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ASSESSMENT OF GULLY EROSION FROM COASTAL PLAIN SANDS OF OGBURU, ILARO, OGUN STATE

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ABSTRACT

The field measurements were used to calculate the discharge using hydraulic equations. The calculated discharges with limited hydraulic and hydrologic data were then used to establish an erosion rate equation i.e. $E = 0.025\ (1.022Q)^{15/8}\ L^{3/8}\ So^{3/2}$ (Kg/m^2/hr) which was used to estimate erosion rate. Three established functional relationships were found to be highly correlated, these are; discharge as a function of erosion rate $Q = f(E)$; shear stress as a function of discharge $□ = f(Q)$ and shear stress as a function of erosion rate $□ = f(E)$. The simple linear regression model results are $Q = 28.63 + 17.38E$, $□ = 19.47 + 3.19Q$ and $□ = 120.24 + 22.45E$ with correlation coefficients, $r = 0.86, 0.89$ and 0.93 and coefficient of determination, r^2 = 74%, 79% and 86% respectfully , the very high coefficient of correlation (r) and determination (r^2) is enough justification to conclude that the derived equations can be used to estimate the magnitude of erosion rate or extent and its future severity can be predicted from hydraulic parameters measured on site. The established relationships from limited hydraulic parameters can be used to assess the gully erosion from the site.

Key Words: Erosion Rate E (Kg/m^2/hr), Shear stress □ (N/m^2), Mannings Roughness Coefficient (n).

INTRODUCTION

Ogun State can be divided geographically into three major zones, considering the susceptibility of the rock sequences to erosion. According to information obtained from undated map compiled from a 1:2,000,000 map GNS2215 about 37% of the area is moderately susceptible to erosion (zone 1).This consists of rocks of crystalline Precambrian to Paleozoic age and its associated younger intrusive of generally high relief. Approximately 28% of the area is described as highly susceptible to erosion (Zone 2A); this is sediments of Cretaceous to Tertiary age, 35% is very highly susceptible (Zone 2B). This area coincides with the unconsolidated sediments of the Quarternary Coastal Plain Sands (Fig.1), the undated map referred to earlier on.. The experimental site falls within this area i.e. Zone 2B.

Jones and Hockey (1964) described Coastal Plains Sands as consisting soft, very poorly sorted, clayey sands, pebbly sands, sandy clays and rare, thin lignite's. They are indistinguishable in the field from much of the Ilaro Formation and from the basal continental beds of the Abeokuta formation, which is similar lithologically, also unfossiliferous, and weather to the same, familiar, red and brown sandy earths and clayey grits.

Soil erosion is a serious threat to man's existence, particularly in developing countries where scarce financial resources are being committed to combat the menace. Its assessment requires careful use of predictive

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techniques to determine the extent of erosion and its future severity.

Most parameters used in erosion rates equation are derivable from studies in small flumes and backed by mathematical analysis. The main objective of this study is to establish a procedure that will require only hydraulic parameters that can be easily measured on site without the need to consider hydrological parameters. This will also alleviate the problems of inadequate rainfall data and hydrometric measurements as is frequently encountered in most developing nations

REVIEW OF PAST WORKS

The rate of soil erosion can be estimated using climatogic and hydraulic variables. Early works of Zingg (1940) evaluated the effect of length and degree of slope on erosion rate Smith (1941) later introduced the concept of permissible soil loss and evaluate the crop factor and effect of degree of mechanical protection. Musgrave (1947) studied slope and farming practice as variables in empirical equation for estimating erosion while Wischmeier et al.(1958) did an analysis of about 8,000 experimental plot on soil loss prediction popularly known as "Universal Soil loss equation. Douglas (1967) related the suspended – sediment yield to the mean annual runoff as: -

