Modelling and Prediction of Gully Initiation in the University of Benin Using the Gultem Dynamic Model

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Abstract
For a very long period of time there was environmental equilibrium between rainfall and soil erosion in the University of Benin until man's intervention caused a disruption in the equilibrium by the improper termination of the external drainage structures in the University of Benin, Benin City Nigeria. This led to the initiation of gully erosion which has caused the University a lot of environmental damages and if left unchecked, the effect will escalate and become very devastating and disastrous. The study was to evaluate and analyze the gully erosion problem that is developing in the western end of the University of Benin with a view to providing useful information for future planning, land conservation and control. Topographical Survey of the gully site were carried out using Differential Global Positioning System (GPS) Survey for controls and Total Station instrument for mapping of gully bed, gully walls and bank. This was to acquire morphological data of the gully site and generate geospatial data needed for monitoring the progressive growth of the gully. Using the generated 3D co-ordinates, spot heights, contour and Triangular Irregular Network models were generated in ARC-GIS environment. Soil samples were collected from the gully site for laboratory analysis and tests carried out included Specific gravity test, Particle size analysis, Compaction test and Shear Strength test in order to ascertain the overall contribution of the soils to the erosion problem. The data obtained from the surveys and investigations were inputed into the GULTEM Dynamic Erosion Model, for the evaluation of the rate of gully channel initiation. From the results the area affected by the gully erosion in this site is 11,100 m^2. The geotechnical investigation carried out, revealed that the clay content of the soil in the area is only about 18%. This makes the soil highly susceptible to erosion as soils with less than 30% clay content are easily erodible. It also showed that the soil is finely graded, fairly cohesive and does not compact well. Information from the geospatial data of the gully site, revealed that the University of Benin Gully became steeper between the years 2005 to 2012 and thereafter the slope began to flatten out. The result of the model showed that the computed rate of gully channel initiation increases initially and then began to decrease steadily with the longitudinal distance of the gully for the period under study and also correlates well with the physical observation of the gully at various time interval monitored.. These models were validated using the data on gully morphology and dynamics from University of Benin Gully Erosion site.
Keywords: environmental equilibrium, Gully erosion, Network models, GULTEM Dynamic Model.

1.0 INTRODUCTION

Gullying is one of the most important erosion processes which largely contribute to the sculpturing of the earth surface. The development of gullies has many negative impacts as it involves the loss and in some cases the deposition of a great amount of soil. These gullies cause real danger for constructions and transportation facilities and their activity has led to regional ecological catastrophe. For many countries, the loss of large soil masses by gully erosion often results in the depletion of many basic natural resources.

Moreover, the formation of gullies implies an alteration of overland flow, a shortening of runoff lag time and an increase in runoff. Over the last decade, significant progress in the understanding of gully erosion and its controlling factors has been made but there are still several unanswered questions related to gully erosion (Poesen, 2011).

The problems that come from gully erosion are many and varied. They include human, material, political, psychological, sociological and economic problems all rolled into one. Gully erosion have become pandemic especially over the South senatorial districts of Edo State. Various aspects of accelerated erosion particularly, gully erosion, has been studied all over Nigeria, (Egboka, 2005: Okagbue and Uma, 1987; Ofomata, 1978). Common to most of these studies are observations that gully erosion in Nigeria is caused by human activities, geological factors, ground water conditions and soil characteristics. In the case of the University of Benin, for a very long period of time there was environmental equilibrium between rainfall and soil erosion in this area of the campus until man‘s intervention caused a disruption in the equilibrium by the improper termination of the external drainage structures in the University (Ehiorobo, 2010).

In a review of gully erosion and environmental change, Poesen *et al*. (2003) concluded that there was a great need for monitoring, experimental studies and modelling of gully erosion processes as a basis for predicting the effects of environmental change (climatic and land use changes) on gully erosion rates. All physically deterministic models simulate splash erosion, interrill erosion and rill erosion in some way, sometimes distinguishing flow erosion in the interrill zone and in the rills (e.g. European Soil Erosion Model

EUROSEM, (Morgan et. al. 1998). Gully erosion has been modeled by Chemical Runoff and Erosion from Agricultural Management Systems CREAMS (Knisel, 1980) and Water Erosion Prediction Project WEPP (Flanagan and Nearing, 1995), but these models do not account for a change of the hill slope morphology when gully erosion occurs. Other successfully used gully models are Ephermeral Gully Erosion Model EGEM (Woodward,1999) and Gully Thermo erosion and Erosion Model GULTEM (Sidorchuk, 1999). Both are two-dimensional models that simulate incision along a transect, the former using an empirical approach and the latter a purely physical approach.

In spatial modelling of Gully development, several types of surface models are used within the context of Geographical Information System (GIS). Geographic Information System (GIS) have become a well-known tool for spatial analysis for more than 40 years. GIS is a tool to create, store, organize, demonstrate and model spatial phenomena. For instance all relevant erosion factors; rainfall and runoff factor, topography, land use, soil types and agricultural practice patterns, can be converted in different GIS data formats as they are spatial information (Kufoniyi,1998).

