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A Study of the Mechanisms of Gully Erosion Head Retreat at the University of Benin Gully Site, Benin City, Nigeria

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Abstract

This study is aims at predicting gully head retreat at the University of Benin gully erosion site and to provide understanding for its effective management. Three main processes in gully head retreat namely headcut (upstream retreat), channel widening, and channel deepening are common features contributing to gully size increase that is responsible for mass destruction to life and infrastructure in the area under study. The morphological parameters measured include (length, Width, and Depth). Soil samples taken from the gully site were analysed at the University of Benin geotechnical laboratory following British Standard Specification (BS), 1377, 1990, and American (ASTM) standard method. Rainfall data obtained from Nigerian Metrological Agency (NIMET) were analysed from 1989 to 2016. Channel Hill Slope Integrated Landscape Development (CHILD) model was adapted to model the gully head retreat. Soil loss was analysed with Surface Difference Tool (SDT) in a GIS environment. The results generated with the Model and the surveyed gully extent of the same year was compared. Wilcoxon sign ranking test s, t-Test statistic and a regression analysis was run to ascertain the level of statistical relation between the model and the surveyed/satellite image data. From sieve analysis, critical gully bed share stress (τ_c) to run the CHILD model was obtain to show a standard based on soil distribution particles as derived from the U.S A Geological Survey Scientific Investigation report. Rainfall analysis report shows average annual rainfall of 2,156.63 mm, 687.9 mm for September 1998, while the lowest rainfall data of 1,532.99 mm recorded in 2015, which could be responsible for the low gully growth as seen in the Historical Google Earth images from 2015 to 2019. Statistical comparison of head retreat for CHILD model, Survey data and the Google Earth imagery shows a strong correlation. Furthermore, the results obtained with Historic Google Earth images, show gully arm A and B to be 130.26 m and 73.31 m, while those obtained with the CHILD model for the same gully arms showed cumulative retreat length of 112.30 m and 86.95 m. The average gully head retreat rate for the period of 2010 – 2019 from observed data using satellite imagery and CHILD model for gully arm A and B is 6.94 m/yr. and 3.92 m/yr. and 5.92 m/yr. and 4.61 m/yr. respectively, showing a strong correlation with gully growth. The result of total soil loss computed for the study area is 64,130.89 m^3. The length of the gully by the year 2025 from prediction is 237.90 m and the land area at risk is 101,019.70 m^2. The application of GIS/Remote sensing technology alongside the CHILD model has proven very useful in the prediction and management decision of gully head retreat and can be employed for similar studies in related areas of Engineering.

Keyword: Gully, CHILD, Soil loss, GIS, RS

1.0 Introduction

In the southern part of the country Nigeria, Edo State, in particular, soil erosion by water which is gradual but constantly dissecting the landscape is the greatest threat to environmental setting. Several factors that contribute to land degradation and gully erosion processes include an unprecedented increase in population, rapid rate of urbanization, resistance to erosion offered by the ground surface, and the way ground cover and terrain characteristics affect runoff and soil erodibility (Odemerho and Sada, 1984; Ehiorobo, 2011). The activities of man and animals brought about the compaction of the surrounding soil surface thereby reducing infiltration and increasing runoff rate which causes gully erosion that is presently devastating human existence everywhere. Aggressive deforestation by man in quest for livelihood exposes the land to high intensive rainfall resulting in heavy runoff from high-sloppy terrain through rill and inter rill which eventually forms gullies. Gully comes with varying problems which encompass political, sociological, human, psychological, and material (Ehiorobo, 2011). It's known that heavy runoff from the upper parts of the terrain and the catchment due to a heavy down pour of rain lead to the removal of a thin layer of soils and sediments that cannot be replaced and undermined in a hurry in years (Egboka, 2005). In the study area (University of Benin) Edo State, high torrential rainfall, highly erodible soils, poor land use, poor maintenance of existing drains by the inhabitants and the local authorities, poor solid waste management, and poor road construction habits create enabling environment for catastrophic soil erosion by water. This is one of the major environmental problems which became even more severe due to population growth and climate changes in the study areas. Worse still is the lack of legal and institutional laws in respect of building of houses, road construction, land-use, and agricultural management. Often, the after-effects of heavy rain, runoff, and the proceeding processes such as headcount and sidewall retreat, plunge pool, and deposit of huge sediments occasionally lead to a loss in human and material capitals. During the rains, deep plunge pools are formed which undercut the base of the gully formed leading to sliding and cavitation of the surrounding walls, creating retreat at the nick point and sidewalls. In the course of these processes, many private and public properties are affected, very wide and deep gully which separate towns and villages are created, making communication and transportation difficult (Ehiorobo and Izinyon, 2011; Ehiorobo and Izinyon, 2013; Ehiorobo and Izilein, 2014; Ehiorobo and Ogirigbo, 2013; Ehiorobo, and Audu, 2012). The aim of this study is to model gully processes using CHILD and further validate the model by comparison with field data and remote sensing options.

Figure 1: Map of the Study Area

2.0 Methodology

2.1 Soil Sampling Collection/Analysis

A geotechnical investigation was done to determine the effects of the geotechnical properties of the soil on gully erosion processes and to generate data for modelling. Soil samples were collected around the gully site with a hand auger up to a depth of 6m and stored in poutine bags to preserve the moisture content before being tested. A total of five samples were collected from the gully head points, sidewalls, and the gully bed (floor) to complement the summary of the geotechnical properties results of the gully head of previous years. The sampling points are shown in Figure 2.

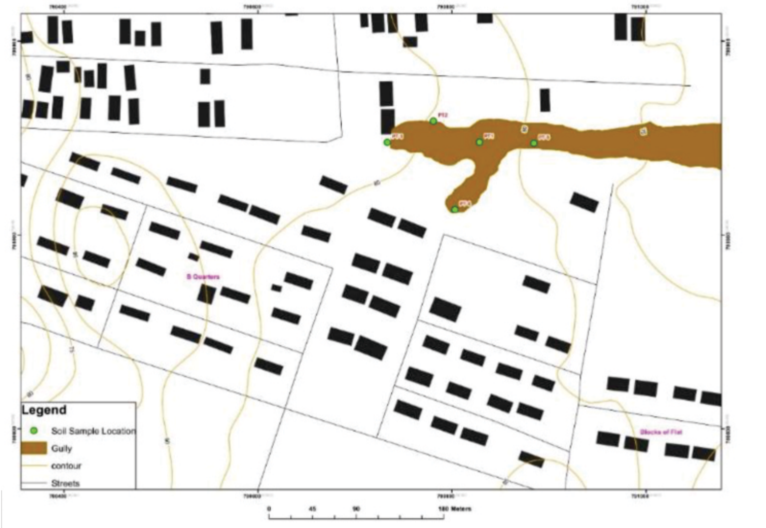

Figure 2: Distribution of Soil sample Location

To achieve this, the following equipment was used: One hand Auger, two shovels, two cutlasses, cellophane bags, and a hand scoop. Soil samples were collected at depth of 1 m – 6 m using Hand Auger, shovel, containers, and cutlasses in different locations. The sampling points were recorded using a handheld GPS receiver. Table 1 shows the sample location and their GPS point.

