MONITORING GULLY FORMATION AND DEVELOPMENT FOR EFFECTIVE REMEDIATION AND CONTROL

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INTRODUCTION

Recent research and field studies have shown that gully erosion is one of the most soil degradation processes in most states of the South East and South South zones of Nigeria as it causes considerable soil loss and produces larger volume of sediment.

One of the main causes of gully erosion in the study area, Edo State includes road construction with inappropriately terminated drainage network. While damages, by surface run off to the road may be limited, off site effects can be severe as withnessed in the study area (Ehiorobo and Izinyon 2011). Although gullies are visually striking, their small spatial extent generally renders them undetectable in most generally available topographical maps and low resolution satellite imageries.

As a result, it is necessary to carryout ground monitoring and modeling of the gully erosion phenomenon in order to predict their environmental impact and take remedial measures.

Short term monitoring of gully head or gully wall retreat has been conducted by measuring the change in distance between the edge of the gully head or wall and bench mark points installed on the gully walls (Vandekerekhova et al 2001). Some other researchers have used aerial photographic methods to determine the volume of soil loss by concentrated flow erosion

This study involves the integration of GPS with Total Stations, remote sensing and GIS for the monitoring and experimental studies of gully morphology for the planning of land reclamation and control of the gully in order to prevent further land degredation in the study area

THE STUDY AREAS

The gully area is bounded by UTM coordinates 700800mN to 702500mN and 795800mE to 79600mE. The gully runs in a south – easternly direction down to Ikpoba river. The elevation of the study area ranges from 16m to 110m above sea level (fig1). The average temperature in this area is 28^{0}c. The raining season commences usually from April to October with a break during the month of August, commonly referred to as August break. Maximum recorded rainfall 2001–2011 was 439mm with a minimum of 3.75mm. There is however a sharp deviation this year 2012, probably as a result of climate change, as heavy rains have been experienced from January to date. Humidity is generally high about 98% for most of the year. The area lies within the tropical rain forest zone of Nigeria

QUEEN EDE GULLY CATCHMENT AREA

BACKGROUND TO THE PROBLEM

The Queen Ede problem is said to have started sometime in the 1990’s as a result of abrupt termination of the drainage channel along the Benin-Asaba road in front of the current location of the gully.

A gully of length 200m and 2m wide and almost 5m deep run along Edobor street to join another gully of the same width and depth and about 400m long along Pogha road.

This gully continues for about 60m along Igunbor street carrying along its part sediment and waste, which are dumped along Ogunbor street. As the run off in this area continue towards the highway with very high velocity it joins the storm generated along the Benin Asaba highway, crosses the highway at almost a right angle and with increase velocity of flow, continue down slope to cause more devastating damage around the Queen Ede secondary school.

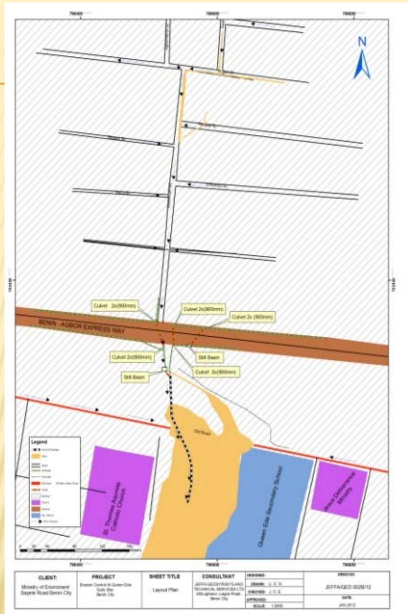


Fig 2:Layout of Existing Drainage Infrastructure

DATA ACQUISITION

- The surveys carried out for gully control and remediation included:
- Mapping of catchment basin and location of secondary gullies contributing run off to the main gully
- Detailed surveys of existing control infrastructure including gutters, culverts, catch pits, drainage channels e.t.c
- Longitudinal bed profile from head to outlet of the main gully.
- Planimetric survey of the gully head at large scale
- Cross sectional surveys of the gully to determine the nature of the stage of gully development i.e whether V or U shaped.