Despite several national soil conservation projects, gully erosion has continued at an astounding rate. One of the reasons for this is possibly that the interaction between soil properties and erosion in these areas are not well understood. Although several attempts have been made to develop empirical and process based models for predicting gully erosion rates in a range of environment, there remains no validated models available allowing one to predict effects of environmental change on gully erosion or gully infilling rates at various temporal and spatial scales. (Ehiorobo, 2011) This is a major challenge in gully erosion research that need to be addressed.

It is necessary to take steps to prevent or control gully erosion as a result of the devastating effect, hence this study; modelling and prediction of the rate of gully channel initiation in the University of Benin gully site in Benin City, Edo State.

The aim of this study is to evaluate and analyze the gully erosion problem that is developing in the western end of the University of Benin with a view to providing useful information for future planning, land conservation and control.

2.0 Description of Study Area

The University of Benin campus extends from the Benin-Lagos Road in the West to the Benin-Auchi Road in the Northeast. The V-shaped campus is divided into two (Western and Eastern) parts by the large basin of the Ikpoba River. The Western sector slopes at between 3-8° into Ikpoba River. On the Western sector, the slope breaks just behind the Capitol. From this point, runoff due to a change in gradient accelerates into Ikpoba River. The map of Benin City showing the study area (University of Benin) is presented in figure 2.1

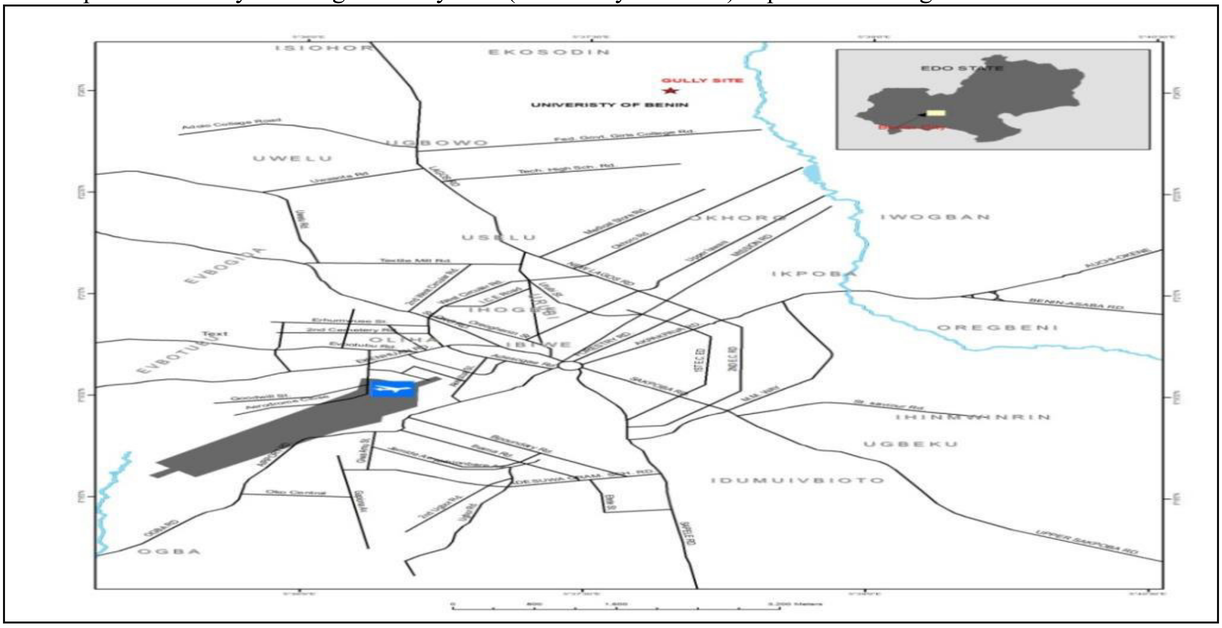

Figure 2.1 : Map of Benin City showing the Study Area

2.1: Topographical Mapping of the Gully Erosion Site

Detailed topographical survey of the gully erosion was carried out by using Leica Total station instrument. Location and assessment of spatial coverage of the Gully erosion sites were made 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 coordinates system were 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 a Triangulated Irregular Network (TIN) created using the Z coordinates. The DEM (Digital Elevation Models) were generated by converting the TIN into Raster. Contours 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.

2.2: Geotechnical Investigations

A total of eighteen samples were collected from six boreholes spread over the entire length of the gully site. Figure 3.2 shows the sampling points within the gully area. The samples were obtained from the erosion site by the use of hand auger in boring the soil to about 2 m depth from which samples at 0.5, 1.0 and 2.0 m were collected, put in the perforated membrane (cellophane bag) to prevent the loss of moisture from the samples during the process of transportation to the University of Benin geotechnical laboratory for geotechnical tests and analysis.