Table 1: soil sample Location

Soil Sample Label	Longitude (m)	Latitude (m)
PT1	790828.36159	708895.749111
PT2	790780.81728	708917.48831
PT 3	790733.312388	708895.532716
PT 4	790803.028686	708826.019673
PT 5	790884.431092	708894.62772

The samples were taken to the University of Benin Geotechnical Engineering Laboratory for standard classification and other tests which included particle size distribution that enabled us to determine the physical property (texture) of the soil. This test was carried out to enable us estimate the critical share stress by particle size classification (USGS scientific investigation report 2008 Table 1) for CHILD modeling, For gully erosion modeling, attention was given to particle size distribution, moisture content, specific gravity, and triaxial test (for Φ and C in gully bank/embankment stabilization).The samples were spread to air dry for five days (before the commencement of laboratory testing and analysis) as soon as they arrived at the University of Benin Civil Engineering geotechnical laboratory.

2.2 Rainfall Computation

Monthly rainfall data was obtained from the Nigerian Metrological Agency using the Benin City Airport as a metrological station. The data covers a period of 1986 – 2016. Average Annual Rainfall was computed for the period using this monthly rainfall data by equation 1.

$$\text{Average Annual Rainfall, } X_{avg} = \sum \frac{x_i}{n} \quad (1)$$

Where

$x_i = monthly\ rainfall\ magnitude\ (mm)$

$n = number\ of\ months$, n = 12

Average Annual Rainfall for 30 years was used to form an annual rainfall series which was imputed to the CHILD model. The generated value from this annual rainfall series was used as a major parameter for precipitation distribution within the CHILD model.

2.3 Gully Survey and Digital Elevation Model Generation

Field survey data was collected for this study between 2010 and 2016. To carry out the mapping and monitoring of the gully erosion site, control points were established around the gully head using the Differential GPS survey method. The WGS84 coordinates were converted to UTM Coordinate reference frame. Detailed topographical surveys of the Gully head site together with the gully floor were carried out using the Total Station instrument. Also, Total Station measurements were collected at a centimetre-level resolution to capture breaks in slope and other topographical features important for producing higher resolution Digital Elevation Models (DEM).

During the topographical Surveys, the point's density data carrying the X, Y, and Z values were generated using the Total station. This data was plotted into ArcMap 10.1 for visualization of surveyed data and the measurement of morphological (such as the gully cross-sections along with topographic profiles running along the gully channel) information. The morphological parameters of the gully (including depth, width, length, and the area of the gully) were measured using the ArcMap 10.1

2.4 Adjustment of Digital Elevation Model

The Digital Elevation Model (DEM) is an important input data for landscape modeling. DEM determines the flow direction of water and the regions contributing to runoff as such it is used to develop the catchment region. NASA's Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), released September 23rd, 2014 was used for this study. The DEM has a resolution of 30 m.

The 30 m DEM faced difficulty with the visibility of the gully as the gully width in some regions was less than 30 m. To resolve this issue, the DEM was adjusted using ArcMap10.1 by adjusting the DEM values around the gully region with the 2010 survey data.

Elevation points acquired in this period were simplified into the 30 m DEM in the ArcGIS environment. With the 'Resample' tool, the grids of the DEM were resampled to a 5 m resolution by USING the 'Extract by Mask'- tool with the gully polygon as a mask to select the gully cells. This results in a 5 m resolution DEM of the gully. With Raster Calculator, the given depth and width were extracted from the 5 m gully DEM. Thereafter, the 5 m gully DEM and the original 30 m gully DEM were combined to form a new 30 m Resolution Raster, including the gully with the 'Topo to Raster tool. Figure 3a and 3b show the DEM before and after gully adjustment to include the gully depth.

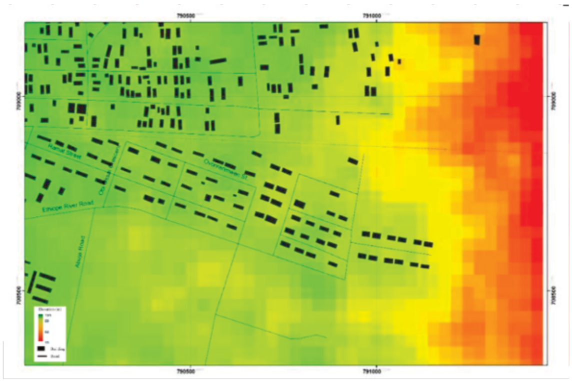

Figure 3a: 30 m DEM before adjustment.

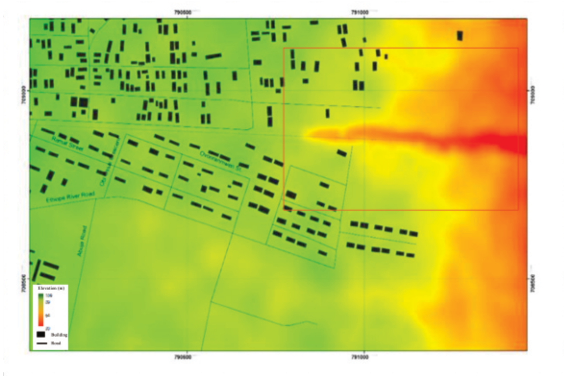

Figure 3b: 5 m DEM after resampling and inclusion of gully for 2010

Finally, the 'fill'- tool was used to eliminate the flat areas in the DEM by creating a minimal gradient that cause water to flow. After these steps, the skinless and flatness 5 m resolution DEM was used for modelling in the CHILD model. This adjustment of DEM was made for each surveyed in the year 2010, 2015, and 2016. The DEM generated for each period was used to generate geomorphological attributes (depth, width, length, and area) of the gully.

2.5 Creating a Mesh for Channel Hillslope Integrated Landscape Development Model (CHILD)

To create a mesh for the CHILD model, point data files are created in which the generated resampled DEM is imported. To import the generated resampled 5 m DEM into CHILD, the DEM points are extracted from the adjusted 5 m DEM using ArcGIS and saved as ASCII file format before they are read as point data into CHILD. The format for the point data file consists of a header line that gives the number of points followed by a series of rows that contains the x, y, and z coordinates and a boundary code for each point. The boundary codes are: 1(closed boundary), 2 (open boundary), and 0 (mesh interior) Nodes flagged with boundary code zero must always be within the mesh interior; otherwise, errors will result if the model encounters an active (0 boundary code) node on the mesh perimeter. Figure 4 shows a typical array of point data arrangement and their boundary code.