Two field observation sessions were carried out within the gully area, the first in December 2010 and the second in November 2011. Each observation session consisted of detailed topographical surveys of the gully site with the associated catchment basins using a total station instrument. The total station instrument was used to capture XY and Z coordinates covering the entire gully site at about 10m interval as well as other points of significant changes in slope along the bank, gully walls and gully floor.

During the topographical surveys, the average point density in some areas such as the gully head, gully floor and terraces were more intense than in other parts of the gully.


Fig 3: Ikonos Imagery of Queen Ede Gully Site

The total station measurements in each epoch were collected at centimeter level resolution to capture break in slope and other topographic features necessary for producing accurate Digital Elevation Model (DEM). The gully cross sections along with topographical profile of the gully bed from head to outlet was carried out using Automatic level with Telescopic staff. Ikonos imagery was acquired to measure and monitor the extent of the eroded area as well as providing a quantifiable estimate of the landed area and in the analysis of physical structures that have been affected or endangered by the gully (See Fig 3).

DATA PROCESSING

The morphological data and cross sectional data were used to determine the cross sectional areas and the volume of soil loss in each case.

The eroded volume of each gully segment was calculated using the cross sectional area and the distance between cross section as:

$$V = \sum L_i A_i \qquad (1)$$

Where L is length of gully section in meters
A_i is crossectional area in m^2

Short term erosion rates (t ha^{-1} yr^{-1}) (E_S) were calculated in order to determine the rate of erosion over the period of study using the equation given as (Nyssen et al 2006).

$$E_z = \frac{(V_{2010} - V_{2011})\rho_d}{TA} \qquad (2)$$

Where E_z - Erosion rate

ρ_d - Bulk density of soil occurring in the contributing area

T – Period of gully development in years.

A – Watershed area in hectares

Erosion per unit gully surface ($t.m^{-2}$) was estimated using the equation

$$E_p = \frac{V\rho_d}{A_p} \qquad (3)$$

Where V – Current volume of soil loss in the gully

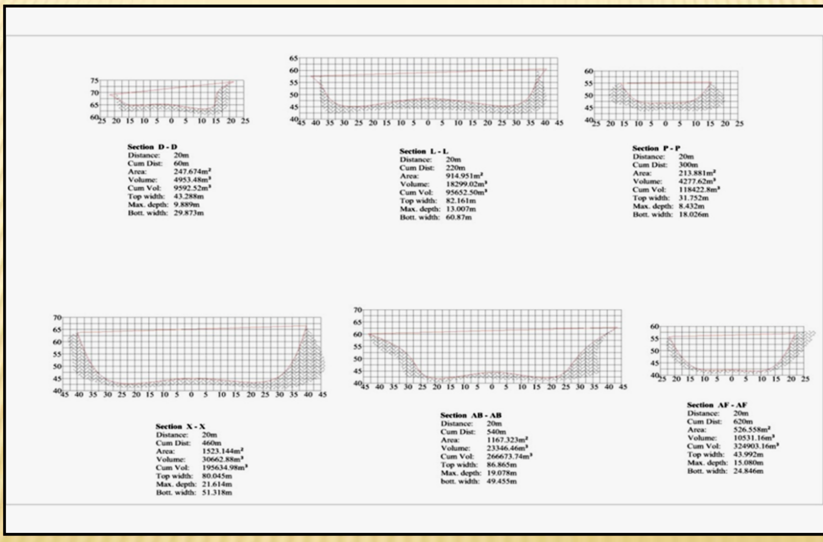
A_p - Plan area of gully (m^2)

E_p - Erosion per unit gully surface

ρ_d - Bulk density

RESULTS AND DISCUSSIONS

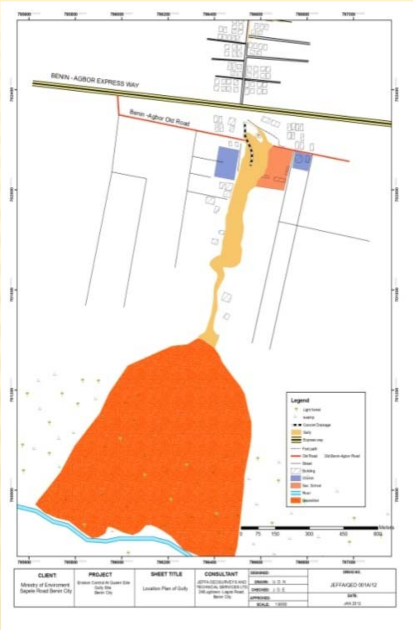
Typical cross sections for the Queen Ede gully are shown below