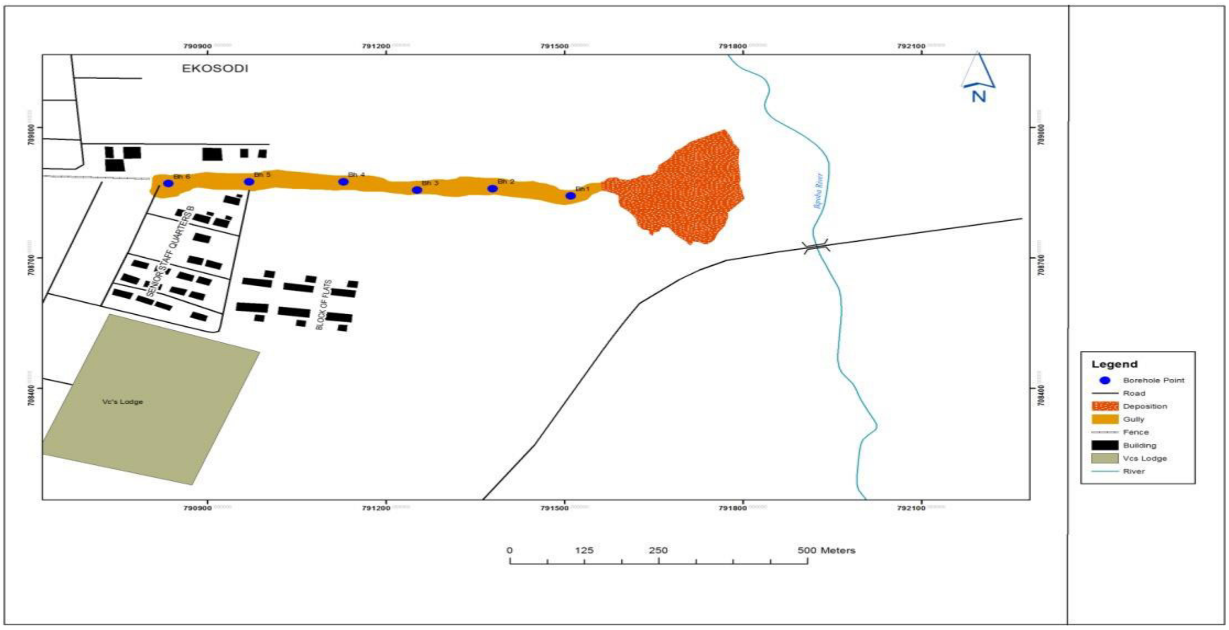

Figure 2.2: Soil Sampling Points

2.3: Laboratory Tests and Analysis of Soil Samples

The laboratory tests were conducted in University of Benin Geotechnical Laboratory. All laboratory tests were done according to the general specification given in the British specification BS 1377, 1990, Methods of Testing Soil for Civil Engineering Purposes and American (ASTM) standards.

2.4: Collection of Meteorological Data

The rainfall data from the year 1960 to 2014 were obtained from NIMET and are presented in Table 2.1 to 2.2. They were used to calculate the return period of rainfall which also added to the planning and conservation functions of the GULTEM model.

Table 2.1 Summary of Rainfall Data for Benin City (1960 - 1980)

Year	Total Annual Rainfall (mm)	Mean Annual Rainfall (mm)	Max. Rainfall (mm)	Min. Rainfall (mm)
1960	2,249.42	187.46	373.4	2.8
1961	2,340.10	195	617.5	4.3
1962	2,109.22	175.77	469.1	1.5
1963	2,392.43	199.37	504.2	4.6
1964	1,985	165.41	384	0
1965	3,049	254.08	358.4	2.8
1966	2,203	183.63	504.2	14.5
1967	2,145	178.75	523.5	0
1968	2,123	176.93	429.8	1.5
1969	2,285	190.38	362.7	0
1970	2,155.20	179.60	579.3	0
1971	2,100.60	175.05	539.3	10.4
1972	1,702.00	141.83	323.6	2.6
1973	2,105.60	175.47	379.4	0
1974	2,193.20	182.77	489.4	0
1975	2,313.60	192.80	501.4	0
1976	2,417.40	201.45	425.3	0
1977	1,715.80	146.23	351.4	7.5
1978	2,435.40	202.50	437.1	20.5
1979	2,234.10	174.98	529	0
1980	2,585.06	215.42	482.4	3.2

Table 2.2 Summary of Rainfall Data for Benin City (2001 - 2010)

Year	Total Annual Rainfall (mm)	Mean Annual Rainfall (mm)	Max. Rainfall (mm)	Min. Rainfall (mm)
2001	1,558.10	129.84	273.8	0
2002	1,962.40	163.53	489.1	0
2003	2,119.70	176.64	300.7	0
2004	2,170.30	180.86	388.4	0
2005	2,132.10	177.68	379.4	0
2006	2,132.30	178.69	569.2	12.8
2007	2,351.30	195.94	445.3	7.5
2008	2,395.20	199.60	434.8	0
2009	2,442.40	203.53	722.4	1.1
2010	2,618.30	218.19	386.3	3.2
2011	1,715.80	146.23	351.4	7.5
2012	1,666.40	138.90	366.6	10.8
2013	1,785.50	148.80	395.3	21.0
2014	1,512.6	126.05	262.8	22.4