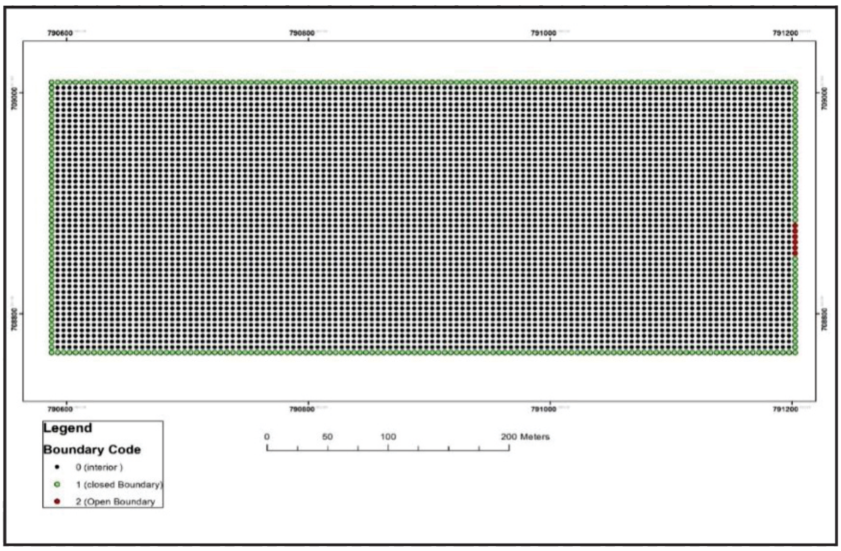

Figure 4: Typical Data points extracted from DEM showing Boundary Conditions for CHILD Modeling.

2.6 Parameterization of Channel Hillslope Integrated Landscape Development (CHILD) Model

Channel Hillslope Integrated Landscape Development (CHILD) model is executed using Detachment and Transport model and results generated visualized in MatLab and spatial analysis was carried out in ArcGIS 10.1. For the detachment of soil material using the CHILD model, a simple power-law describing detachment-capacity, (D_c), as a function of excess shear stress is formulated following Howard and Kerby (1983), used by Tucker (2004). The model is analytically tractable and has been used in previous studies of long-term landscape evolution (Tucker, 2004). The model equation as earlier given in Equation 2 can be written as:

$$D_c = K_{br}(\tau^{P_b} - {\tau_c}^{P_b}) \quad (2)$$

Where:

D_c = detachment capacity

K_{br} = rate coefficient (bedrock or regolith)

τ_c= threshold below which no detachment takes place (to be represented as shear stress or

Critical unit stream power)

P_b = user-defined exponent

Also, the sediment transport (Q_c) equation from (Equation 3 was selected, this is a model based on Meyer-Peter and Muller (1948).

$$Q_C = K_f W \left(\tau_0^{P_f} - \tau_C^{P_f}\right) \quad (3)$$

Where:

Q_C= sediment transport

K_f = transport efficiency factor (m^3/s per unit excess stress)

W = Channel width (m)

τ_0 = bed shear stress (Pa)

τ_c = critical shear stress required for erosion (Pa)

P_f= user-defined exponent

Sediment Transport Equation Q_c (Equation 3) was selected as a component of shear stresses. It applies to small catchments composed of homogenous material (Crosby and Whipple, 2006), which is similar to University of Benin gully site. Also it maintains higher gradients at lower transport rates and represents the morphological features of incised gullies.

Table 2: Parameters to set up CHILD Model

Parameter	Unit	Value	Remark
τ_{cr} - critical bed shear stress*	Nm^2	0.27	Critical shear stress was selected based on particle-size classification (United States Geological Survey USGS)
P_f - user-defined exponent	-	1	User-Defined
P_b – User-defined exponent	-	1	User-defined
Yearly Average Rainfall	mm	2,136.63	Calculated from average rainfall for 1986 - 2016

*critical bed shear stress is approximated from Table 2

Table 2 outlines the major parameters used to set up the CHILD model to run the University of Benin gully model. The parameter used to execute the model analysis is as seen in Figure 5 and the results generated from the CHILD model are visualized in Matlab. The data format is presented as a text file bearing the x, y, and z values. This is represented in Figure 6.

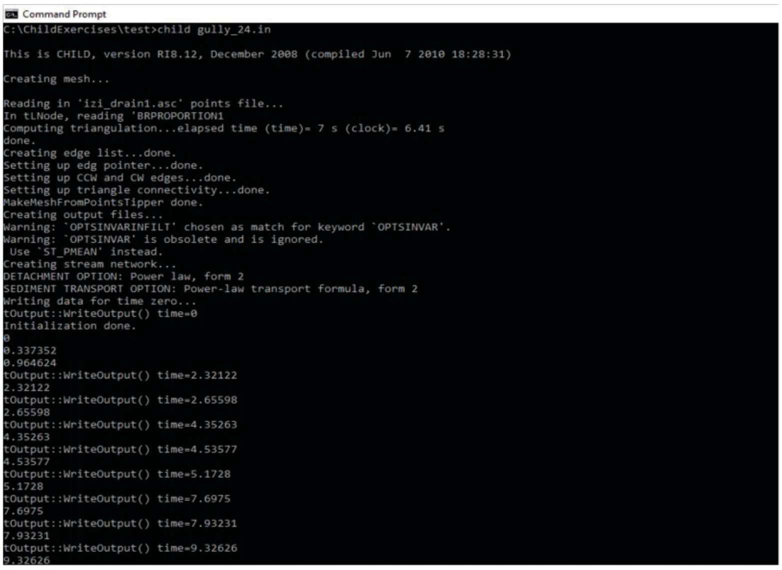

Figure 5: CHILD Simulation Process

Soil Loss Computation

The Change in landscape volume after each model run was generated by the CHILD model as an output bearing the x, y, and change in z of each cell. This computed file is imported into ArcGIS to create raster grids which are used to compute the loss in soil volume due to erosion.

The change in surface landscape was computed for each period (2010 - 2018) using the Surface Difference tool in ArcGIS 10.1. Using a raster tool, the raster of (2010) is subtracted from the raster of the next period (e.g raster 2010 – raster 2012). The difference in the surface is recorded as a new raster showing negative values for eroded landscape and positive values for regions with an increase or no change in surface elevation. The volume of soil loss is determined by considering the change in elevation of each cell and the cell area.

