Gully Erosion Control along NWORIE River in Owerri, Imo State-A Deterministic Model Approach

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The study developed a model for gully erosion control. The model, helped to predict total soil loss per annum particularly in the catchment area of Nworie river. Other theoretical models were used to compare results obtained for soil prediction in gully erosion. A Deterministic Model was developed for the study which is called "Project Model" was formulated as for soil loss prediction in the catchment area. The model (formulated as an algorithm for optimizing the amount of soil loss). Soil loss value for Project model in the month of highest annual rainfall was 76.15 metric ton and while that of Universal Soil Loss Equation for the same month was 78.86 metric ton. The study also showed that rainfall depth contributed to soil loss in gully erosion. Test of confidence was carried out with Student t-test and Fisher's test at 5% level of significance and found adequate of the deterministic model. It was recommended that for any known soil value, the project model can be adopted in calculating confidently the amount of soil loss in the area that may precipitate gully erosion.

Key words: *Critical Depth, Erodibility, Gully Erosion, Determinstic Model, Shear Stress, Soil Loss,*

I. INTRODUCTION

Taking steps to preserve the quality and quantity of global soil resources should require no justification. Our future ability to feed ourselves and to live in an unpolluted environment depends on our ability to understand and to reduce the rates at which our soils are currently eroding. Over the last decades, most research on soil erosion by water has concentrated on interrill (sheet) and rill erosion processes operating at the runoff plot scale. Relatively few studies have been conducted on gully erosion operating at larger spatial scales. Recent studies like, Water Erosion Prediction Project (WEPP) Flanagan, (2001), Precision Agricultural-Landscape Modeling System (PALMS) etc. indicate that soil losses by gully erosion are far from negligible in a range of environmental problems. Consequently, there is a particular need for monitoring (through experimental and modeling studies of gully erosion) as basis for predicting the effects of global changes (landuse and climate changes) on gully erosion rates as well as on the contribution of this soil degradation process to overall land degradation Todd, (2010).

For some years recently, channels in some parts along Nworie River were noticed to have entrenched into valleys. These channels generally eroded into red-earth and unconsolidated geologic materials establishing prominent gullies with near vertical slopes.

Increased erosion activities in the vicinity of the early gullies have continued to expand these gullies into a complex system. Most of the gullies especially those with high discharge value are now of canyon proportion, and constitute the most threatening environmental hazard in parts of Nworie River which runs along the Metropolis of Owerri, Imo State (Acholonu, 2008).

The control measures so far adopted in the affected areas have been concentrated on control of surface waters runoff (their volume and velocity), by the construction of some hydraulic structures and planting of trees to strengthen the soil. These measures appear to have given some success in the shallow (4 - 15m deep) gullies which cut mainly into red clayey earth; they have however failed in deep gullies which cut into very permeable and cohesionless sand where the gully walls are indented with spring sand seepages at various horizons.

II. METHODOLOGY

The study focused on development of a model for determining the erosion occurring along the waterside area of Nworie River of Imo State Nigeria.

2.1 LOCATION OF STUDY AREA

Figure 1: Location of the Study Area.

Nworie River catchment basin area was used as the study. The river originates from Mbaitolu LGA of Imo State and passes though Owerri Municipal LGA of Imo State and then empties into the Otamiri River at Nekede, Owerri West LGA, Imo State. The measured length of the river is approximately 9 kilometers and the area of the catchment is approximately, 30 square kilometers.

2.2 RAINFALL DATA IN OWERRI

Rainfall distribution in Owerri, with peaks in July and September and a two-week break in August. The rainy season begins in March and lasts till October or early November. See Table 1. Rainfall is often at its maximum at night and during the early morning hours. However, variations occur in rainfall amount from year to year.

Table 1: Average rainfall from 1979 to 2010

	[mm]
Jan	20.9
Feb	31.8
Mar	155.6
Apr	186.1
May	278.1
Jun	290.1
Jul	312.6
Aug	375.5
Sep	429.9
Oct	313.4
Nov	103.4
Dec	9.8
Ann.	2507.0

Source: AIRBDA Weather Report 2010.

The result of temperature measured in degree centigrade is based on average monthly temperature of the study area, see Table 2.