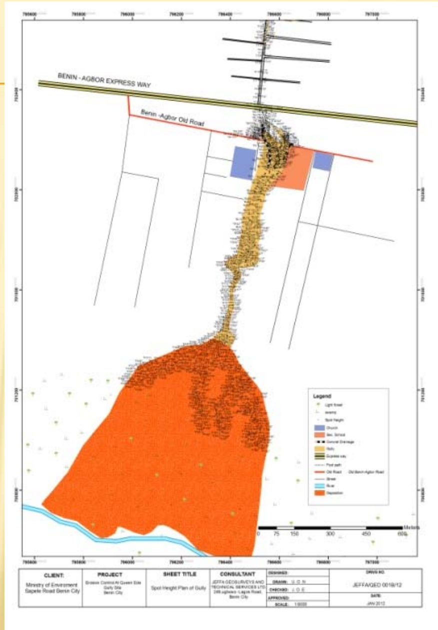
Typical Cross sections of Queen Ede gully

From the cross sections above, it can be seen that the gully is U – shaped, thus; we can conclude:

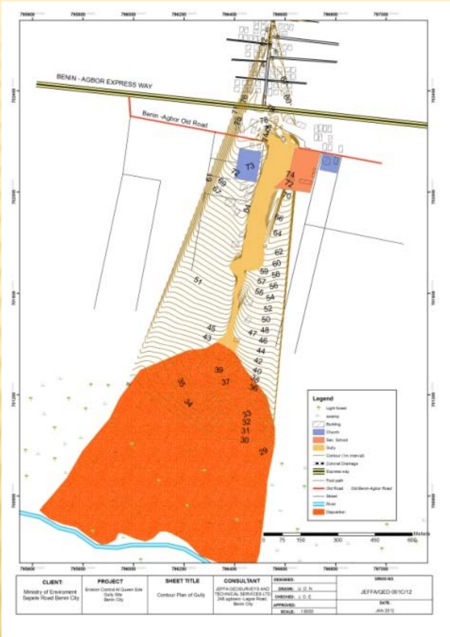
- The run-off contributing catchment area is large and therefore the discharge passing through the gully is also large
- The longitudinal slope of the gully bottom is parallel to the land slope
- The run off enters the gully from the head and from the sides at points where adjacent land is slightly lower than the surrounding.
- The gully have been formed by under cutting and collapse of the bank walls
- The gully continue to expand towards the head as active erosion action occurs mainly from side walls near the head as a result of under cutting of the base and walls



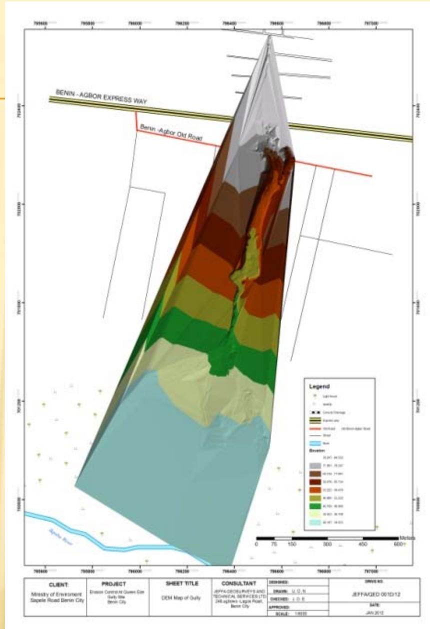
Location Map of Queen Ede Gully



Spot Height Map of Queen Ede Gully Site.



