Gully Erosion Study and Control: A Case Study of Queen Ede Gully in Benin City

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Abstract: This paper presents findings from studies carried out on the Queen Ede gully erosion site in Benin City, in the south-southern zone of Nigeria. The studies involved detailed topographical, geotechnical, meteorological and hydrological data acquisition. The data were processed and analyzed to determine catchment size, gully morphology, soil characteristics, rainfall pattern and hydrological pattern. These were then interpreted and used to determine the method of control to be adopted. The adopted control measures is a combination of structural and non-structural methods. The structural method involved the use of gully control structures to divert the runoff entering the gully from the head, while the non-structural method involved the use of boulders and vegetation to stabilize the gully walls around the head region.

Key words: Queen Ede gully, gully erosion, catchment, control structures.

1. Introduction

Gully erosion is an enormous type of environmental degradation which results in loss of valuable land used for agricultural, domestic, industrial and aesthetic purposes, as well as loss of property and even human lives [1]. It is formed as a result of water moving in rills, which concentrate to form larger channels. When rill erosion can no longer be repaired by merely tilling or disking, it is defined as gully erosion.

Generally, gully erosion occurs when runoff concentrates and flows at a velocity sufficient to detach and transport soil particles. In Nigeria, high land use pressure particularly in the south-east and south-south regions render the landscape more vulnerable to gully erosion. Land use changes have also caused the development of bank gullies along some river banks [2]. A recent study conducted in the south-eastern parts of Nigeria, showed that the primary causes of gully erosion in this region is as a result of roads lacking

proper drainage, unguided cultivations, and indiscriminate channelling of flood water on sloped terrain [3]. Also, changes in drainage pattern associated with urbanization can give rise to the formation of gullies especially where illegal settlements exist.

Gully erosion is the most destructive form of erosion as it destroys the soil structure, damage farm lands, destroy infrastructure, alter transportation corridors and lower water tables [4]. According to Ref. [5], the formation of gullies in the south-eastern part of Nigeria has become one of the greatest environmental disasters facing many towns and villages, as many agricultural lands have become unsuitable for cultivation and hundreds of people have had to relocate. Efforts are however being made to control some of these gullies as reported in Ref. [6].

A study conducted by Poesen [7] stated that soil shear strength at saturation of various soil horizons is a good indicator of their resistance against concentrated flow erosion. In Ezezika and Adetona [3], it was concluded that most of the gullies in the south-eastern part of Nigeria can be prevented from expanding by embarking on enhanced public awareness programs and better land management practices. While these

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practices can prevent the formation of future gullies, they are insufficient to control the huge gully erosion sites already existing.

Apart from the south-eastern parts of Nigeria, gully erosion still plagues other areas like the south-southern regions where Edo state is located. In order to adequately address the problems associated with gully erosion in this region, proper studies would have to be carried out to determine the topographical, geological, geotechnical, meteorological and hydrological characteristics of gullies in the region. On the gullies in this region, very little research have been done on the state of the gullies, the processes involved and control measures (both temporary and long-term) that can be put in place to ensure that the growth of the gullies are investigated.

It is to be noted that despite several case studies reported in literature, there is still the need for more research on the effectiveness and cost-efficiency of gully prevention and control measures. This is because, the effectiveness of many of these control measures depends on local conditions. For instance, it was reported that stabilizing a bank gully head in central Belgium with rock plug did not work in loess-derived soils and an alternative technique with geo-membranes had to be developed [8, 9].

This paper presents the findings from studies carried out on the Queen Ede gully erosion site in Benin City (south-south zone of Nigeria), and the solution adopted to prevent further growth and expansion of the gully by applying both structural and non-structural measures.

2. Methodology

2.1 The Study Area

The Queen Ede gully erosion site is located in Benin City, the capital city of Edo state in Nigeria. It lies within the UTM (Universal Traverse Mercator) zone 31 and is bounded by UTM coordinates 700,800 mN to 702,500 mN and 795,800 mE to 796,000 mE. The gully runs down to the Ikpoba River in a south eastern

direction, covering a total land area of 59,250.099 m², with a perimeter of 2,219 m.

The study area lies within the tropical rain forest zone and is characterized by annual rainfall ranging from 1,558.1 mm in 2001 to 2,618.3 mm in 2010. The elevation of the study area ranges from 16 m to 110 m above mean sea level. The location plan of the queen Ede gully erosion site in Benin City is shown in Fig. 1.