Table 2: The Average Temperature of the Catchment

	Mean temp. [deg C] 1985-1990	Mean Temp [deg C] 2007	Mean temp. [deg C] 2008
Jan	26.50	26.00	26.25
Feb	28.50	27.00	27.75
Mar	28.00	27.00	27.50
Apr	28.00	27.00	27.50
May	27.00	27.00	27.00
Jun	26.50	25.00	25.75
Jul	25.00	25.00	25.00
Aug	25.30	25.00	25.15
Sep	25.50	25.00	25.25
Oct	26.00	26.00	26.00
Nov	27.00	26.00	26.50
Dec	26.50	26.00	26.25
Ann.	26.65	26.00	26.33

Source: AIRBDA Weather Report (2010)

2.3 MODEL DEVELOPMENT FOR SOIL LOSS

The model was based on the governing sediment continuity equation. The governing sediment continuity equation as stated by Nearing et al. (1989) as:

$$\frac{dq_{sb}}{dx} = q_{ie} + q_{re} \quad 1$$

where

x (m) = distance downslope.

q_{sb} (kg s^{-1} m^{-1}) = sediment load.

q_{ie} (kg s^{-1} m^{-2}) = interrill erosion rate.

q_{re} (kg s^{-1} m^{-2}) = rill erosion rate.

Integrating equation (1), with respect to independent variable x, the sediment load becomes the model transport capacity and we have the equation as follow;

$$ASL = q_{ie}x + q_{re}x + C \quad 2$$

where

C = constant of integration (kg/km^2)

q_{re} = rill erosion rate (kg $s^{-1}km^{-2}$)

q_{ie} = interrill erosion rate (kg $s^{-1}km^{-2}$)

x = integration independent value (s)

C is taken as amount of soil loss due to gully erosion, measured in kg/km^2 and is denoted as q_g. in the same way $q_{re}x$ is soil loss due to rill erosion, measured in kg/km^2 is denoted as q_r, while $q_{ie}x$ is amount of soil loss due to interrill erosion, measured in kg/km^2 is denoted as q_i. Substituting these terms into equation (2) gives the project model equation as shown in equation (3).

$$ASL = q_g + q_i + q_r \quad 3$$

where

ASL = Amount of soil loss in the catchment, measured in kg/km^2.

q_g = Amount of soil loss due to gully erosion

q_i = Amount of soil loss due to interrill erosion

q_r = Amount of soil loss due to rill erosion

2.4 DETERMINATION OF SOIL LOSS DUE TO GULLY EROSION, q_g

In the determination of soil loss due to gully erosion, Agunwamba (2001) gave the equation from soil loss due to gully erosion as:

$$q_g = K_t \tau_f V_c \quad 4$$

where

K_t = Erodibility of the transport,

The value of K_t depends on density of the soil. This value ranges from 0.077 to 0.11(Gilley, 1990). It is measured in $s^2m^{0.5}kg^{-0.5}$.

τ_f = Shear stress of the soil,

Shear stress of soil, τ_f is the ability of the soil to resist cutting effect from cutting loads. It is measured in N/mm^2. Gilley, (1990) gave the equation of shear stress of soil as:

$$\tau_f = \gamma_w S_f R \left(\frac{f_s}{f_t}\right) \quad 5$$

For wide channels, f_s/f_t is taken as 0.7. R means the hydraulic radius and it is equal to the critical depth of flow, y_c for wide channels. It is measured in meters (m). The equation of critical depth of flow Henderson, (1966) is:

$$d_c = \sqrt[3]{\frac{q^2}{g}} \quad 6$$

where q = discharge per ft. (m) of width m^3/s/m (cfs/ft.).

Thus for rill erosion purpose, the hydraulic radius can be taken as y_c:

$$R = y_c = \sqrt[3]{\frac{Q^2}{g}} \quad 6a$$

S_f means slope along the wide channel. It is a dimensionless parameter.

(Ken, 2004) it is given as:

$$S_f = 1.3 * S \quad 7$$

where S is the normal slope of the land near the river.