Cell area for this work = 5 m × 5 m = *25 m^2 per cell*

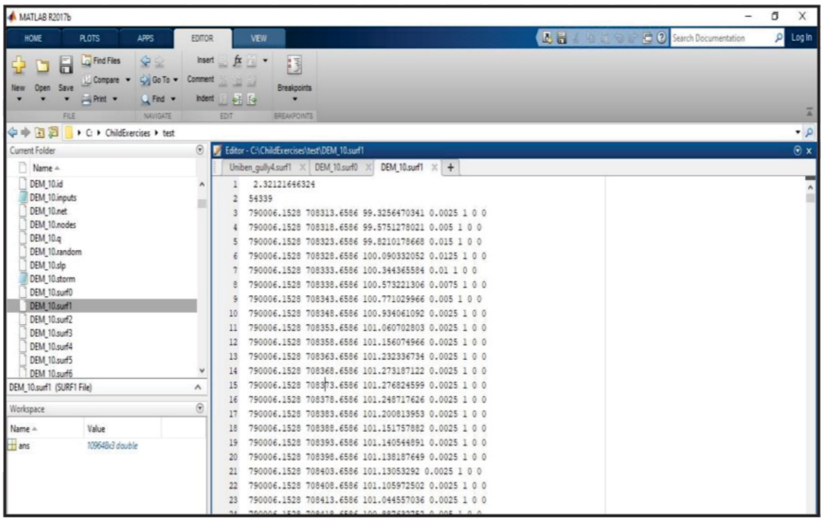

Figure 6: MatLab Visualization of model data

2.6 Validation of Models

To carry out a model validation of this work, a comparison of Gully Morphology between the adopted CHILD model and Field Observation 2016 for Gully Arm A and B was carried out using Wilcoxon Sign Rank Test.

The following procedure was adopted for validation of the model:

1. Formulation of Hypothesis (Ho = null Hypothesis)
2. Selection of appropriate model
3. Selection of the level of significance
4. Computation of test statistics
5. Definition of the region of acceptance
6. Selection of appropriate Hypothesis (Decision)

Wilcoxon Sign Rank Test is used to check whether two samples follow the same distribution. This is a non-parametric test which like a parametric test compares the means (H_o: $\mu_1 = \mu_2$) between independent groups.

For the nonparametric test, the null and two-sided hypotheses are stated as follows

Two-tailed statistical test:

1. Null hypothesis: $H_{O:}$: $\mu_1 = \mu_2$ i.e. the two samples mean are equal
2. Alternative hypothesis: Ha: $\mu 1 \neq \mu 2$ i.e. the two samples mean are not equal
3. The decision rule for an α-level test: For large sample: Reject Ho in favour of Ha

According to Woolson and Clarke (2002)

If $Z_{obs} = T1 - 0.5n1\,(n1+n2+1)/sqrt\,(n1 \cdot n2(n1+n2+1))/12 > Z1$ (4)

or if $Z_{obs} = T_1 - 0.5n_1(n_1+n_2+1)/\text{sqrt}\,(n_1 \cdot n_2\,(n_1+n_2+1))/12 - Z_{1-\alpha/2}$ (5)

where n_1 is the number of contents in sample 1, and n_2 is the number of contents in sample 2. The total number of contents is $n = n_1 + n_2$

Equations 4 and 5 were executed with XLSTAT Software.

For an equal sample size, the rank-sum statistics are the minimum of T_1 and T_2. For unequal sample size, the rank-sum statistics is T_1. Where $T_2 = n_1\,(n_1 + n_2 + 1) - T_1$. And T is the minimum of T_1 and T_2. Sufficiently small values of T caused the rejection of the null hypothesis that the sample means were equal.

Also, to validate the results of the CHILD model, a coefficient of correlation (R) which defines the relationship between the observed and predicted values can be employed. Mathematically, the coefficient of correlation (R) is defined as;

$$r = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2\sum(y_i-\bar{y})^2}} \quad (6)$$

Two variables were used, the Observed (Field/image data) and predicted CHILD Model) using equation 6

Where
r = correlation coefficient
x_i = values of the Observed variable
y_i = values of the Predicted variable
$\bar{y}$ = mean of the values of the Observed variable
$\bar{x}$ = mean of the values of the Predicted variable

Two-tailed t-Test was performed to establish if two groups are different from one another.

The formula for the two-sample t-test (a.k.a. the student's t-test) is shown in Equation. 7

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\left(s^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)\right)}} \quad (7)$$

In equation 7, t is the t-value, x_1 and x_2 are the means of the two groups being compared, s^2 is the pooled standard error of the two groups, and n_1 and n_2 are the number of observations in each of the groups.

A larger *t*-value shows that the difference between group means is greater than the pooled standard error, indicating a more significant difference between the groups.

You can compare your calculated *t*-value against the values in a critical value chart to determine whether your *t*-value is greater than what would be expected by chance. If so, you can reject the null hypothesis and conclude that the two groups are in fact different.

2.7 Field Data (Surveyed Data) Versus CHILD Model Prediction

Results generated from the CHILD model were compared to field survey data to determine the morphological relationship and how well the model predicts the erosion process. The correlation value R was determined by plotting observed values against the predicted value.

2.8 Google Earth Historical Imagery versus CHILD Model Prediction

Google Earth Historical imageries were compared to the CHILD model results of the head retreat rate over time. This was done by estimating head retreat distance on the Google Earth Imagery using the Distance calculation tool. The result was plotted to show the statistical relationship between Image observation and the CHILD model

Satellite imageries of the gully head were acquired from the Google Earth historical image archive, using the Google Earth historical image tool from 2010 to 2018. This was used to validate the head growth of the gully.

Using Profile lines, the gully region was cut to determine the width and head retreat for each period and compared to that generated by the adapted CHILD model. A regression analysis was run to ascertain the level of statistical relation between the model and the surveyed/satellite image data. The comparison included the gully width, depth, and linear head retreat. Furthermore, gully morphology between the CHILD model and field observation was carried out in 2016 to further validate the model.

The yearly average gully head retreat of the gully site was measured with the historical Google Earth images and CHILD model. A linear relationship between the CHILD model-predicted and observed gully head advancement was carried out. Also, the graphical plot of the head retreat of the gully for the CHILD model and satellite imagery was done.

3.0 Results and Discussion

3.1 Rainfall analysis

The result of rainfall analysis is presented in Figure

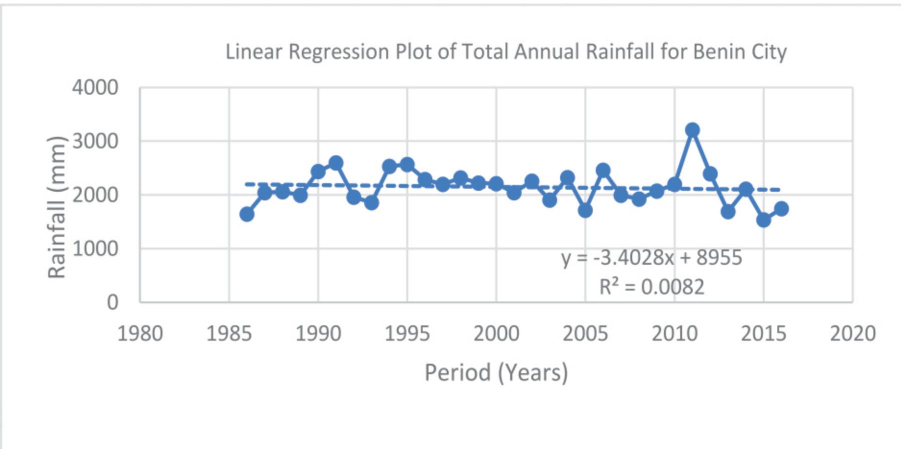

Figure 7: Annual rainfall Trend around UNIBEN Gully site

From the rainfall trend analysis presented in Figure 7, the negative value of the slope indicates that the trend is decreasing. A total of 3,211.50 mm of annual rainfall occurred in 2012. This is the year Nigeria recorded the highest rainfall and flooding during the period under consideration. This is obvious in the spike as shown in the graph.