Contour Map of Queen Ede Gully Site



DEM of Queen Ede Gully Site

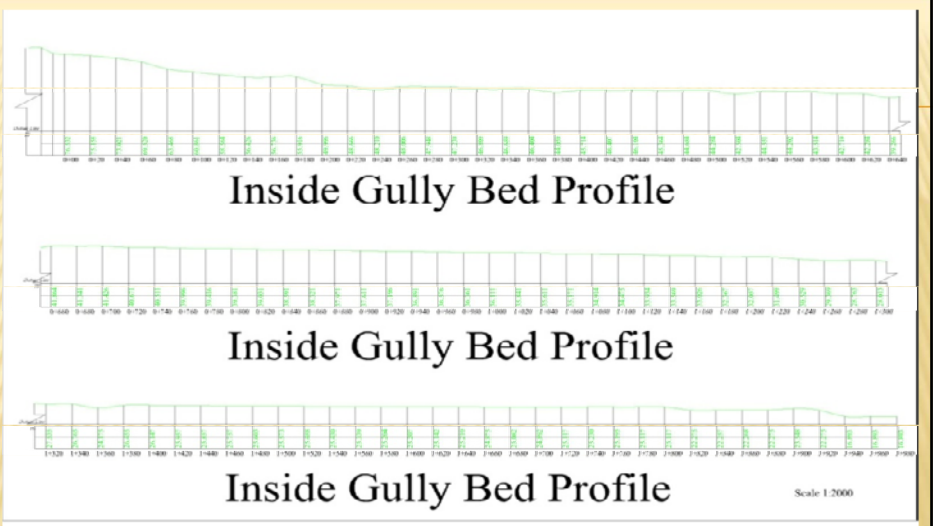
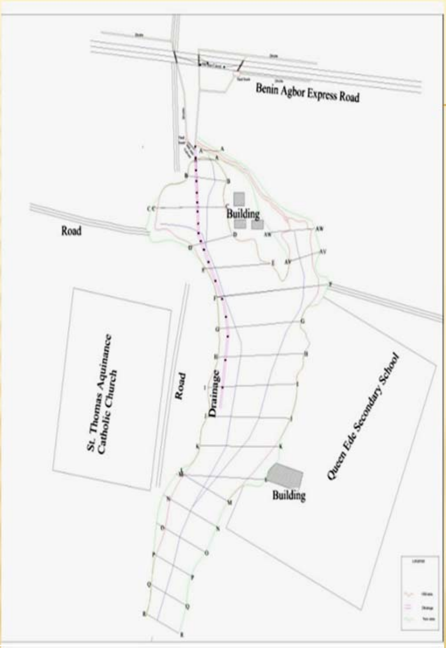


Fig 6: Bed Profile of Queen Ede Gully as at November.

The longitudinal profile of the gully bed from head to the outlet at Ikpoba river is shown in Fig 6 while a planimetric survey plan of the gully head at large scale is shown in Fig 7.



Planimetric View of Gully Head and Gully head Retreat between 2010 and 2011.

Satellite imagery delineation and field measurement of the gully growth indicated that the planimetric area of the gully has increased from 9.48 Hectares to 10.44 Hectares. From Table I, it can be shown that the value of soil loss increased from 375,322m^3 in 2010 to 393070m^3 in 2011.

Short term erosion rates was calculated using equation (2), to be 0.541 t ha^{-1} yr^{-1}

The average was based on measured gully volume and the average soil bulk density. This indicate the severity of soil loss due to gully erosion in the Queen ede catchment basin

During the period of observation, the top and bottom width of the gully experienced increase between ch 00+40 – ch 00 +100, between ch00+220 – ch00+280 and between ch00+940 and 00+980 respectively (See Table I). It is however expected that with heavy rain in Benin city since January 2012, slumping in various part of the gully walls will occur as a result of ground water exerting pressure on the overlaying saturated soil profile. This in turn will cause the soil to loose its stability and consequently causing the slumping of gully walls with consequent further widening of the gully and deposition of higher volume of sediment at the down stream of the gully. This will create further environmental degradation and loss of valuable properties and land resources.