2.5: GULTEM Dynamic Erosion Model

The rate of gully erosion is controlled by water flow parameters (velocity, depth and turbulence) and soil parameters such as texture, soil cohesion, shear stress, Manning roughness and vegetation cover. These characteristics are combined in equations of mass conservation and deformation, which can be written in the form [20].

$$\frac{\partial Q_s}{\partial X} + \frac{\partial AC}{\partial t} = C_w q_w + M_o W + M_b D - CV_f W \qquad (2.1)$$

and

$$(1-\varepsilon)W\frac{\partial Z}{\partial t} = -\frac{\partial Q_s}{\partial X} + M_b D + C_w q_w \qquad (2.2)$$

In equations (2.1) and (2.2)

Q = water discharge (m^3/s); X = longitudinal coordinate (m); t = time (s); C_o = volumetric sediment concentration in the near bed layer; A = flow cross-section area (m^2); C_w = sediment concentration of the lateral input; q_w = specific lateral discharge; M_o = upward sediment flux (m/s); M_b = sediment flux from the channel banks (m/s); Z =gully bottom elevations (m); W = flow width (m); D = flow depth (m); V_f = sediment particles fall velocity in the turbulent flow (m/s); ε = soil porosity.

Equations for the Rate of Gully channel Initiation Solution

When the sediment storage is neglected, equation (2.1) becomes

$$\frac{\partial Q_s}{\partial X} = C_w q_w + M_o W + M_b D - CV_f W \quad (2.3)$$

Substituting equation (2.17) in equation (2.2), gives

$$(1-\varepsilon)\frac{\partial Z}{\partial t} = -M_o + CV_f \quad (2.4)$$

Sidorchuk (1998) showed that soil particle detachment rate in gullies is a product of bed shear stress τ and mean flow velocity U (for τ more than critical bed shear stress of erosion initiation τ_{cr}), then,

$$M_o = K\tau U \quad (2.5)$$

Where; $\tau = -\rho g D \frac{\partial z}{\partial x}$; ρ is the water density, g is acceleration due to gravity, D is flow depth and $-\frac{\partial z}{\partial x}$ is the longitudinal flow slope. Substituting equation (2.5) into equation (2.4) and assuming $V_f = 0$ because of the case of thin particles and turbulence, it will take the form of transport equation for bottom elevations Z for the case of erosion process:

$$(1-\varepsilon)\frac{\partial z}{\partial t} - a\frac{\partial z}{\partial x} = 0 \quad (2.6)$$

Here; $a = kg\rho q$, and $q = UD$ is specific discharge. The erosion coefficient k = 0.0002, if $\tau > \tau_{cr}$ and 0if $\tau \leq \tau_{cr}$. So the GULTEM dynamic model equation for computing the rate of gully channel initiation takes the form:

$$\frac{\partial z}{\partial t} = a\frac{\partial z}{\partial x}\frac{1}{(1-\varepsilon)} \quad (2.7)$$

This equation was used to compute the rate of gully channel initiation based on the measured longitudinal distance.

2. 5.1: PREDICTION OF GULLY CHANNEL INITIATION USING GULTEM MODEL

For the GULTEM Dynamic Model, flow must be turbulent. This underscores that the Reynolds number of the flow must be greater than 4000.

$Re < 2000$ *Flow is Laminar*

$2000 < Re < 4000$ *we have Mixed flow*

$Re > 4000$ *flow is turbulent*

Where $Re = \frac{\rho u L}{\mu}$

(Khurmi and Gupta 1997)

Where p = *desnsity*

u = *flow velocity*

L = *length of plate*

μ = *dynamic viscousity*

but recall that $\mu = F/(A \times t) = ma/A \times t = \rho UV/A \times t \times t = \rho AdU/At^2 = \rho dU/t^2$

Therefore

$Where\ Re = \rho uL/(\rho dU/t^2) = Lt^2/d$

$L = distance\ of\ Chainages$

$D = observable\ depth$

$T = time\ of\ flow$

Taking a distance of 20m, the average velocity of flow is 1.4m/s, while the average depth observed is 0.72m and the time it take for the flow is 14.286secs

$Re = 20 \times 14.286^2/0.72 = 5669$ and this is greater than the 4000 benchmark.

We can now proceed with the GULTEM Dynamic model solution by solving the differential equation.

$Since\ dz/dt = a\,dz/dx(1/1-e)$

Separating the variables will result in $dz = a\,dz/dx(1/1-e)dt$

Integrating both side we have $\int dz = a\,dz/dx(1/1-e)\int dt$

This will give $Z = a\dfrac{dz}{dx}\left(\dfrac{1}{1-\text{e}}\right)t$

This signifies that at any time *t* we can calculate the depth of initiation *Z* of gullies.

Model Validation

This analytical models was validated with Total Station instrument measurements of the University of Benin Gully Erosion Site at different time intervals, in order to obtain physical measurement of gully incision rate and also using the return periods of rainfall data

3.0 Results and Discussions

From the topographical survey data, various maps were plotted which included the contoured map and TIN Model of the erosion sites using Arc GIS 9.3 software. These are presented in figures 3.1 and 3.2.