3.2 Mathematical Modelling using CHILD Model

Figure 8 shows the results generated in 3D from MathLab visualization before exporting the data to ArcGIS to carry out spatial computation of depth and length of the head retreat. This was carried out for each model simulation.

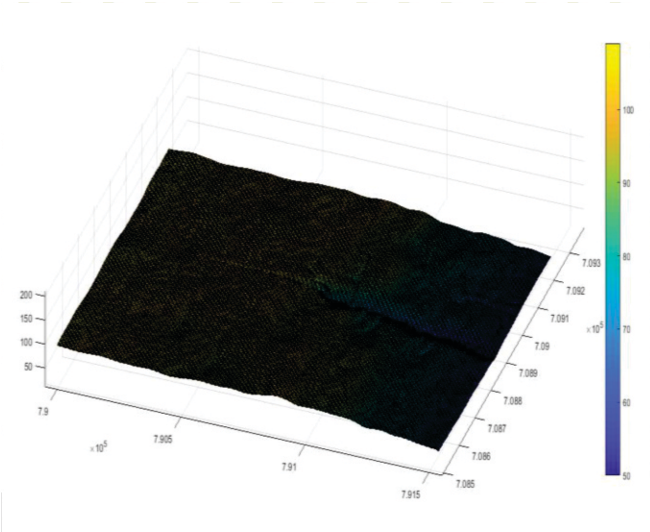

Figure 8: MathLab Visualization of CHILD gully erosion simulation

3.3 *Channel Hillslope Integrated Landscape Development (CHILD) Model Head Retreat Prediction*

Figure 8 shows the field survey of the gully head in 2010, while Figures 9 - 13 shows gully head recession prediction carried out from 2010 – 2018. The results show a change in gully head growth, sidewall expansion, and deepening of the gully erosion for every 2 years interval.

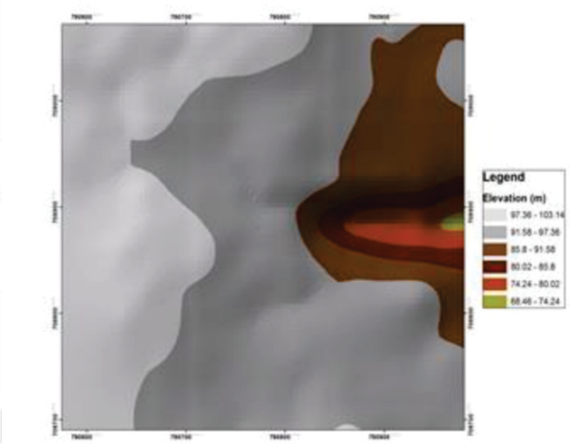

Figure 9: Surveyed Gully Head Extent in 2010

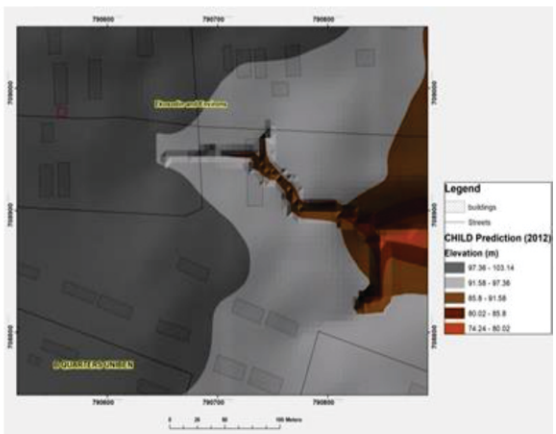

Figure 10: Predicted Gully Head Extent 2012

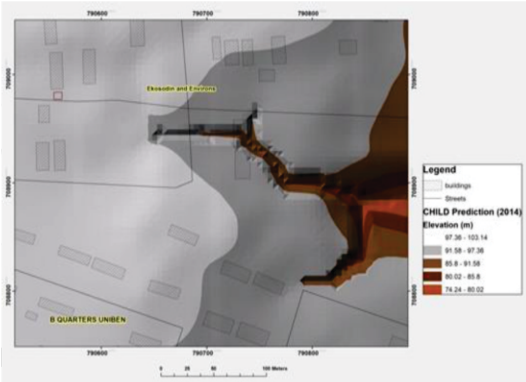

Figure 11: Predicted Gully Head Extent 2014

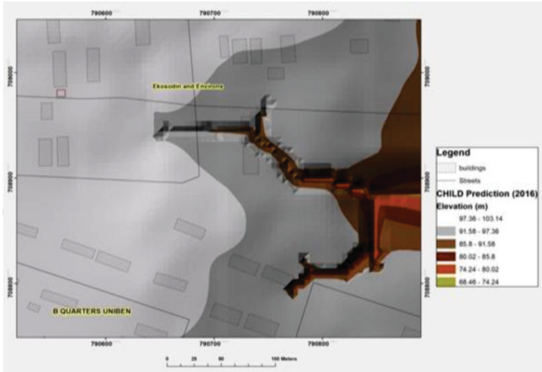

Figure 12: Predicted Gully Head Extent in 2016

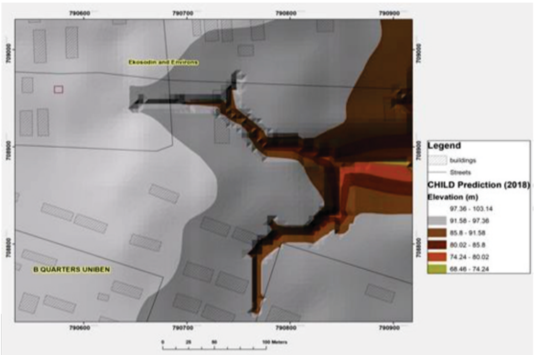

Figure 13: Predicted Gully Head Extent 2018

To calculate the change in predicted gully morphology, profile lines were cut at 10 m intervals across the gully head. Due to bifurcation of the gully head, the upper arm towards Ekosodin and environs was named Arm A, and the gully arm extending furthermore towards the University of Benin was named Arm B.