2.2 Causes of Gully Erosion Problem and Previous Efforts at Rehabilitation

The Queen Ede gully is believed to have started sometime in the 1990s, as a result of the abrupt termination of the outlet drain from the Benin-Agbor highway around the current location of the gully. Additionally, the runoff for the steep slope from streets within the upland catchment area contributed largely to the formation of the gully. For instance, there are four 900 mm diameter culverts under the Benin-Agbor highway, which carry the storm discharge from the neighbouring streets located around the gully head to two catch pits located on the opposite side of the highway. An assessment of the catch pits indicated that they are inadequate in size compared to the volume of storm runoff they receive at a time and therefore they can not serve the purpose for which they were constructed.

Efforts have been made in recent years by both the State and Federal Government to arrest the acceleration of the erosive action of the storm water in the area but these have not succeeded. Even recently, the local residents constructed a local earth channel to divert the storm runoff coming towards the gully from the streets within the upland catchment area, but this resulted in creating a secondary gully at the gully head.

2.3 Field Survey Measurements

Field reconnaissance survey was carried out using handheld Garmin 76 GPS, to capture key coordinates. Three control points were established at some distance on stable ground from the gully head by method of

Fig. 1 Location of Queen Ede gully erosion site in Benin City.

Differential GPS. Leica Total Station instrument was then used for detailed surveys within the catchment basin to capture both the primary gully at Queen Ede and the other secondary gullies along Edebor and Pohgah streets.

Measurements were carried out to obtain the cross section of the gully and the topographical profile along the axis of the main gully channel from the head to the terminal point at Ikpoba River.

Total station measurements were collected at 1 cm

level resolution to capture break in slopes and other topographic features necessary for producing DEM (digital elevation models) and to determine various morphological parameters such as width, depth, volume of soil loss, etc..

High resolution Ikono Imagery was acquired for the study area in order to measure and monitor the extent

of the land area at risk, land use pattern, delineation of the catchment basin and analysis of infrastructure at risk or endangered by the gully. The topographical map of the Queen Ede gully erosion site is shown in Fig. 2. TIN (Triangulated Irregular Network) model of the gully site is shown in Fig. 3a while SPOT satellite image map of the site is shown in Fig. 3b.

Fig. 2 Topographical map of Queen Ede gully and its catchment basin.

(a)

(b)

Fig. 3 The gully: (a) TIN (triangulated irregular network) model of the gully; (b) Ikono imagery of gully.

2.4 Geotechnical Investigation

Soil samples were collected from gully cross section along the bed and walls at specific locations and taken to the laboratory for testing and analysis. The tests carried out included natural moisture content, Atterberg limit tests, specific gravity tests, gradation, California Bearing Ratio tests, compaction tests, U-U triaxial and direct shear tests.

2.5 Hydrological Studies

Nigeria receives rainfall from the south westerlies which invade the country from the Gulf of Guinea

Coast. The moist air stream is overlain by the north east trade wind which originates from the Sahara, which is dry and dusty. The zone where these two air masses meet is a zone of moisture discontinuity and it is referred to as the ITD (inter tropical discontinuity). The rainfall producing system for Nigeria is a function of the migration pattern of the ITD.

Meteorological data have shown that the rainfall pattern in Nigeria have changed in the past decades, due to climate changes caused primarily by the effects of global warming. For example, the rainy season for the year 2012 began in late January, as against the usual periods of March and April. The monthly rainfall

distribution for 2001-2010 was obtained from Benin meteorological station.

Using a design period of 2, 5, 10, 25, 50 and 100 years duration, respectively, IDF (intensity duration frequency) curves were prepared for the study area.

Once the catchment basin has been delineated, rainfall intensity for the study area was computed using rainfall duration, equal to the time of concentration

(T_c), where, $T_c = \frac{0.195L^{0.77}}{S^{0.385}}$, in minute [1].

3. Data Processing and Results

Spot elevation along with points coordinates were obtained from the Total Station instrument using the in-built software of the instrument.

Based on the points coordinates, morphological cross sections were obtained at 20 m interval. Other morphological parameters were calculated including length, width, depth and areas. The morphological parameters are shown in Tables 1 and 2.

Using arc GIS 9.2 software, DEMs (digital elevation models) along with contours were plotted. This was then superimposed on the Ikono Imagery for catchment basin delineation and analysis.

Also cross sections were plotted at 20 m interval and bed profile from the head to the point of discharge. These are shown in Fig. 4, Figs. 5a and 5b, respectively.