γ_w means the unit weight of the water. It is measured in N/m^3. In most cases, it is taken as 9.8 KN/m^3

V_c = Critical velocity,

Critical velocity means the velocity of water at the critical depth of flow. It is measured in m/s. The equation for critical velocity Agunwamba, (2001) is given as:

$$V_c = \sqrt{g y_C} \quad 8$$

where g means acceleration due to gravity taken as 9.81m/s^2,

2.5 DETERMINATION OF SOIL LOSS DUE TO RILL EROSION, q_r

The equation for the rate of soil loss (Flanagan, 1995) is given as:

$$q_{re} = q_c\left[1 - \frac{qsb}{q_g}\right] \quad 9$$

Rill detachment capacity for clean water, q_c

q_c means rill detachment capacity for clean water. It is measured in kg/m^2/s. the equation for calculating q_c Elliot, (1988), is given as:

$$q_c = k_r(\tau_f - \tau_c) \quad 10$$

K_r is rill erodibility (sm^{-1}) factor, and it can be calculated using the equation Kr = 0.00197+0.03 vfs + 0.03863e$^{-184orgmat}$.

τ_f is the soil shear stress as defined in equation 5.

τ_c is the soil critical shear stress, it can be calculated using the equation $\tau_c = \gamma RS$ and is measured in MPA or N/mm^2 Carlos, (2007).

Volumetric unit bed sediment transport rate, q_{sb}

q_{sb} means Volumetric unit bed sediment transport rate. It is measured in m^3/s. the equation for q_{sb} Howard, (1994):

$$q_{sb} = \Phi * \omega * d(1 - \mu) \quad 11$$

q_g means the soil loss due to gully erosion as we have it on equation (4).

Φ is a dimensional parameter in the equation and can be calculated with this equation Hood, (2002) as;

$$\Phi = k_e\left\{\frac{1}{\Psi} - \frac{1}{\Psi_c}\right\}^p$$

where ke is effective saturated conductivity (mm/h) from Table A5.

Ψ is taken from Table A1 as 110mm or 0.11m and ψ_c is negligible, it takes value of zero while p is the power of the equation and is 3.

ω is the fall velocit y of the sediment grains, measured in m/s.

d is the sediment grain size, measured in mm.

μ is alluvium porosity

2.6 DETERMINATION OF SOIL LOSS DUE TO INTERRILL EROSION, q_i

The equation for interrill erosion rate, q_{ie} Nearing et al. (1989) is given as:

$$q_{ie} = k_i I_e^2 C_e G_e\left(\frac{R_s}{w}\right) \quad 12$$

where

K_i means, baseline interrill erodibility and it is measured in kgs/m. the equation to calculate K_i is given by Flanagan and Nearing (1995) as:

$$K_i = 2728000 + 19210000\, vfs \quad 13$$

Where, vfs = very fine sand fraction.

I_e means effective rainfall intensity. It is measured in mm/s. The value is the rainfall intensity collected from metrological station of the catchment for the period in question.

C_e means the effect of canopy on interrill erosion. This is the way catchment surface is being covered. This cover can come from leaves and branches of trees, grasses and other man made canopies. It can be estimated with the equation by Nearing et al. (1989) as:

$$C_e = 1 - F_c\, e^{-0.34 H_c} \quad 14$$

Laflen et al. (1985), F_c means portion of the soil the canopy covered. This is estimated from site observation to know the percentage of the catchment that is being covered by the canopy and the ones uncovered, the fraction being covered is the F_c. The height of this canopy is denoted as H_c. It is measured in meters.

G_e means the effect of ground cover on interril erosion. Ground cover in this case means humus and dead grasses and leaves, which cover the surface of soil and thus protect it from direct attack of rain drops. It is being estimated (Nearing et al., 1989) as:

$$G_e = e^{-2.5\, g_i} \quad 15$$

g_i is the fraction the catchment covered by the humus.

R_s means the average spacing between one rill and the other. It is measured in meters and got from site observation and measurement.

W means the average width of the rill in the catchment. It is measured in meters and got from site observation and measurement.

2.7 DATA REQUIREMENTS

The parameters used in the study included:

- Rainfall data
- Slope of the land
- Drainage of the catchment area
- Soil characteristics
- Watershed length

- Runoff (discharge) measured in cubic meters

Then from the point where the slope starts to increase to the stream was about 250m and the slope increases to 30% which is $130/100 * 0.39 = 0.507$.