Typical cross-sections are shown in Figure 14 which shows the line profile for the gully head with A1-A14 and B1- B13 representing Arm A and Arm B of the gully head respectively. These cross-sectional lines were used to calculate the change in depth and width for the gully as it progresses. A graph showing typical cross-sectional lines for profile line B1 and B2 are presented in figures 15a and 15b. The gully head retreat was determined by measuring the linear distance covered by the gully from 2010 - 2018.

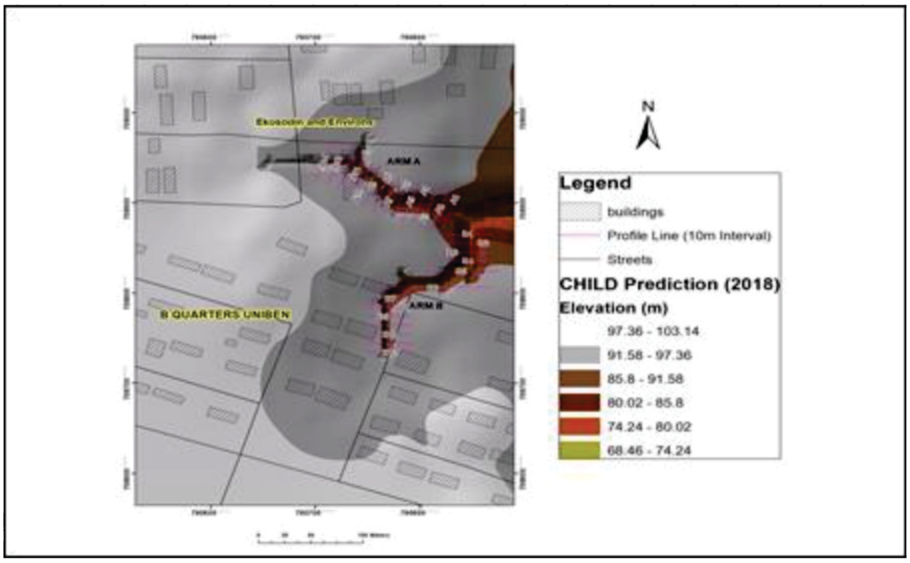

Figure 14: Profile Line for Gully Arms A and B (Arm A towards Ekosodin, and Arm B towards University of Benin)

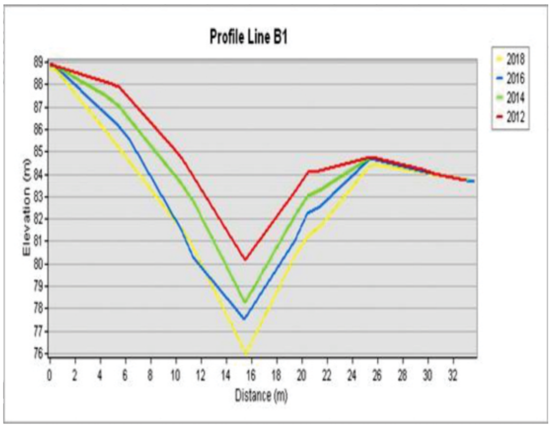

Figure 15a: Graph showing a typical cross-sectional line for profile lineB1 and B2

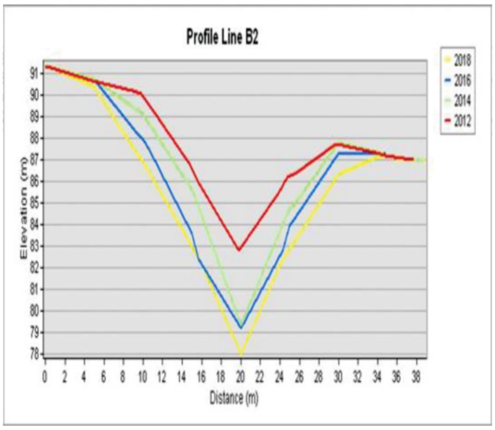

Figure 15b: Graph showing typical sectional lines for profile line B1 B2

Table 3: Morphological changes in the predicated gully models.

	2012		2014		2016		2018	
Profile Line	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)
A1	6.3	17.5	8.8	18.2	16.9	19.6	10.2	25
A2	8	20.1	8.3	21	16.9	21.3	10.8	30
A3	6.2	16	7.3	20	14.5	20.2	9.6	25.2
A4	7.1	21.2	9.3	26.1	15.1	26.2	12.2	27.2
A5	8.2	22.1	9.5	25.2	14.6	26.8	12.7	26
A6	7.8	20.8	9	24.8	16.9	25.2	11	25.9
A7	6.3	26.5	8	27	15.2	27	9.2	27.5
A8	6.9	20.1	8	26	17.9	26.3	10.2	26.2
A9	5.7	19	6.8	21	15.9	21	8.5	21
A10	5.6	18.5	7	20.2	14.2	21.1	9.1	21.6
A11	7.5	28	7.5	28	7.5	28	7.6	28
A12	5.1	22	5.8	22.1	6	22.3	6.4	22.6
A13	4.7	19.2	5	19.2	5	19.3	19.5	5.1
A14	4.2	9	5.1	20	5.1	20	20	5.2
B1	8.8	20.5	10.8	26	11.3	26.1	13	26.3
B2	7.1	21.2	11	20	11.8	20.1	13.1	20.2
B3	8	20.2	11	24	9.3	26	11.4	26.3
B4	8.2	24.1	8.5	24.2	13.3	25	14.2	25.1
B5	6.6	34	7.2	34.1	8.5	34.1	10	34.5
B6			5.8	47.1	6.2	54.8	7.2	55
B7					6.2	20	5.5	25.5
B8							5.5	15.5
B9							5.3	10.1
B10							5.3	10
B11							5.2	9.9
B12							5.8	11.1
B13							3.8	10.1

The result shows an average depth of 6.8 m in 2012, 8.0 m in 2014, 8.7 m in 2016, and 10.1 m in 2018 which shows a steady increase in-depth about a 1 m increase every year. Also, the gully shows an average width of 23.1 m. Maximum width is found in profile line B6 with 54.8 m.

3.4 Model Validation

To carry out a model validation of this work, a comparison of Gully Morphology between the CHILD model and Field Observation of 2016 for Gully Arm A and B using Wilcoxon Sign Rank Test on XLSTAT software was done.

3.5 Model validation using Surveyed Data

To validate the CHILD model it was compared against the gully field survey carried out in 2016. The comparison was carried out for head retreat/depth and width expansion for the year 2016. Tables 4a and 4b, are the Field Survey and CHILD Model measurements.