The results of the soil tests from samples taken from

both the gully bed and gully walls revealed that:

- The soil's specific gravity ranged from 2.37-2.66;
- More than 37.69% of the samples passed through Sieve No. 0.075 mm;
- Liquid limit ranged from 27.71%-3.55%, plasticity limit (10.39%-27.04%), plasticity index (13.11%-49.8%);
- Maximum dry density ranged from 1.19-1.87 g/cm³;
- Angle of internal friction, $\phi = 15^\circ$ and cohesion, $C = 2$ kN/m²;
- CBR (California bearing ratio) values were very low (less than 5%) for both soaked and unsoaked.

The monthly rainfall for 2001-2010 is presented in Table 3 and Fig. 6. Using Eq. (1), the time of concentration was computed to be equal to 34 min. This is the time required to move surface runoff from the remotest point of the catchment basin to its outlet.

Rainfall Intensity Duration Curve was used estimate the effect of rain drop on gully wall and gully head erosion at the site (Table 3 and Fig. 6)

4. Analysis and Discussion

From Tables 1 and 2, the maximum width of the gully as in January 2012 was 112 m and the minimum width was 15.6 m. The maximum depth was 16.4 m and the minimum depth was 0.4 m. The WDR (width to depth ratio) varied from 2 to 42. The volume of soil

Table 1 Morphological parameters of Queen Ede Gully as at January 2012.

Chainage (m)	Top width, B (m)	Depth, D (m)	BDR	Cross sectional area, A (m ²)	Cumulative volume, V (m ³)
00 + 000	15.604	0.374	42	3,510	0.000
00 + 100	101.218	9.155	11	431,335	25,544.340
00 + 200	74.184	12.394	6	709,756	77,353.480
00 + 300	31.752	8.432	4	213,881	118,422.800
00 + 400	56.205	8.981	6	381,768	144,309.500
00 + 500	70.000	16.378	4	841,278	227,958.000
00 + 600	112.000	13.409	8	970,039	314,372.000
00 + 700	17.363	9.854	2	128,751	344,273.800
00 + 800	19.365	7.780	2.5	127,897	354,944.560
00 + 900	77.226	3.890	20	196,260	368,975.840
00 + 960	40.815	4.480	9	85,271	393,069.580

Table 2 Morphological parameters of Queen Ede for 2010-2011.