$$\text{Log } E = 0.527 \log Q_y + 0.668$$

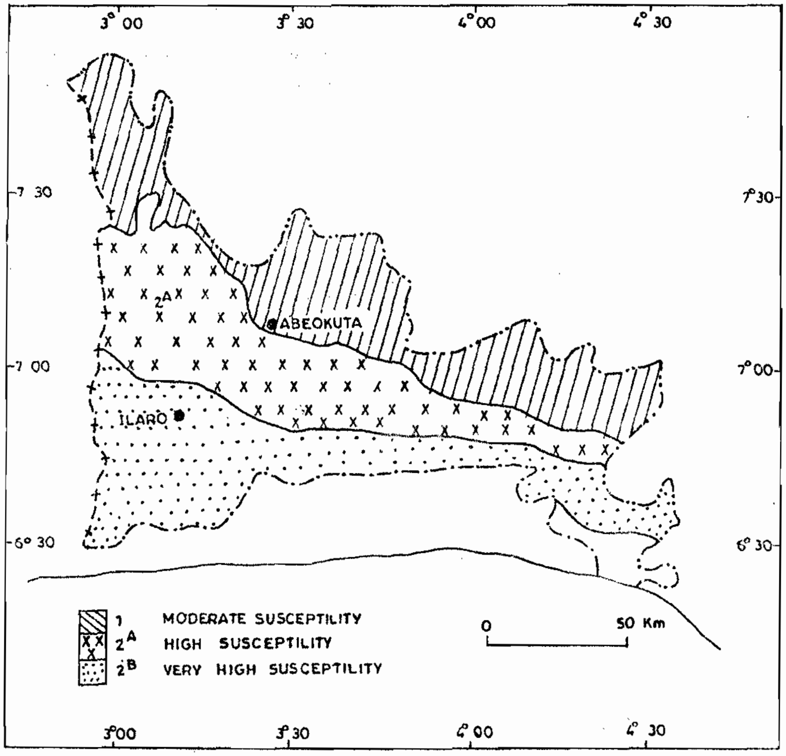

Fig 1 SOIL EROSION SUSCEPTIBILITY MODIFIED AFTER UNDATED MAP COMPILED FROM A 1:2,000,000 MAP GSN 2215 PUBLISHED BY THE GEOLOGICAL SERVICE OF NIGERIA RECOMPILED AND PRINTED BY THE FEDERAL DEPARTMENT OF FORESTRY LAGOS.

Table 1: Field Measurements

Distance L(m)	Depth Y(m)	Width B (m)	Area A(m^2)	Hydraulic Radius R = A/P(m)	Mean Slope S x10^{-2}
0	*4.21	0.8			
20	4.12	2.07	13.08	1.25	0.9
40	2.92	0.88	10.71	1.14	3
55	2.70	2.05	7.32	0.91	4.4
75	2.60	0.76	6.19	0.87	11.11
96	1.50	1.10	3.73	0.67	5.25
105	1.36	0.74	2.19	0.54	0.7
110	*1.22	0.47	1.81	0.50	0.9
150	1.23	0.90	1.89	0.51	0.19
180	1.41	0.72	2.2	0.56	0.9

*Indicates location of maximum and minimum depth.

Table 2. Sieve Analysis Results

	%Passing /Sizes(mm)					
Samples	D_{10}	D_{30}	D_{50}	D_{60}	D_{65} *	D_{90} *
I	0.17	0.3	0.35	0.4	0.42	1.00
II	0.17	0.28	0.5	0.65	0.80	1.45
Mean	0.17	0.29	0.425	0.525	0.61 *	0.125 *

*Values required for the calculation of Mannings Roughness Coefficient (n)

Table 3. Estimated values of Discharge and Erosion Rates.