Figure 3.1: Map Showing Annual Changes in Gully Morphology

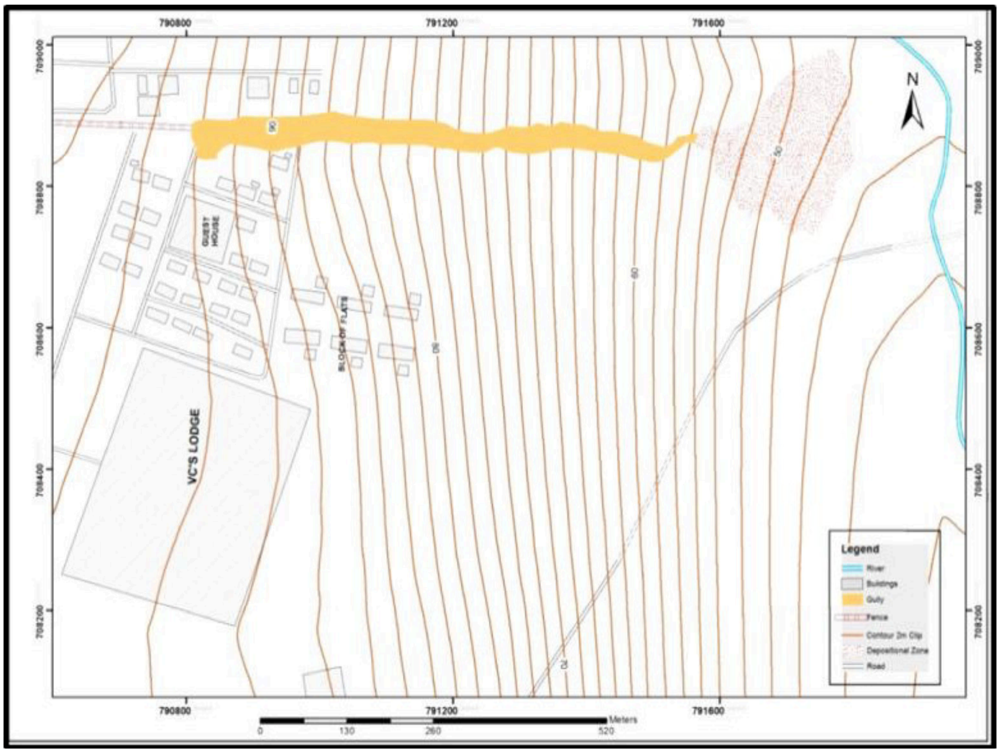

Figure 3.2 Contour plan for University of Benin Gully Erosion Site

The contour map of the gully erosion site presented in figure 3.2 was generated to ascertain the slope of the study area while Triangulated Irregular Network (tin) was used to visualize the depth of the gully. Triangulated irregular network (TIN) is a vector data structure that partitions geographic space into contiguous, non-overlapping triangles. The vertices of each triangle are sample data points with x-, y-, and z-values (representing northings, eastings and gully depth). The results of the computed morphological data are presented in Table 3.1.

Table 3.1: Result Of The Gully Morphological Parameters for University Gully Site

S/N	Chainages (m)	2012 Depth (m)	2014 Depth (m)	Change. in Depth (m)
1	00+00	12.30	17.60	5.3
2	00+20	12.50	16.30	3.8
3	00+40	12.00	14.30	2.3
4	00+60	11.33	12.60	1.247
5	00+80	12.53	13.60	1.077
6	00+100	13.20	14.42	1.22
7	00+120	13.20	13.39	0.19
8	00+140	12.97	13.46	0.43
9	00+160	12.18	12.42	0.24
10	00+180	9.76	10.81	1.05
11	00+200	11.50	11.76	0.26
12	00+220	12.54	12.94	0.40
13	00+240	13.88	13.97	0.09
14	00+260	12.80	13.43	0.63
15	00+280	13.10	13.16	0.06
16	00+300	14.40	14.40	0.00
17	00+320	13.62	13.71	0.09
18	00+340	12.10	12.14	0.04
19	00+360	11.30	11.33	0.03
20	00+380	12.10	12.43	0.33
21	00+400	13.90	13.93	0.03
22	00+420	11.50	11.72	0.22
23	00+440	12.40	12.45	0.05
24	00+460	11.30	11.35	0.05
25	00+480	10.90	10.96	0.06
26	00+500	11.70	11.73	0.03
27	00+520	10.10	10.09	0.01
28	00+540	11.10	11.11	0.01
29	00+560	9.02	9.035	0.015
30	00+580	10.50	10.60	0.1
31	00+600	10.50	10.60	0.1
32	00+620	9.758	9.76	0.002
33	00+640	9.426	9.43	0.004
34	00+660	9.10	9.10	0
35	00+680	7.06	7.063	0.003
36	00+700	6.94	6.94	0
37	00+720	5.34	5.34	0.02
38	00+740	1.304	1.307	0.03

The Graphical presentation of the Gully depth and computed gully initiation results from Table 3.1 is shown in Figure 3.3 while the gully bed Profile is presented in Figure 3.4.