Table 4a: Gully Head Depth for Gully Arm A

Period	Profile Line	2016 Surveyed Depth	2016 CHILD Model
	A1	16.3	16.9
2016	A2	16	16.9
	A3	14.4	14.5
	A4	15	15.1
	A5	14.5	14.6
	A6	15.8	16.9
	A7	16	15.2
	A8	15.8	17.9
	A9	16	15.9
	A10	14	14.2

Summary of statistical analysis using Wilcoxon signed-rank test / Two-tailed test. As the computed p-value (0.109) is greater than the significance level alpha = 0.05, one cannot reject the null hypothesis H0, hence it was concluded the survey depth data are similar to the Survey depth data are similar to the CHILD predicted data. This tends to validate the CHILD model as being able to predict the gully head retreat.

Table 4b: Gully Head Width for Gully Arm A

	Gully Head Width for Gully Arm A		
	A1	21	14.5
	A2	22.2	15.1
	A3	25.6	14.6
	A4	28.5	16.9
2016	A5	25.1	15.2
	A6	23.8	17.9
	A7	27.4	15.9
	A8	26.9	14.2
	A9	22.4	21
	A10	24.1	21.1

H0: The two samples follow the same distribution.

Ha: The distributions of the two samples are different.

As the computed p-value (0.109) is greater than the significance level alpha = 0.05, one cannot reject the null hypothesis H0, hence it was concluded that the Survey depth data re similar to the CHILD predicted data. This tend to validate the CHILD model as being able to predict the gully head retreat.

Table 4c: Gully Head Depth for Gully Arm B

Period	Profile Line	2016 Surveyed Data	2016 CHILD Model
2016	B1	14	11.3
	B2	14.2	11.8
	B3	14.5	9.3
	B4	13.5	13.3
	B5	11	8.5

Test interpretation:

H0: The two samples follow the same distribution.

Ha: The distributions of the two samples are different.

As the computed p-value (0.063) is greater than the significance level alpha = 0.05, one cannot reject the null hypothesis H0, hence it was concluded that the Survey depth data re similar to the CHILD predicted data. This tend to validate the CHILD model as being able to predict the gully head retreat.

Table 4d: Gully Head Width for Gully Arm B

Gully Head Width for Gully Arm B			
2016	B1	25.2	26.1
	B2	23.3	20.1
	B3	26.1	26
	B4	26	25
	B5	24.3	24.1

Test interpretation:

H0: The two samples follow the same distribution.

Ha: The distributions of the two samples are different.

As the computed p-value (0.375) is greater than the significance level alpha = 0.05, one cannot reject the null hypothesis H0, hence it was concluded that the Survey depth data re similar to the CHILD predicted data. This tend to validate the CHILD model as being able to predict gully head retreat

Table 5: Summary of Model validation with Wilcoxon Sign Rank Test

Location	Test Performed	Wilcoxon Sign Rank Test computed p-value	Numbers of Observations .	Significance Level Alpha (α)	Decision: Accept Ho: when p-value > Alpha (α)
Gully Head Depth for Gully Arm A	Wilcoxon (Rank Sum Test)	0.109	10	0.05	Accept H_O
Gully Head Width for Gully Arm A	Wilcoxon (Rank Sum Test)	0.063	10	0.05	Accept H_O
Gully Head Depth for Gully Arm B	Wilcoxon (Rank Sum Test)	0.375	5	0.05	Accept H_O
Gully Head Width for Gully Arm B	Wilcoxon (Rank Sum Test)	0.313	5	0.05	Accept H_O

Table 5; Shows a Summary of Model validation obtained by using Wilcoxon Sign Rank Test. The Wilcoxon Sign Rank Test statistics in Tables 5 was calculated using Equations 4 and 5 and a 5% significance level. The Implication of the decision column of Table 5 is that we have to accept the null hypothesis (H_{o}): that the adopted CHILD Model fits the field Observed data. This has validated the adopted CHILD model and therefore it can be reliably used for future prediction and management decisions of gully head retreat in the University of Benin and other places with a similar gully erosion problem.

3.6 Model Validation Using Satellite Imagery

Satellite imagery is applied to validate the CHILD model, Historical data of the gully head retreat was examined to get an idea about the magnitude of head retreat. Table 6 shows the summary of the head retreat as computed from Google Earth satellite images as shown in Figure. The images were acquired for 3 years interval from 2010 - 2018. Using control points, the images were georeferenced in ArcGIS 10.1 before linear measurements were carried out. Also, the predicted gully head retreat from the CHILD model was computed for the same period and the cumulative head retreat compared as shown in Table 6.

Table 6: Gully head retreat summary

Gully Arm A				
Period	**Gully Head Retreat from Google Earth Imagery (m/yr)**	**Gully Head Retreat from CHILD (m/yr)**	**% Difference**	**Average % Difference**
2010 – 2013	39.24	30.23	22.96	12.05
2013 – 2015	51.65	48.47	6.16	
2015 – 2019	39.37	36.60	7.04	
Cumulative Head Retreat (m/yr)	130.26	115.30	11.48	
Ave. Head Retreat Rate (m/yr)	14.47	12.81	11.48	
Gully Arm B				
Period	**Gully Head Retreat from Google Earth Imagery (m/yr)**	**Gully Head Retreat from CHILD (m/yr)**	**% Difference**	**Average % Difference**
2010 – 2013	39.26	41.2	-4.94	-19.06
2013 – 2015	27.73	25.63	7.57	
2015 – 2019	6.32	10.1	-59.81	
Cumulative Head Retreat (m/yr)	73.31	76.93	-4.94	
Ave. Head Retreat Rate (m/yr)	8.14	8.53	-4.94	

Table 6 shows the cumulative head retreat measured with Historical Google Earth images and CHILD model for (2010 - 2019). For gully arm A, a 12.05% average difference is recorded for the period with a cumulative head retreat of 130.26 (m/yr.) from Google Earth Imagery and 115.30 (m/yr.) was recorded for the CHILD model. For gully arm B, an average % difference of -19.06 % was recorded with a cumulative head retreat of 73.31 (m/yr.) for Google Earth Imagery and 76.93 (m/yr.) for the CHILD model. The period of 2015 – 2019 recorded a major change of -59.81% between the Google Earth Imagery and CHILD model. The Google Earth Imagery recorded 6.32m/yr. and CHILD model recorded 10.1m/yr. The change can be attributed to the diversion of runoff from drain emptying into gully head arm B.