TABLE 1: MOPHOLOGICAL PARAMETERS OF GULLY INCLUDING CROSS SECTIONAL AREAS AND VOLUME OF SOIL LOSS IN 2010 AND 2011 MONITORING PERIOD

S/N	CHAINAGES	TOP WIDTH			BOTTOM WIDTH			DEPTH			CROSS SECTION AREA			VOLUME			CUMULATIVE VOLUME OF SOIL LOSS		
		2010	2011	DFFERENCE	2010	2011	DIFFERENCE	2010	2011	DIFFERENCE	2010	2011	DIFFERENCE	2010	2011	DIFFERNCE	2010	2011	DIFFERENCE
1	00+00	15.604	15.604	0.000	10.000	10.000	0.000	0.374	0.374	0.000	3.510	3.510	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	00+20	36.993	36.993	0.000	13.466	13.466	0.000	3.478	3.478	0.000	55.172	55.172	0.000	1103.440	1103.440	0.000	1103.440	1103.440	0.000
3	00+40	62.702	68.582	5.880	28.556	28.920	0.364	4.751	4.751	0.000	173.467	176.780	3.313	3469.340	3535.600	66.260	4572.780	4639.040	66.260
4	00+60	39.300	43.288	3.988	29.873	30.002	0.129	9.889	9.889	0.000	242.322	247.670	5.348	4846.440	4953.480	107.040	9419.220	9592.520	173.300
5	00+80	61.687	61.687	0.000	17.500	17.500	0.000	7.846	7.846	0.000	316.256	316.256	0.000	6325.120	6325.120	0.000	15744.340	15917.640	173.300
6	00+100	99.454	101.218	1.764	81.556	82.877	1.321	9.155	9.155	0.000	429.739	431.335	1.596	8594.780	8626.700	31.920	24339.120	24544.340	205.220
7	00+120	76.554	76.554	0.000	65.996	65.996	0.000	6.988	6.988	0.000	328.321	328.321	0.000	6566.420	6566.420	0.000	30905.540	31110.760	205.220
8	00+140	80.297	80.297	0.000	66.556	66.556	0.000	13.788	13.788	0.000	726.142	726.142	0.000	14522.840	14522.840	0.000	45428.380	45633.600	205.220
9	00+160	81.627	81.627	0.000	69.246	69.246	0.000	10.585	10.585	0.000	593.031	593.031	0.000	11860.620	11860.620	0.000	57289.000	57494.220	205.220
10	00+180	76.533	76.533	0.000	71.784	71.784	0.000	7.112	7.112	0.000	283.207	283.207	0.000	5664.140	5664.140	0.000	62953.140	63158.360	205.220
11	00+200	74.184	74.184	0.000	60.000	60.000	0.000	12.394	12.394	0.000	709.756	709.756	0.000	14195.120	14195.120	0.000	77148.260	77353.480	205.220
12	00+220	75.820	82.161	6.341	60.870	60.000	-0.870	13.007	13.007	0.000	897.077	914.951	17.874	17941.540	18299.020	357.480	95089.800	95652.500	562.700
13	00+240	40.418	50.173	9.755	32.232	32.232	0.000	10.727	10.727	0.000	357.197	386.809	29.612	7143.940	7736.180	592.240	102233.740	103388.680	1154.940
14	00+260	41.971	54.266	12.295	37.500	38.060	0.560	7.492	7.492	0.000	288.332	313.481	25.149	5766.640	6269.620	502.980	108000.380	109658.300	1657.920
15	00+280	36.292	49.53	13.238	22.500	22.500	0.000	7.208	7.208	0.000	204.210	224.344	20.134	4084.200	4486.880	402.680	112084.580	114145.180	2060.600
16	00+300	31.752	31.752	0.000	18.026	18.026	0.000	8.432	8.432	0.000	213.881	213.881	0.000	4277.620	4277.620	0.000	116362.600	118422.800	2060.200
17	00+320	32.290	32.290	0.000	22.098	22.098	0.000	8.855	8.855	0.000	220.372	220.372	0.000	4407.440	4407.440	0.000	120769.600	122830.240	2060.640
18	00+340	30.000	30.000	0.000	23.894	23.894	0.000	7.975	7.975	0.000	218.855	218.855	0.000	4377.100	4377.100	0.000	125146.740	127207.340	2060.600
19	00+360	31.780	31.780	0.000	19.505	19.505	0.000	7.046	7.046	0.000	179.625	179.625	0.000	3592.500	3592.500	0.000	128739.240	130799.840	2060.600
20	00+380	41.297	41.297	0.000	30.705	30.705	0.000	8.737	8.737	0.000	283.715	283.715	0.000	5674.300	5674.300	0.000	134413.540	136474.140	2060.600
21	00+400	56.205	56.205	0.000	40.841	40.841	0.000	8.981	8.981	0.000	391.768	391.768	0.000	7835.360	7835.360	0.000	142248.900	144309.500	2060.600
22	00+420	62.090	62.090	0.000	46.441	46.441	0.000	10.306	10.306	0.000	499.879	499.879	0.000	9997.580	9997.580	0.000	152246.480	154307.080	2060.600
23	00+440	62.348	62.348	0.000	47.829	47.829	0.000	11.046	11.046	0.000	533.251	533.251	0.000	10665.020	10665.020	0.000	162911.500	164972.100	2060.600