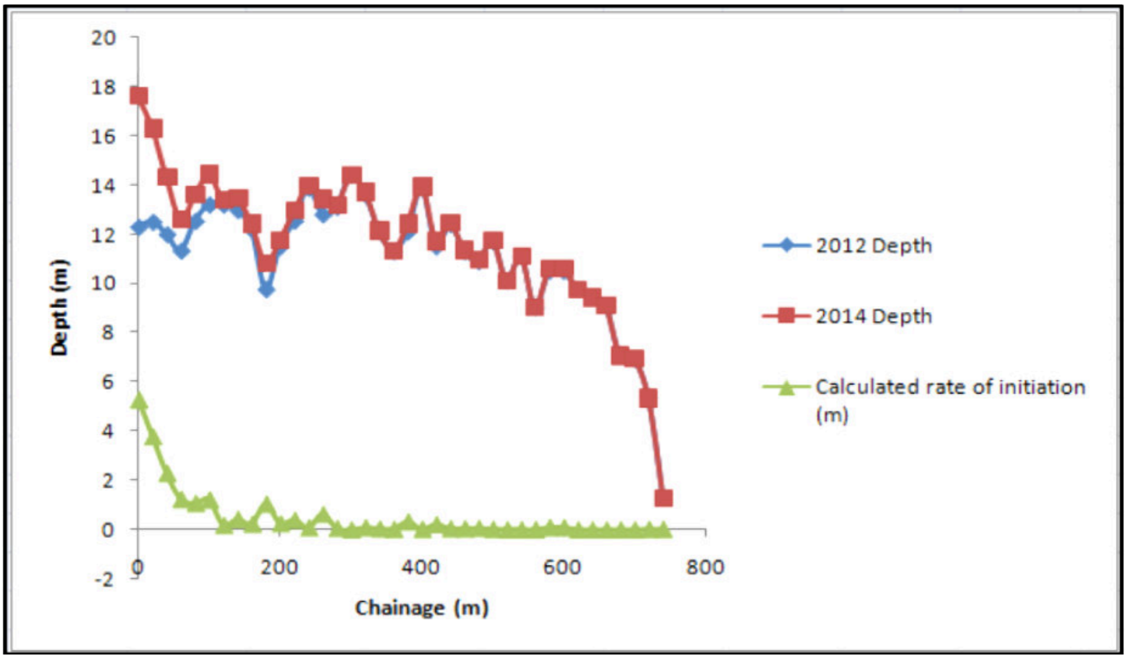

Figure 3.3: Graphical Representation of the Depths and the Calculated Initiation Rate