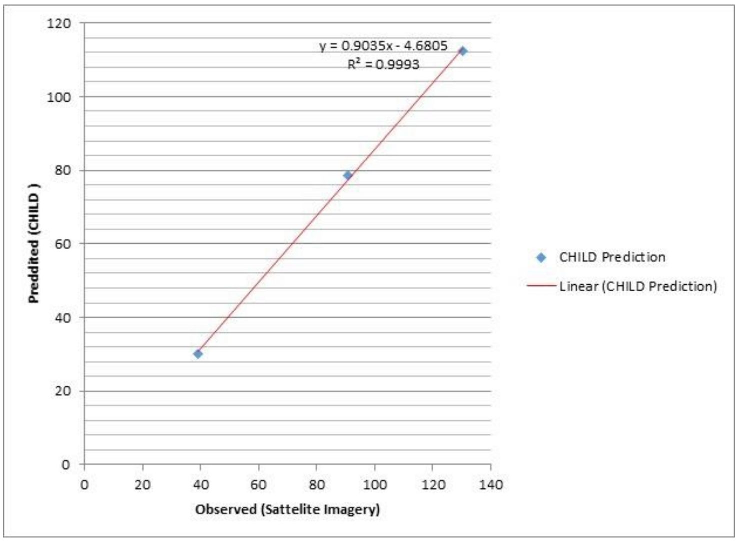

Figure 16: (A) Linear relationship between CHILD model predicted and Observed Gully head advancement (2010 - 2019

A statistical comparison of head retreat for the CHILD model and the Google Earth Imagery shows a strong correlation with r^2 = 0.97 as shown in Figure 16 (A) and (B). This could be attributed to the drainage constructed 2015 - 2016 by NDDC to divert water from the gully head which may have contributed to the decrease in the retreat rate of the gully head. This has shown that runoff from precipitation is a major contributor to gully head retreat.

3.4 Computation of Soil Loss in ArcGIS Environment

Triangulated Irregular Network (TIN) was created for 2012 – 2018 using the CHILD modelled gully data as shown in Figure 17. Each year was superimposed on the subsequent year to estimate the soil loss using the Surface Difference Tool (SDT) in the ArcGIS environment. The computation of soil loss using Surface Difference Tool (SDT) is as shown in Table 7.

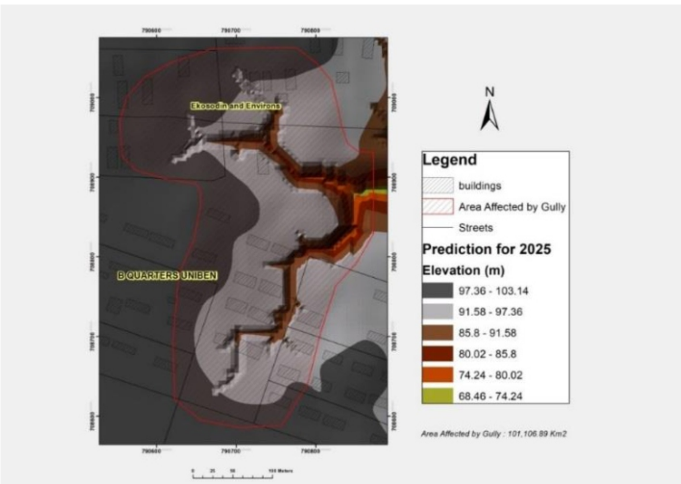

Figure 17: Triangulated irregular Network (TIN) showing Gully Head region for Soil Loss Computation

Table 7: Computation of soil loss using Surface Difference Tool (SDT)

Year	Volume of soil Loss (m^3)
2012-2014	36,540.65826
2014 -2016	17,981.12539
2016 -2018	9,609.10
Total Soil Loss	64,130.88

3.5 CHILD Prediction for Risk Assessment

The map in Figure 18 shows the prediction using the CHILD model for gully head retreat by 2025.

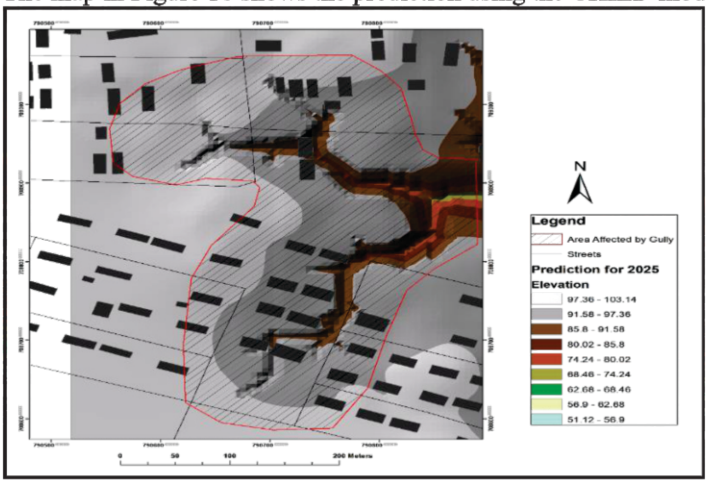

Figure 18: A map showing Predicted Gully head Retreat for 2025

From the map (Figure 18), it is seen that the gully arm A is not as extensive as that of arm B. This is strongly associated with the slope angle, like that of Arms A is seen to flatten out at this stage and the gully growth is not as rapid. The gully prediction shows deepening of the gully at this period (approximately 12 m depth) and widening of the gully heads. Also, the gully arm A is seen to bifurcate towards the head leading to head growth toward the Ekosodin community. The area of land at risk around the gully head between the years 2010 to 2025 is estimated to be 101,019.70 m^2 put together with more than 30 buildings at risk within and outside the university campus. The average cost of this damage is in Billions of Nigerian Naira.

4.0 Conclusion

From analysis, the soil properties around the gully are non-cohesive and friable, and therefore easily erodible during a heavy rainstorm. It, therefore, means it will not withstand the construction of heavy structures for erosion control. Prediction using the adopted CHILD model shows that the gully head has a retreat rate of 23.7 m/yr. for steep slope region and 9.3 m/yr. as the gully flattens out. Adopted CHILD model has shown that the gully Arm A, (heading towards Ekosodin) decreases in gully head retreat as the slope of the terrain flattens out towards the west. Adopted CHILD model prediction for gully head retreat from 2010, shows that the naturally occurring drainage line in Ekosodin and the improper channeling of runoff water through gutters in UNIBEN lead to the bifurcation of the gully into arms A and B respectively. The application of ground survey, satellite imagery, and geospatial analysis to gully head retreat modeling is useful in the mathematical modeling of gully head retreat. Improper termination of drainages and mass inflow of runoff water into the gully has contributed to the retreat, widening, and deepening of the gully head. The following are therefore recommended: Urgent steps should be taken to stop further head retreat towards UNIBEN by building a retaining wall or blocking the drain taking runoff to the gully; runoff from Ekosodin and its environs should be redistributed to reduce the concentration of runoff on the gully head; Regulating and controlling structures such as drop structures, dams, and gabion boxes should be erected to regulate and control further gully head retreat; the adapted CHILD model should be absolved as a decision support tool in gully erosion management; the gully sidewalls should be cut to reduce their steepness, while vetiver grass, shrubs, and bamboo (Indian grass) should be planted to control further erosion and collapse of the walls

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