Ch	Top width				Bottom width				Depth				Cross-section area				Volume				Cum volume of soil loss			
	2010	2011	DIFF		2010	2011	DIFF		2010	2011	DIFF		2010	2011	DIFF		2010	2011	DIFF		2010	2011	DIFF	
00+00	15.604	15.60	0.000	0.000	10.000	10.000	0.000	0.374	0.374	0.374	0.000	3.510	3.510	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
00+20	36.993	36.99	0.000	0.000	13.466	13.466	0.000	3.478	3.478	3.478	0.000	55.172	55.172	0.000	1,103.440	1,103.440	0.000	1,103.440	1,103.440	0.000	1,103.440	1,103.440	0.000	0.000
00+40	62.702	68.58	5.878	5.878	28.556	28.920	0.364	4.751	4.751	4.751	0.000	173.467	176.780	3.313	3,469.340	3,535.600	66.260	4,572.780	4,639.040	66.260	4,572.780	4,639.040	66.260	66.260
00+60	39.300	43.29	3.990	3.990	29.873	30.002	0.129	9.889	9.889	9.889	0.000	242.322	247.670	5.348	4,846.440	4,953.480	107.040	9,419.220	9,592.520	173.300	9,419.220	9,592.520	173.300	173.300
00+80	61.687	61.69	0.003	0.003	17.500	17.500	0.000	7.846	7.846	7.846	0.000	316.256	316.256	0.000	6,325.120	6,325.120	0.000	15,744.340	15,917.640	173.300	15,744.340	15,917.640	173.300	173.300
00+100	99.454	101.20	1.746	1.746	81.556	82.877	1.321	9.155	9.155	9.155	0.000	429.739	431.335	1.596	8,594.780	8,626.700	31.920	24,339.120	24,544.340	205.220	24,339.120	24,544.340	205.220	205.220
00+120	76.554	76.55	0.000	0.000	65.996	65.996	0.000	6.988	6.988	6.988	0.000	328.321	328.321	0.000	6,566.420	6,566.420	0.000	30,905.540	31,110.760	205.220	30,905.540	31,110.760	205.220	205.220
00+140	80.297	80.30	0.003	0.003	66.556	66.556	0.000	13.788	13.788	13.788	0.000	726.142	726.142	0.000	14,522.840	14,522.840	0.000	45,428.380	45,633.600	205.220	45,428.380	45,633.600	205.220	205.220
00+160	81.627	81.63	0.000	0.000	69.246	69.246	0.000	10.585	10.585	10.585	0.000	593.031	593.031	0.000	11,860.620	11,860.620	0.000	57,289.000	57,494.220	205.220	57,289.000	57,494.220	205.220	205.220
00+180	76.533	76.53	0.000	0.000	71.784	71.784	0.000	7.112	7.112	7.112	0.000	283.207	283.207	0.000	5,664.140	5,664.140	0.000	62,953.140	63,158.360	205.220	62,953.140	63,158.360	205.220	205.220
00+200	74.184	74.18	0.000	0.000	60.000	60.000	0.000	12.394	12.394	12.394	0.000	709.756	709.756	0.000	14,195.120	14,195.120	0.000	77,148.260	77,353.480	205.220	77,148.260	77,353.480	205.220	205.220
00+220	75.820	82.16	6.340	6.340	60.870	60.000	-0.870	13.007	13.007	13.007	0.000	897.077	914.951	17.874	17,941.540	18,299.020	357.480	95,089.800	95,652.500	562.700	95,089.800	95,652.500	562.700	562.700
00+240	40.418	50.17	9.752	12.299	32.232	32.232	0.000	10.727	10.727	10.727	0.000	357.197	386.809	29.612	7,143.940	7,736.180	592.240	102,233.740	103,388.680	1,154.940	102,233.740	103,388.680	1,154.940	1,154.940
00+260	41.971	54.27	12.299	37.500	38.060	38.060	0.560	7.492	7.492	7.492	0.000	288.332	313.481	25.149	5,766.640	6,269.620	502.980	108,000.380	109,653.300	1,657.920	108,000.380	109,653.300	1,657.920	1,657.920
00+280	36.292	49.53	13.238	22.500	22.500	22.500	0.000	7.208	7.208	7.208	0.000	204.210	224.344	20.134	4,048.200	4,486.880	402.680	112,084.580	114,145.180	2,060.600	112,084.580	114,145.180	2,060.600	2,060.600
00+300	31.752	31.75	0.000	18.026	18.026	18.026	0.000	8.432	8.432	8.432	0.000	213.881	213.881	0.000	4,277.620	4,277.620	0.000	116,362.600	118,422.800	2,060.200	116,362.600	118,422.800	2,060.200	2,060.200
00+320	32.290	32.29	0.000	22.098	22.098	22.098	0.000	8.855	8.855	8.855	0.000	220.372	220.372	0.000	4,407.440	4,407.440	0.000	120,769.600	122,830.240	2,060.640	120,769.600	122,830.240	2,060.640	2,060.640
00+340	30.000	30.00	0.000	23.894	23.894	23.894	0.000	7.975	7.975	7.975	0.000	218.855	218.855	0.000	4,377.100	4,377.100	0.000	125,146.740	127,207.340	2,060.600	125,146.740	127,207.340	2,060.600	2,060.600
00+360	31.780	31.78	0.000	19.505	19.505	19.505	0.000	7.046	7.046	7.046	0.000	179.625	179.625	0.000	3,592.500	3,592.500	0.000	128,739.240	130,799.840	2,060.600	128,739.240	130,799.840	2,060.600	2,060.600
00+380	41.297	41.30	0.000	30.705	30.705	30.705	0.000	8.737	8.737	8.737	0.000	283.715	283.715	0.000	5,674.300	5,674.300	0.000	134,413.540	136,474.140	2,060.600	134,413.540	136,474.140	2,060.600	2,060.600
00+400	56.205	56.21	0.000	40.841	40.841	40.841	0.000	8.981	8.981	8.981	0.000	391.768	391.768	0.000	7,835.360	7,835.360	0.000	142,248.900	144,309.500	2,060.600	142,248.900	144,309.500	2,060.600	2,060.600
00+420	62.090	62.09	0.000	46.441	46.441	46.441	0.000	10.306	10.306	10.306	0.000	499.879	499.879	0.000	9,997.580	9,997.580	0.000	152,246.480	154,307.080	2,060.600	152,246.480	154,307.080	2,060.600	2,060.600

Fig. 4 Cross sections at 0 m, 200 m, 400 m, 600 m and 800 m.

Fig. 5 Gully bed profile: (a) 0 m to 560 m; (b) 560 m to 960 m.

Table 3 Monthly rainfall distribution for Benin City from 2001-2010, in mm.