Distance L(m)	Discharge Q (m^3/s) Equation 1	Erosion Rate E (Kg/m^2/hr) Equation 2
0		
20	120.12	0.5422
40	168.62	6.2328
55	124.95	5.6657
75	156.93	38.821
96	54.75	1.782
105	10.11	0.0027
110	8.97	0.0025
150	2.26	5.36×10^{-3}
180	11.75	0.0081

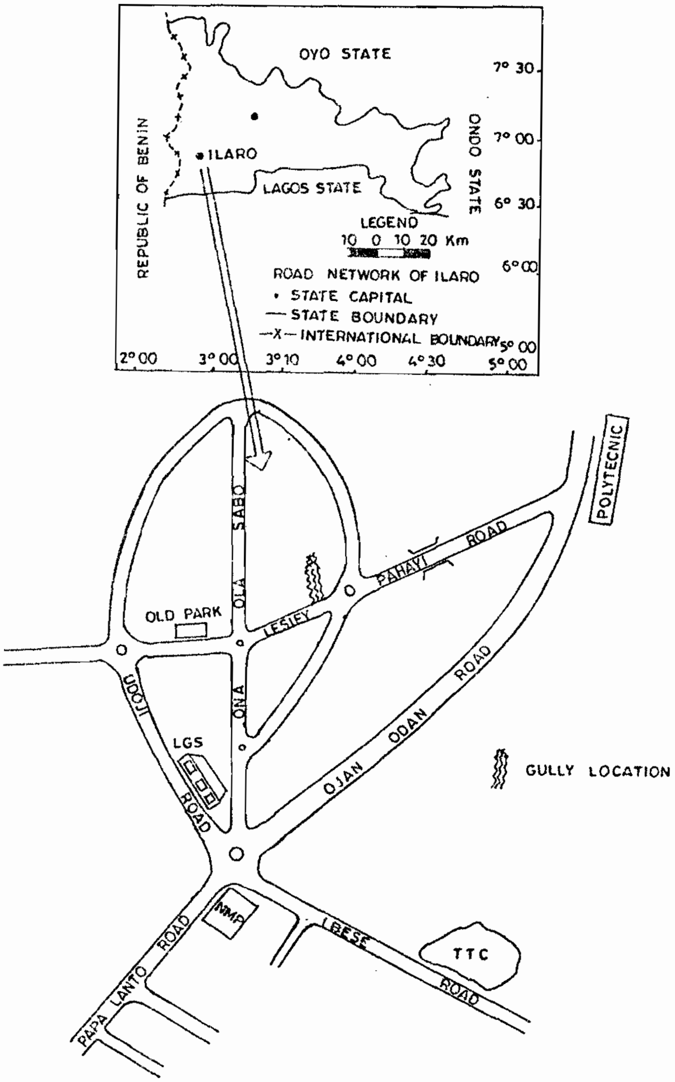

Fig 2 ROAD NETWORK OF ILARO AND GULLY LOCATION

With correlation coefficient (r) = 0.498
Where E = suspended – sediment yield ($m^3/km^2/yr$),
Qy = Runoff (mm).

Younkin (1973) developed an equation that may be used for computing the suspended sediment load carried by a stream during periods of rainfall induced erosion of disturbed soils, a problem common in highway construction.

A general equation for computation of slope erosion by overland flow in turbulent flow regions based on Kalinske bed load function was suggested by Komura (1976). Ogbonna (1990) using pilot studies obtained a fairly modified version of the Kamura equation as: -

$$E = \frac{0.00105}{D}\, CACE\, (fl)^{15/8}\, L^{3/8}\, So^{3/2}$$

E = slops Erosion rate ($Kg/m^2/hr$)
CA = bare soil area ratio (ratio of bare soil area to total slope area)
CE = Erodibility Coefficient
f = runoff coefficient for the soil
l = rainfall intensity (mm/hr)
L = Slope length (m)
So = the slope gradient
D = the mean sediment size of the slope material: (mm).