24	00+460	80.045	80.045	0.000	51.318	51.318	0.000	21.614	21.614	0.000	1523.144	1523.144	0.000	30662.880	30662.880	0.000	193574.380	195634.980	2060.600
25	00+480	69.267	69.267	0.000	51.288	51.288	0.000	16.874	16.874	0.000	774.903	774.903	0.000	15498.060	15498.060	0.000	209052.440	211133.040	2080.600
26	00+500	70.000	70.000	0.000	54.260	54.260	0.000	16.378	16.378	0.000	841.278	841.278	0.000	16825.560	16825.560	0.000	225598.040	227958.600	2360.560
27	00+520	69.477	69.477	0.000	52.584	52.584	0.000	16.125	16.125	0.000	768.434	768.434	0.000	15368.680	15368.680	0.000	241266.680	243327.280	2060.600
28	00+540	86.865	86.865	0.000	49.455	49.455	0.000	19.078	19.078	0.000	1167.323	1167.323	0.000	23346.460	23346.460	0.000	264613.140	266673.740	2060.600
29	00+560	85.458	85.458	0.000	55.914	55.914	0.000	9.362	9.362	0.000	445.352	445.352	0.000	8907.040	8907.040	0.000	273520.180	275580.780	2060.600
30	00+580	111.139	111.139	0.000	65.229	65.229	0.000	12.857	12.857	0.000	969.522	969.522	0.000	19390.440	19390.440	0.000	292910.620	294971.220	2060.600
31	00+600	112.000	112.000	0.000	59.430	59.430	0.000	13.409	13.409	0.000	970.039	970.039	0.000	19400.780	19400.780	0.000	312311.400	314372.000	2060.600
32	00+620	43.992	43.992	0.000	24.806	24.806	0.000	15.080	15.080	0.000	526.558	526.558	0.000	10531.160	10531.160	0.000	322342.500	324903.160	2560.660
33	00+640	31.865	31.865	0.000	20.279	20.279	0.000	11.392	11.392	0.000	286.565	286.565	0.000	5731.300	5731.300	0.000	328573.800	330634.460	2060.660
34	00+660	32.077	32.077	0.000	23.008	23.008	0.000	13.889	13.889	0.000	372.530	372.530	0.000	7450.600	7450.600	0.000	336024.460	338085.060	2060.600
35	00+680	23.191	23.191	0.000	15.000	15.000	0.000	11.000	11.000	0.000	180.686	180.686	0.000	3613.720	3613.720	0.000	339638.180	341698.780	2060.600
36	00+700	17.363	17.363	0.000	14.300	14.300	0.000	9.854	9.854	0.000	128.751	128.751	0.000	2575.020	2575.020	0.000	342213.200	344273.800	2060.600
37	00+720	15.000	15.000	0.000	11.379	11.379	0.000	9.586	9.586	0.000	105.702	105.702	0.000	2114.040	2114.040	0.000	344327.240	346387.840	2060.600
38	00+740	16.790	16.790	0.000	11.090	11.090	0.000	8.496	8.496	0.000	103.483	103.483	0.000	2069.660	2069.660	0.000	346396.900	348457.500	2060.600
39	00+760	12.312	12.312	0.000	9.461	9.461	0.000	4.393	4.393	0.000	46.675	46.675	0.000	933.500	933.500	0.000	347330.410	349391.000	2060.590
40	00+780	22.282	22.282	0.000	13.941	13.941	0.000	8.877	8.877	0.000	149.781	149.781	0.000	2995.620	2995.620	0.000	350326.020	352386.620	2060.600
41	00+800	19.363	19.363	0.000	13.948	13.948	0.000	7.780	7.780	0.000	127.897	127.897	0.000	2557.940	2557.940	0.000	352883.960	354944.560	2060.600
42	00+820	21.557	21.557	0.000	16.248	16.248	0.000	7.202	7.202	0.000	133.749	133.749	0.000	2674.980	2674.980	0.000	355558.940	357619.540	2060.600
43	00+840	24.080	24.080	0.000	18.115	18.115	0.000	6.422	6.422	0.000	124.698	124.698	0.000	2493.960	2493.960	0.000	358052.900	360113.500	2060.600
44	00+860	31.696	31.696	0.000	20.000	20.000	0.000	5.361	5.361	0.000	128.396	128.396	0.000	2567.920	2567.920	0.000	360620.820	362681.420	2060.600
45	00+880	42.771	42.771	0.000	25.000	25.000	0.000	3.771	3.771	0.000	118.461	118.461	0.000	2369.220	2369.220	0.000	362990.040	365050.640	2060.600
46	00+900	77.226	77.226	0.000	32.500	32.500	0.000	3.890	3.890	0.000	196.260	196.260	0.000	3925.000	3925.000	0.000	366915.040	368975.640	2060.600
47	00+920	119.049	119.049	0.000	100.000	100.000	0.000	5.458	5.458	0.000	298.924	298.924	0.000	5978.480	5978.480	0.000	372893.520	374954.120	2060.600
48	00+940	22.401	29.604	7.203	7.500	7.500	0.000	5.126	5.126	0.000	70.761	82.052	11.291	1415.220	16410.04	14994.820	374308.740	391364.160	17055.420
49	00+960	18.367	40.815	22.448	7.890	7.890	0.000	4.480	4.48	0.000	50.656	85.271	34.615	1013.000	1705.42	692.420	375321.740	393069.580	17747.840