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total	Mean	Max	Min
2001	0.00	14.60	111.40	181.77	273.80	202.00	224.30	65.70	296.90	147.80	39.90	0.00	1,558.10	129.84	273.80	0.00
2002	0.00	16.00	165.40	196.50	222.60	351.40	489.10	140.40	148.30	111.40	108.40	12.90	1,962.40	163.53	489.10	0.00
2003	0.00	9.70	78.70	200.80	189.20	272.10	515.90	149.20	300.70	241.10	162.30	0.00	2,119.70	176.64	300.70	0.00
2004	0.00	18.80	97.60	267.30	323.50	388.40	359.10	128.40	383.40	128.10	70.80	4.90	2,170.30	180.86	388.40	0.00
2005	61.60	44.40	110.40	115.20	266.00	308.20	294.70	191.30	379.40	236.20	124.70	0.00	2,132.10	177.68	379.40	0.00
2006	12.80	49.40	157.50	136.50	137.70	352.70	569.20	127.10	393.00	150.30	23.30	22.80	2,132.30	177.69	569.20	12.80
2007	7.50	51.10	108.90	259.70	298.30	351.70	445.30	82.40	402.80	292.20	39.90	11.50	2,351.30	195.94	445.30	7.50
2008	0.00	38.90	42.40	211.40	182.40	385.30	434.80	275.30	410.70	384.20	29.80	0.00	2,395.20	199.60	434.80	0.00
2009	5.60	40.60	148.20	106.30	178.40	250.20	174.30	722.40	369.10	291.70	154.80	1.10	2,442.40	203.53	722.40	1.10
2010	3.20	37.70	109.40	386.30	368.30	277.70	506.10	257.10	336.70	138.40	102.10	91.30	2,618.30	218.19	386.30	3.20
Total	90.70	321.20	1,129.90	2,061.70	2,440.20	3,139.70	4,012.80	2,139.30	3,421.00	2,121.40	860.00	145.00	21,882.00	1,823.50	4,389.00	37.50
Mean	9.07	32.12	113.00	206.17	244.02	313.97	401.28	213.93	342.10	212.14	86.00	14.50	2,188.20	182.35	438.90	3.75
Max	61.60	51.10	165.40	386.20	368.30	388.40	569.20	275.30	410.70	384.20	162.30	91.30				
Min	0.00	9.70	42.40	106.30	137.70	202.00	174.30	65.70	148.30	111.40	23.30	0.00

Fig. 6 Rainfall IDF (intensity duration frequency) curve for Benin City.

Fig. 7 Slope stabilization technique.

loss was estimated to be 393,069.580 m³ over a surface area of 126,480 m² which is equivalent to 3.108 m³/m².

Recent results (Table 1) showed that under—cutting and collapse of gully walls continue to occur around the gully head as a result of active erosive action in this area caused by the storm runoff.

The geotechnical investigation results revealed that the soil is silty clay. Erosion in this type of soil is irreversible and it is reasonable to assume that there is a tendency for widening of gully to occur due to wall slumping especially during the period characterized by high rainfall (from May-September).

Arising from the above, the following control measures

were proposed for the Queen Ede gully erosion:

- Redesign and provide adequate drainage system that will be able to carry all the storm runoff from the catchment area, and channel them away from the gully to appropriate discharge points;
- Implement appropriate reclamation and stabilization of the gully head to prevent further head cutting;
- Provide check dams along the gully bed to control movement and transportation of eroded soils by reducing high runoff and flow velocities along the gully bed and thereby protecting the bed from incision and deepening;

- Provide adequate slope stabilization along the gully walls using gabions as retaining walls at the base and rock boulders placed on the gully walls, which have been trimmed to appropriate slopes. In between these boulders are planted vetiver grass and bamboo trees with firm roots to hold the soil in place against erosion. The boulders are held down by steel meshes, which will later be removed as the grasses and trees begin to grow. Typical cross section of the proposed method is shown in Fig. 7.

5. Conclusions

Based on the findings from the studies conducted, the following conclusions were drawn:

- The likely cause of this gully is as a result of the river bank eating back into the land, and this has been accelerated by the way the accumulated runoff from the catchment enters into the river;
- The recent abrupt growth and expansion of the gully can be attributed to the change in the rainfall pattern in the region, which has been caused by climate change resulting from global warming;
- Apart from the head region of the gully, other regions such as the middle and the tail regions have already stabilized. Thus, only the head region is active;
- The results from the geotechnical studies conducted on the soil showed that the soil is susceptible to water erosion;
- The existing drainage facilities are inadequate to contain the runoff coming from the catchment;
- Control measures such as slope stabilization for the gully walls around the head region, redesigning and upgrading of the existing drainage system, provision of gully control structures at the head region, and provision of check dams at specific intervals along the

gully bed, can be used to prevent the gully from expanding.

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