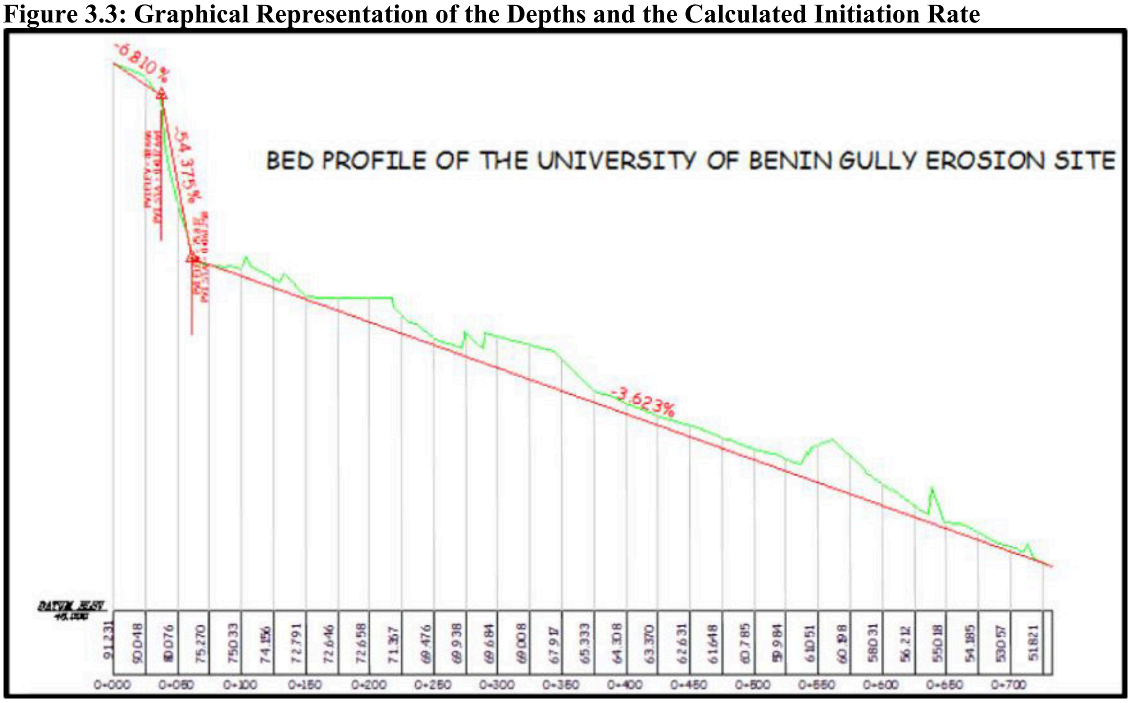

Figure 3.4: University of Benin Gully Bed Profile

Table 3.4: Computed rate of gully channel initiation using GULTEM dynamic model

	Chainages (m)	W (m)	A (m^2)	S	Q (m^3/s)	U (m/s)	D (m)	q	a	$\frac{\partial z}{\partial t}$
1	00+00	36.02	698.3		157,612.41	2.2571	104.75	23,643.1		
2	00+20	27.34	542.2	0.77	79,072.86	1.4584	76.79	11,199.05	21.97	0.2563
3	00+40	20.00	393.1	0.33	36,198.08	0.9208	54.03	4,975.08	9.76	0.0488
4	00+60	22.30	307.5	0.19	47,519.60	1.5454	61.07	9,437.76	18.52	0.0533
5	00+80	16.42	337.6	0.16	22,117.79	0.6551	43.29	2,835.93	5.56	0.0135
6	00+100	25.00	415.9	0.13	63,235.45	1.5204	69.45	10,559.18	20.717	0.0408
7	00+120	23.39	381.0	0.11	53,535.24	1.4051	64.44	9,054.46	17.76	0.0296
8	00+140	21.18	362.5	0.09	41,785.73	1.1527	57.64	6,644.16	13.04	0.0178
9	00+160	23.64	358.8	0.08	54,959.85	1.5318	65.20	9,987.34	19.59	0.0238
10	00+180	22.73	391.1	0.05	49,860.02	1.2749	62.41	7,956.65	15.61	0.0118
11	00+200	24.67	391.1	0.06	61,150.69	1.5636	68.41	10,696.58	20.99	0.0191
12	00+220	22.60	407.0	0.06	49,112.21	1.2067	61.98	7,479.13	14.67	0.0133
13	00+240	32.12	407.0	0.06	118,289.99	2.9064	92.06	26,756.32	52.49	0.0477
14	00+260	28.44	544.1	0.05	87,245.63	1.6035	80.27	12,871.29	25.25	0.0191
15	00+280	26.44	466.8	0.05	72,717.85	1.5578	73.96	11,521.49	22.61	0.0171
16	00+300	27.46	522.3	0.05	79,936.16	1.5305	77.17	11,810.86	23.17	0.0176
17	00+320	20.00	397.9	0.04	36,198.08	0.9097	54.03	4,915.11	9.64	0.0058
18	00+340	19.27	338.2	0.04	32,976.32	0.9751	51.81	5,051.99	9.91	0.0060
19	00+360	20.00	325.4	0.03	36,202.61	1.1126	54.03	6,011.38	11.79	0.0054
20	00+380	11.26	311.5	0.03	8,603.34	0.2762	28.30	781.65	1.53	0.0007
21	00+400	24.27	424.5	0.03	58,713.81	1.3822	67.17	9,284.23	18.22	0.0082
22	00+420	16.35	339.0	0.03	21,882.86	0.6455	43.08	2,780.81	5.46	0.0025
23	00+440	17.58	357.0	0.03	26,232.70	0.7348	46.74	3,434.46	6.74	0.0031
24	00+460	14.20	278.9	0.02	15,383.69	0.5516	36.76	2,027.68	3.98	0.0012
25	00+480	18.42	292.8	0.02	29,4^{7}8.91	1.0068	49.26	4,959.49	9.73	0.0029
26	00+500	25.51	379.8	0.02	66,516.48	1.7514	71.05	12,443.69	24.41	0.0074
27	00+520	23.30	346.6	0.02	53,033.09	1.5301	64.16	9,817.12	19.26	0.0058
28	00+540	16.30	305.4	0.02	21,699.33	0.7105	42.92	3,049.46	5.98	0.0018
29	00+560	21.98	259.7	0.02	45,838.37	1.7651	60.09	10,606.48	20.81	0.0063
30	00+580	19.80	271.5	0.02	35,317.74	1.3008	53.44	6,951.47	13.64	0.0041
31	00+600	22.93	296.2	0.02	50,952.80	1.7202	63.02	10,840.70	21.27	0.0064
32	00+620	27.94	265.9	0.01	83,498.10	3.1402	78.70	24,713.37	48.48	0.0073
33	00+640	15.58	239.5	0.01	19,372.28	0.8089	40.78	3,298.69	6.47	0.0010
34	00+660	19.87	250.2	0.01	35,603.77	1.4230	53.63	7,631.55	14.97	0.0023
35	00+680	16.96	177.3	0.01	23,991.60	1.3532	44.90	6,075.87	11.92	0.0018
36	00+700	15.00	152.3	0.009	17,633.51	1.1578	39.09	4,525.84	8.88	0.0012
37	00+720	12.59	91.92	0.007	11,380.86	1.2381	32.10	3,974.30	7.79	0.0008
38	00+740	13.52	18.65	0.001	13,610.48	7.2978	34.79	25,389.81	49.81	0.0008

Table 3.4 shows the computed rate of gully channel initiation as a function of the longitudinal distance of the gully in addition to some geotechnical parameters which were useful variables in the application of the GULTEM dynamic model.