Awokola et al (1996) concluded that given the mean sediment size of the slope material of Manning roughness coefficient n = 0.012 for the bare land without vegetation and fort gully type of erosion, the rate of erosion may be computed from hydraulic parameters

$$E = 0.025\, (1.022Q)^{15/8}\, L^{3/8}\, So^{3/2}\, (Kg/m^2/hr).$$

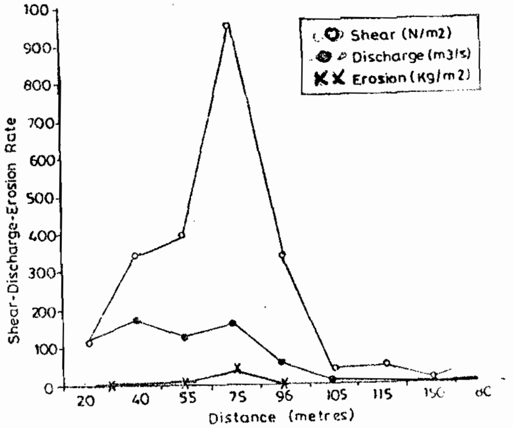

Fig 3. Distance Shear-Discharge-Erosion-Rate Relationship

Table 4: Estimated value of □, Q, and E.

□ $^N/m^2$ Equation (3)	Q m^3/s Equation (1)	E $Kg/m^2/hr$ Equation 2
110.54	120.12	0.5422
335.50	168.62	6.2328
390.63	124.95	5.6657
950.38	156.93	38.821
347.13	54.75	1.783
37.15	10.11	0.0027
43.79	8.97	0.0025
9.01	2.26	$5.36x10^{-5}$
49.00	11.26	0.0081

Table 5: Simple Linear Regression Model Results

Regression equation	Correlation Coefficient (r)	Coefficient of determination $(r^2)\%$
Q = 28.63 + 17.38 E (eq. 4)	0.86	74
□ = 19.47 + 3.19 Q (eq.5)	0.89	79
□ = 120.24 + 22.45 E (eq.6)	0.93	86

THE STUDY AREA

Location: Ilaro is a town located in the South-Western part of Ogun State, Nigeria. It is the Headquarters of Yewa South Local Government. The study area lies between latitude 6° 50′and 6° 57′ North and longitude 2° 58′ and 3° 05′ East. The Ogburu gully experimental site is located in the center of Ilaro township (Fig2). The location under study shown in Figure2 is described as very highly susceptible; the area coincides with the unconsolidated sediments of the Quaternary Coastal Plain Sands. The Gully channels are two in number, the first the Old Ogburu gully is very deep measuring about eleven-metres 11m) and with average width of 1.5m. It is ow largely stabilized and covered by egetation. The second gully is still very active; it has a total length of 400m with average width and depth of 1.24m and 2.34m respectively.

Climate: the climate is of tropical type, the rainy season starts between March and April, while the dry season commences around October and November to February each year. The rainfall pattern is bimodal with peak in June and October, the latter is more prominent.

Geology: The geological formation of the region is composed of; Ilaro Formation which predominates the surface of this region and hence its name. This sedimentary formation from the Eocene period is about 100m thick and is coposed of alternating layers of Schists, Sandstone, Sand and clay. Ewekoro Formation from the PalEocene period which is about 120m thick. It is composed essentially of Schists and clay. Abeokuta Formation fom Cretaceous period, which varies in thickness from 120-200m. It s alternating layers of sand and clay is generally known as aquiferous (Jones and Hockey, 1964).

METHOD OF STUDY

Field Measurements: The channel was surveyed using Dumpy Level, Theodolite, Tape and staff. The length, depth and width of the channel was accurately measured (Table1).

