gave a value of$4.63tha^{-1}yr^{-1}$ for 2010 and 5.32 $tha^{-1}yr^{-1}$for 2012. Erosion per unit gully surface was $15.407tm^{-2}$ for 2010 and $16.063tm^{-2}$ for 2012. It can therefore be seen that the rate of gully erosion is high and appropriate remediation measures should be adopted for their control.

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