The graphical relationship between the measured longitudinal distance and the computed rate of gully channel initiation based on the GULTEM dynamic model is presented as shown in figure 3.5

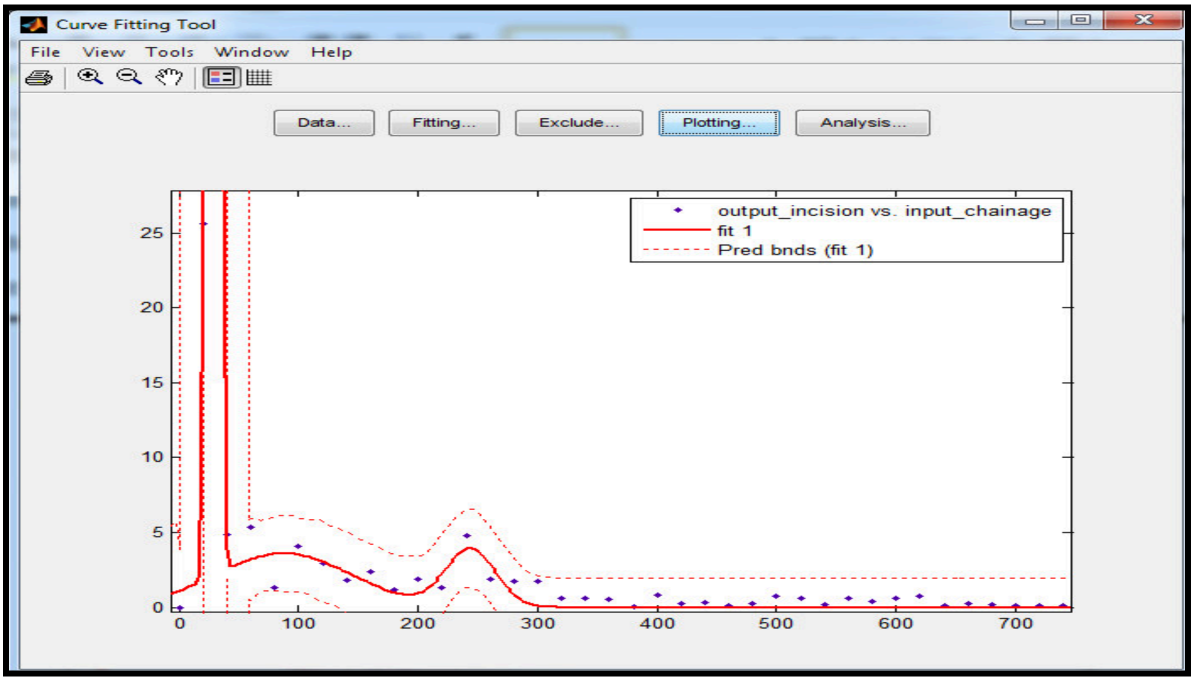

Figure 3.5: Relationship between Rate of Gully channel initiation and longitudinal distance **based on Gultem dynamic model**

It could be seen from the result of the model that the computed rate of gully channel initiation increases initially and then begins to decrease steadily with the longitudinal distance of the gully for the period under study. This initial increase in the rate of gully channel initiation could be traced to the uncontrollable volume of water that the gully had to accommodate. The later steady decrease is due to the ongoing erosion control project within and around the gully site.

4.0 Conclusions and Rec0mmendations

The following main conclusions are drawn from the study:

a) Gully erosion modelling and prediction carried out on University of Benin Gully Erosion Site revealed that the gully is transiting into the stability stage. This transition to stability can be attributed to the ongoing erosion control measures embarked upon by Niger Delta Development Commission (NDDC).
b) It is seen from the outcome of the research that satellite imageries, GPS information, contours, Triangulated Irregular Network TIN and soil physical properties are important variables for studying the formation, progress and dynamics of gully erosion initiation and development.
c) Using Gully Thermo Erosion Model (GULTEM) the rate of gully initiation and evolution has been simulated. The results from the model correlates well with the physical observation of the gully at various time interval monitored.
d) Geotechnical parameters such as porosity, specific gravity, particle and dry density, cohesion, consistency properties and topographical data were observed to have significant influence on the rate of gully initiation and evolution. The parameters were the basic input data for the GULTEM Dynamic modelling.
e) GULTEM dynamic gully erosion modelling, has been seen as highly reliable tools for gully erosion studies at the University of Benin Gully Erosion site.
f) Results of this study is of value to the University in that it will help the University solve the problem of further land loss due to the effect of Gully erosion.

From the results of the studies, it is recommended that:

i. Further studies on the sidewall initiation and prediction on the University of Benin Gully Erosion Site need to be carried out to understand the current and projected state of the gully sidewalls.
ii. Other control measures on the gully head and sidewalls as recommended by past researchers such as bioremediation including vegetation and tree planting by the Faculty of Agriculture in the University should be undertaken to proffer a permanent solution to future environmental deterioration.

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