For Nworie Catchment area, Area = 30km^2 (Ministry of Lands, Survey and Urban Planning (2010)) and in circular manner its radius is 3.0902km and diameter is 6.1804km, so L = 9km, Lc = 3.0902km, C_t = 1.7, C_p = 0.8. Considering the exit point along Nworie River, the area of interest is about 2km^2 and the L = 500m and Lc = 230m, all other constants remain the same.

2.8 DISCHARGE FROM THE CATCHMENT

SCS Dimensionless Unit Hydrograph

The Soil Conservation Society Method (SCS) dimensionless hydrograph is a synthetic hydrograph in which the discharge is expressed by the ratio of discharge q to peak discharge q_p and the time t to the time of rise of unit hydrograph, T_p. Given the peak discharge and lag time for the duration of excess rainfall, the unit hydrograph can be estimated from the synthetic dimensionless hydrograph for a given basin. It can be shown that:

$$q_p = \frac{CA}{T_p} \qquad 16$$

where: C = 2.08 and A = drainage area 30 km^2, Tp = Time of rise or Time to peak.

Example of Peak Discharge on September rainfall

$$Q_P = \frac{2.78 C_p A}{T_P} = \frac{2.78 * 1 * 0.4 * 2}{0.407107} = 5.462937262\ m^3/s$$

2.9 UNIVERSAL SOIL LOSS EQUATION (USLE) MODEL:

This is a well recognized model for soil loss prediction from raindrop splash, which loses and raises particles of soil that are then transported by overland flow to reach the hydrographic network. Control measures applied against surface erosion are derived from Universal Soil Loss Equation (U. S. L. E.). According to Bauman, (2002). U. S. L. E., the quantity of soil, A (in ton /acre) removed by sheet erosion on a slope as a consequence of rainstorm occurring over a defined period usually one year is given by the product of six factors:

A = R*K*(LS)*C*P

where R = Rainfall (and runoff) factor, or erosivity factor
K = soil erodibility factor
L = Slope length factor
S = The slope steepness factor
C = The lower and management factor
P = The soil conservation practices factor.

Soil loss in crop land is reduced by adopting appropriate conservation practices. The expected reduction due to P cannot be more than 0.25 as in contouring.

It has been proved from erosion studies that the only factors which obviously could radically be modified by possible interventions are vegetation cover (C) and the topography of slope.

There are various methods of sheet erosion control. The North American green method of erosion control offers a very effective and advanced method of sheet erosion control. The system offers a variety of Erosion Control blankets to suit a variety of situations. It controls erosion in heavy rains and conserves moisture when there is no rain. The erosion control blankets create an ideal environment for seeds to germinate. Because the blankets are so well constructed and porous, the ground accepts additional moisture through rainfall.

Example; R = Rainfall (and runoff) factor, or erosivity factor = 2638.2/26.375 = 100
K = soil erodibility factor 0.36 }
L = Slope length factor 375 } *16.82*
S = The slope steepness factor 60 }

LS = (λ / 72.6)m (65.41 sin2θ + 4.65 sin θ + 0.065)

C = The lower and management factor 0.85

P = The soil conservation practices factor. 0.9

A = R *K *(LS) *C *P

$$A = 100 * 0.36 * 16.82 * 0.85 * 0.9 = 463.2228\ ton/km^2/year$$

Plate 1: Erosion at Discharge Point

III. RESULTS AND DISCUSSIONS

The summary results of soil samples obtained in the study area are shown in Table 3. Percentage of clay fraction varied between 10% - 18% in the increasing order. However, cohesion of soil from the study area varied between 18KN/ m^2 -23KN/m^2. There is no much variation in the soil cohesion of the study area.