Laboratory Analysis: Soil type is an important parameter to be considered in erosion problems soil samples were taken at locations of maximum and minimum depths (Table1). Sieve analyses was carried out on the soil samples and the results are presented in Table 2.The standard procedure uses percent passing (also termed percent smaller or finer). The particle size analysis of a soil sample involves determining the percentage by weight of particles within different size ranges. From the grain-size distribution obtained grain sizes such as D_{10}, D_{30}, D_{50}, D_{60}, D_{65} and D_{90} were obtained. The D refers to the grain size or apparent diameter of the soil particles and the number subscripts denotes the percent which is smaller or passing the mesh screen. The results obtained showed that the soil sample fall between the fine, coarse to medium sand (sieve sizes No 10- No 100).

HYDRAULICS OF OPEN CHANNELS

Hydraulics calculations make it possible to determine the discharge Q and the average velocity V when all the geometric values of at least two adjacent cross – sections are known. The equation commonly used in open channel hydraulics is Manning equation. The equation is of the form:

$$Q = {}^{A}/_{n}\ R^{2/3}\ S^{1/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where **Q** is discharge (m^3/s), **A** is area (m^2), **n**, is the roughness coefficient, **R** the hydraulic radius (m) and **S** slope (m/m). Manning's roughness coefficient **n** can be obtained from grain size distribution patterns through different approaches. Mean value obtained from three of these methods (shown below) has been adopted in further calculations.

(i) Meyer – Peter and Muller

$$n = \frac{(d_{90})^{1/6}}{26} = \frac{(1.225x10^{-3})^{1/6}}{26} = 0.01258$$

(ii) Transformed Strickler Formula

$$n = \frac{(d_{65})^{1/6}}{75.7} = \frac{(0.61)^{1/6}}{75.7} = 0.01265$$

(iii) Keulegan

$$n = \frac{(d_{90})^{1/6}}{86.7} = \frac{(1.225)^{1/6}}{86.7} = 0.01193$$

($^{d}{}_{65}$ (millimeters) is the grin size for which 65% of the sample is smaller or passing.)
Mean Manning coefficient of roughness (n) is 0.012. This value will be adopted for the study. The discharge calculation is as shown in table 3.

ESTIMATION OF EROSION RATE

Various works had been reviewed in the form of erosion rate calculation e.g Zingg (1940), Smith (1941), Musgrave(1947), Wischmeieret.al(1958), Douglas(1967), Younkin (1973), Komura(!976), Ogbonna (1990), Awokola et.al(1996). The equation derived for the location i.e. $E = 0.025 (1.022Q)^{15/8} L^{3/8} So^{3/2}$ ($Kg/m^2/hr$), will be adopted for this study.
Awokola et al (1990) concluded that the erosion rate can be calculated from the hydraulic parameter i.e.

$$E = 0.025\ (1.022Q)^{15/8}\ L^{3/8}\ \ So^{3/2}$$
$(Kg/m^2/hr)$ 2

The computed values are as shown in table 3.

SHEAR STRESS APPROACH.

The shear stress □ is taken as the important factor measuring the power of the flow to discharge the sediment. This phenomenon is called scour or erosion and the force causing it is known as the tractive force. The equation commonly used to describe the tractive force is the Du Boys Equation

□ = δRS 3

Where □ is the shear stress in N/m^2 , δ unit weight of water, N/m^3, **R** hydraulic radius in (m), **S** the longitudinal slope of stream bed or hydraulic gradient (m/m).
The shear stress (tractive force) □, could be seen approximately as a function of the hydraulic radius **R**, and the slope **S**, i.e. □ = f(R,S).
From the dynamic equation of flow in open channels given by equation 1, discharge **Q** is also a function of the hydraulic values **R** and Slope **S** i.e **Q = f(R,S)**.Hence we may conclude that Shear stress is a function of discharge i.e □ = **f(Q)**. Since discharge as a function of erosion rate had been established i.e **Q = f(E)**, we can also conclude that Shear stress is a function of erosion rate i.e □ = **f (E)**.

The following functional relationships will be computed and compared.