The average was based on measured gully volume and the average soil bulk density. This indicate the severity of soil loss due to gully erosion in the Queen ede catchment basin

During the period of observation, the top and bottom width of the gully experienced increase between ch 00+40 – ch 00 +100, between ch00+220 – ch00+280 and between ch00+940 and 00+980 respectively (See Table I). It is however expected that with heavy rain in Benin city since January 2012, slumping in various part of the gully walls will occur as a result of ground water exerting pressure on the overlaying saturated soil profile. This in turn will cause the soil to loose its stability and consequently causing the slumping of gully walls with consequent further widening of the gully and deposition of higher volume of sediment at the down stream of the gully. This will create further environmental degradation and loss of valuable properties and land resources.

CONCLUSIONS

This paper examined the use of GPS, Total Station Instrument, Remote Sensing and GIS in monitoring Gully formation and development. Results of the topographical surveys of the catchment basin revealed that the gully is at a low point which serves as a receptor for all the run off coming from the entire catchment basin.

The cross sectional surveys revealed that the Gully is U shaped which show that the run off contributing catchment area is large and therefore the discharge passing through the gully is also large.

The recent increase in the growth and expansion of the gully can be attributed to the change in rainfall pattern in the region caused by climatic change.

The use of high resolution satellite imagery in combination with ground survey methods using GPS and Total station enables us to produce different types of maps and develop models, and accurately design structures needed to control the gully process.

The Geo information provided, will enable the Engineer carryout control measures including redesign and upgrading of existing drainage infrastructure, provision of gully control measures at the head region and other remediation measures necessary for healing of the gully and its prevention from further expansion to protect the environment from further degredation