Table 3: Soil Sample Result of the Study Area

i.	Soil	~~Average of~~ Parameters	Ave. values
	Dark brown organic	% organic content :	45%
	Silty sand	% clay fraction :	10%
		Friction (ϕ) :	10^0
		Cohesion(C) :	22kN/m^2
ii.	Soil	Average of Parameters	
	Light brown silty	% organic content	23%
	Sand	% clay fraction	12%
		Friction	30^0
		Cohesion	18kN/m^2
iii.	Dark red clayey	% Clay fraction	14%
	Sand	Friction	29^0
		Cohesion	21kN/m^2
		Density	19.8kN/m^3
iv.	Reddish Sandy	% Clay fraction	18%
	Clay	Plasticity index	17%
		Friction	27^0
		Cohesion	23kN/m^2

Table 4: Discharge of Flood at Point of Interest of the Study Area (at high depth of rain in each month) (m^3/sec)

	Discharge based on 1 cm drop of water multiply by monthly rain depth in cm		
Month	Area 2km^2 (m^3/sec)	Area 26km^2 (m^3/sec)	Total (m^3/sec)
Jan	11.25	36.13	47.38
Feb	17.15	55.08	72.23
Mar	83.92	269.45	353.37
Apr	100.36	322.26	422.62
May	149.97	481.54	631.51
Jun	156.44	502.32	658.76
Jul	168.59	541.33	709.92
Aug	202.50	650.21	852.72
Sep	231.84	744.41	976.25
Oct	169.02	542.71	711.74
Nov	55.78	179.10	234.88

Dec	5.29	16.97	22.26
Ann.	1352.11	4341.52	

Table 5: Relation Of Climatic Factors to Discharge

Climate factor	Maximum value	Minimum value	Average value
Temperature (^{0}C)	27.75	25.00	26.375
Precipitation [mm/month]	429.9	9.8	219.85
Discharge (m^3/sec/month) one point	231.84	5.29	118.565
Discharge (m^3/sec/month) all points	744.41	16.97	380.69

Universal Soil Loss Equation (USLE Model) Foster, (2003) is computed undergoing the necessary parameter of the equation the annual amount of soil loss is obtained on tonnes per square kilometer (ton/Km^2) and after discretization based on monthly period then the soil loss is summed up to 447.9982ton/km^2 and is presented on Table 4.

Table 6: Monthly Erosion Amount based on Universal Soil Loss Equation (USLE) A = RKLSCP

Month	R	K	LS	C	P	A
Jan	0.794762	0.36	16.82	0.85	0.9	3.681518
Feb	1.146096	0.36	16.82	0.85	0.9	5.308978
Mar	5.657879	0.36	16.82	0.85	0.9	26.20858
Apr	6.766667	0.36	16.82	0.85	0.9	31.34474
May	10.29846	0.36	16.82	0.85	0.9	47.7048
Jun	11.2644	0.36	16.82	0.85	0.9	52.17928
Jul	12.50333	0.36	16.82	0.85	0.9	57.91829
Aug	14.92876	0.36	16.82	0.85	0.9	69.15342
Sep	17.02376	0.36	16.82	0.85	0.9	78.85795
Oct	12.05321	0.36	16.82	0.85	0.9	55.83319
Nov	3.902673	0.36	16.82	0.85	0.9	18.07807
Dec	0.373333	0.36	16.82	0.85	0.9	1.729365
Annual Soil Loss.						447.9982

The Project Model of this study was used in calculating the soil loss caused by Gully, Rill and Interrill erosion in the catchment area and the total is also computed as the Amount of the soil loss under the discretization of monthly period of time and summed up to get that of annual to be 474.92ton/km^2 shown on Table 6 and the significance will publicized on the analysis of hypothesis.

Table 7: Monthly Erosion Amount based Project Model

Month	Mean temp. [deg C]	mm	Discharge in 1cm 2Km^2 m^3/sec	Discharge in 1cm 26Km^2 m^3/sec	Interrill Erosion ton/km^2	Rill Erosion ton/km^2	Gully Erosion ton/km^2	Amount of Soil loss ton/km^2
Jan	26.25	20.86	11.25	36.13	0.0068	-0.0170	3.66	3.65
Feb	27.75	31.80	17.15	55.08	0.0054	0.0371	6.38	6.43
Mar	27.50	155.59	83.92	269.45	0.0023	0.2798	27.32	27.60
Apr	27.50	186.08	100.36	322.26	0.0021	0.3955	37.35	37.74
May	27.00	278.06	149.97	481.54	0.0017	0.4699	48.83	49.30
Jun	25.75	290.06	156.44	502.32	0.0017	0.5738	58.21	58.79
Jul	25.00	312.58	168.59	541.33	0.0016	0.5180	54.89	55.41
Aug	25.15	375.46	202.50	650.21	0.0015	0.7045	75.35	76.06
Sep	25.25	429.85	231.84	744.41	0.0014	0.6695	75.48	76.15
Oct	26.00	313.38	169.02	542.71	0.0016	0.6107	62.89	63.51
Nov	26.50	103.42	55.78	179.10	0.0029	0.1839	18.16	18.35
Dec	26.25	9.80	5.29	16.97	0.0101	-0.0496	1.97	1.93
Ann.	26.33	2506.95	1352.11	4341.52	-	-	470.50	474.92