(i) **Q = f (E)**
(ii) **□ = f (Q)**
(iii) **□ = f (E)**

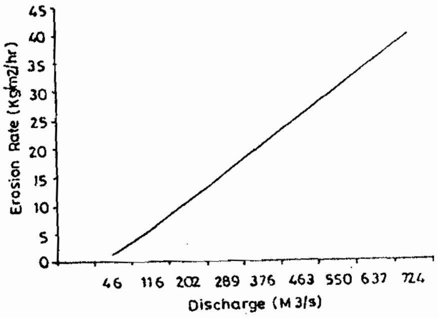

Fig 4. Discharge and Erosion Rate

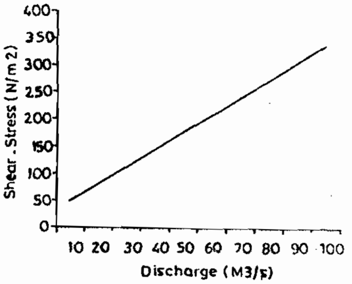

Fig 5 Discharge and Shear-Stress

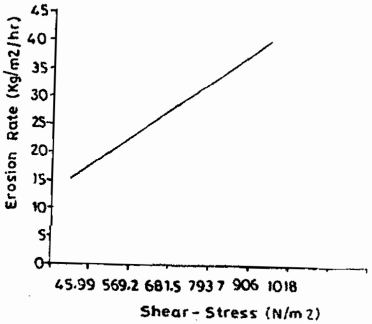

Fig.6 Erosion and Shear-Stress

RESULTS

The field measurements of length, width and depth were used to calculate the area, wetted perimeter and slope. The hydraulic radius R = A/P, where A is the area and P is the wetted perimeter. The results are as shown in Table1. The results of particle size analysis obtained is in Table2, the main reason is to obtain the grain size for which 65% and 90%

of the sample is smaller or passing the mesh size. This was made use of to calculate the Manning's roughness coefficient ($n=0.012$) and subsequently adopted with values in Table1 to calculate the discharge Q using equation1, the results are in Table3. The values of discharge Q obtained was substituted in equation 2 to obtain the erosion rate E as recorded in Table 3, while equation 3 was made use of to obtain the shear stress (□) value from the same hydraulic characteristics. The computed values of □,**Q** and **E** are shown in Table4.

Then simple regression analysis was applied to the three computed values according to their functional relationships the results obtained are as shown in table 5.

DISCUSSIONS

The results show that the shear-stress is an important factor measuring the power of the flow to detach and discharge the sediment, this can be observed from Figure 3, the comparison or relationship of the shear-stress, discharge and erosion rate along the channel i.e longitudinal profile. The shear-stress increase considerably with increase in surface runoff and the erosion rate The shear-stress can be confirmed to be a measure of the power of the flow to dislodge the sediment. Th equations 4,5and 6 in table5 are the confirmed functional relationships between the Discharge (**Q**), Shear Stress (□) and the Erosion Rate (**E**). The three functional relationships were obtained from hydraulic parameters of field measurements.

CONCLUSIONS

The simple linear regression models (table 5) shows that all the three functional relationships i.e **Q** = f (E), □ = f (Q) and □ = f (E) have very high coefficient of correlation and determination. It can be concluded that equations 4,5 and 6 can be used to obtain estimated values of any of the required parameters the very high coefficient of correlation (r) and determination (r^2) is enough justification i.e. $r = 0.86, 0.89$ and0.93 while $r^2 = 74\%, 79\%$ and 86% respectfully, refer to Figures 4,5 and 6.

Q = 28.63 + 17.38 E 4

□ = 19.47 + 3.19Q............................. 5

□ = 120.24 + 22.45 E.......................... 6

The above results can be used to assess the erosion rate of the site by measuring only the hydraulic parameters of the location and obtain any of the independent variables; the equation or the graph can be used to obtain the required parameter. It can therefore be concluded that hydraulic parameter measured from erosion site can be used to estimate the magnitude of erosion rate or extent and future severity using the derived equations.

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