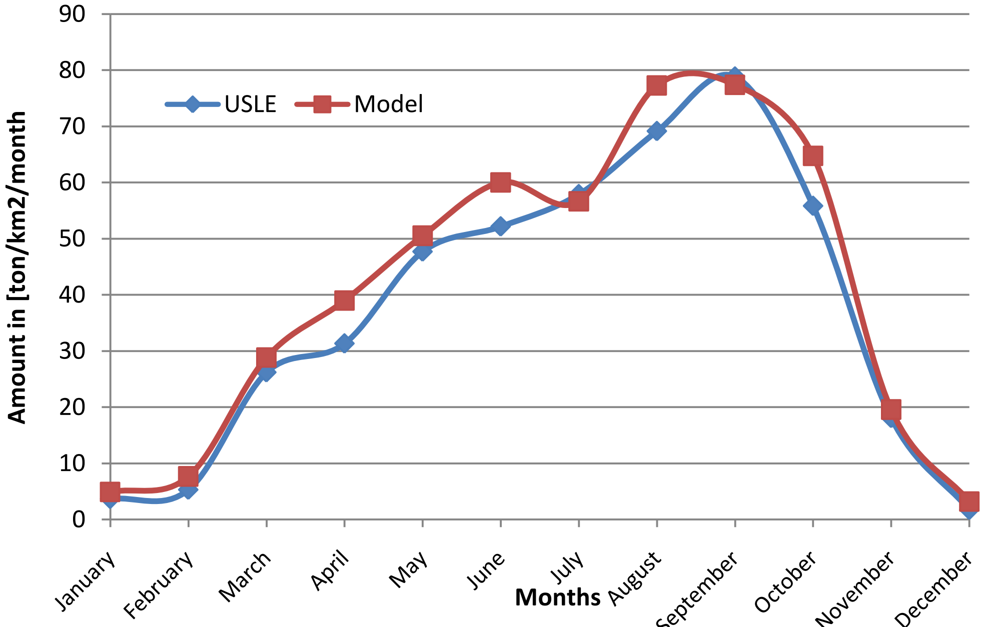

Figure 2: Soil Loss Per Month of Project Model and Universal Soil Loss Equation

Table 8: Monthly Erosion Amount of Project Developed Model and Universal Soil Loss Equation

	Project Developed Model PDM	A USLE	Percentage difference
Month	$Y_{(model)}$	$Y_{(USLE)}$	Δ%
Jan	3.65	3.68	0.815217
Feb	6.43	5.31	21.09228
Mar	27.60	26.21	5.303319
Apr	37.74	31.34	20.42119
May	49.30	47.70	3.354298
Jun	58.79	52.18	12.66769
Jul	55.41	57.92	4.333564
Aug	76.06	69.15	9.992769
Sep	76.15	78.86	3.43647
Oct	63.51	55.83	13.75605
Nov	18.35	18.08	1.493363
Dec	1.93	1.73	11.56069
Ann.	474.92	448.00	6.008929

IV. CONCLUSIONS

The project succeeded in providing information on the type of soil, exposure and soil practices use that play important roles in erosion control. In the study, Interrill(sheet), Rill and Gully erosion have been shown to be significant factors that contributed to the total amount of soil loss. Besides, the project mathematical model that was formulated for optimizing the amount of soil loss was significant in determining control approach for gully erosion.

In addition, the project model results were compared with that of Universal Soil Loss Equation result using Student T-test and Fisher's test and found to be adequate. The results for the T-test and that of the Model were found to be significant at 5% level; the Fisher's test result was significant at 5% level which is adequate, and null hypothesis was rejected.

It could therefore be concluded that for any known soil value, the project model can be adopted in calculating the amount of soil loss in the region confidently without running into difficulties.

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