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Comparison of ESLRM, MSLM and USLE Soil Loss Models in Imo River Basin in Eastern Nigeria

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***Abstract*— *The models Mechanized Soil Loss Model (MSLM) and Empirical Soil Loss Regression Model (ESLRM) were compared in line with USLE on average gully erosion sites in Imo River Basin in Eastern Nigeria. MSLM was based on the shear stress of the soil with equations of gully, rill and interrill erosions were incorporated into the model. While ESLRM was a regression analysis with the following parameters: rainfall intensity, slope of catchment, duration of rainfall, bulk density of soil, catchment area, organic matter and clay content. The models were applied in estimating soil loss in the average sub-catchment and compared with soil loss estimated from Universal Soil Loss Equation USLE. On the average sub-catchment in Imo river basin has the same values on the following parameters; slope S_o, density ρ, catchment area A, organic content O and clay content C as 3.945%, 19.73kN/m^3, 1374100m^2, 24.97% and 11.25% respectively while rainfall intensity and duration varies from January to December. The minimum value of rainfall intensity is 0.85510836mm/min and Maximum value of 37.5069723mm/min for the month of December and September respectively. The duration was also varying from January to December depend on the climatic record. The comparison of the models was done by plotting MSLM and USLE model against ESLRM and they gave a linear soil loss equation with coefficient of determinations R^2 of 0.863 and 0.911 respectively. Their R^2 percentage error was approximately 5%. Then plotting the models against months of the year yield a sum total amount of soil loss in ton/km^2/year on ESLRM, MSLM and USLE produced 120.784, 146.4176 and 129.8045 respectively with their R^2 as 0.935, 0.982 and 0.986 in their polynomial of six order while the area of the average sub-catchment and SCS unit runoff are the same. Considering the R^2 USLE has the perfect relation followed by MSLM and ESLRM which has irregular shape of true natural occurrence of soil loss and is highly recommended.*

***Keywords*— *Comparison, Density, Model, Rainfall intensity, Slope, Soil loss, Sub-catchment.*

I. INTRODUCTION

Soil loss due to the activities of rainfall or water drops on ground, wetting the ground, run as sheet flow, runoff along channels, flooding etc. General called erosion has been a big challenged to most area of under develop country which Imo river basin situated in eastern Nigeria is not an exception. Three model with different ideology is going to be use to determine the annual soil loss in the average sub-catchment of the basin. They are Mechanized Soil Loss Model (MSLM), Empirical Soil Loss Regression Model (ESLRM) and Universal Soil Loss Equation (USLE). The different ideology of the models is base on their contributions and their limitation on which the model was developed and what it can determine.

Empirical Soil Loss Regression Model is an empirical developed model, where all it parameter where measured on the cause of it experiment and regression analysis was used to determine it coefficient or factors according to (Ibearugbulem *et al.*, 2018a) and it parameter is as follows; Rainfall intensity, slope, rain duration, soil density, catchment area, organic content and clay content.

Mechanized Soil Loss Model is a deterministic model formulated to work in an open field of any kind unlike that of USLE concept. Considering that the field can contain; flat terrain, slope terrain, big or small irregular channel etc. that is to say field study is of important, to determine the field parameter needed in the model. The fundamental principle is that for a total soil loss is the summation of rill, interrill and gully soil loss or erosion. The major cause of soil movement here is soil shear stress, when the shear stress of the flow is greater than that of soil shear stress, soil loss will occur. While the rill and interrill channel is taken as wide channel with their erodibility factor, this is the initial stage of soil loss before the final stage which is gully erosion. Gully channel make use of sediment transport principle with it transport factor and model parameters are as follows; transport erodibilities, water properties(unity weight, hydraulic radius), and land terrain features(slope, steepness, channel width). (Ibearugbulem *et al.*, 2018).

Universal Soil Loss Equation is a model developed in a well define basin without a steeping slope and on America soil, which deals with the production of the following parameters. Erodibility, erosivity/runoff, Soil Conservation practices, Lower and Management, Slope length, and Slope steepness factors. (Foster *et al.*, 2003 and Wischmeier and Smith, 1993)

These three models will be use equivocally on the average sub-catchment of Imo river basin in eastern Nigeria. To check their significant difference and how the correlate, using graphical representation and also check their R^2 values, their total soil loss annual which is the summation of the monthly value of soil loss.

A Soil Loss Models

a. Mechanized Soil Loss Model (MSLM)

The Mechanized Soil loss Model (MSLM) (Ibearugbulem *et al.*, 2018) is presented herein as shown in Equation (1):

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$$q_{sl} = K_t \gamma_w S_f R\left(\frac{f_s}{f_t}\right)\sqrt{gR} + k_i I_e^2 C_e G_e \left(\frac{R_s}{w}\right) + k_r \gamma_w R\left(S_f\left(\frac{f_s}{f_t}\right) - S\right) * \left[1 - \frac{k_e\left\{\frac{1}{\Psi}\right\}^3 \omega d(1-\mu)}{K_t \gamma_w S_f R\left(\frac{f_s}{f_t}\right)\sqrt{gR}}\right] \quad (1)$$

Where K_t is gully/sediment transport erodibility, K_r is rill erodibility factor, K_i is interrill erodibility, k_e is effective saturated conductivity, ω is grains sediment fall velocity, d is sediment grain size, μ is alluvium porosity, γ_w is unit weight of water, g is acceleration due to gravity, f_s/f_t for a wide channels is 0.7, R is hydraulic radius, S_f is slope along channel, Ψ is a dimensional parameter, I_e is effective rainfall intensity, C_e is effect of canopy, G_e is effect of ground cover, R_s is average spacing between rill's, S is slope along the channel either rill or interrill or gully, and *w* is average width of the rill in the catchment.

b. Empirical Soil Loss Regression Model (ESLRM)

The empirical soil loss regression model (ESLRM) (Ibearugbulem *et al.*, 2018a) is presented herein as shown in Equation (2);

$$S_L = e^{(-12.2867)} * I^{(2.921707)} * S^{(2.057649)} * D^{(0.87341)} * \rho^{(0.074376)} * A^{(0.234785)} * O^{(-0.68998)} * C^{(-1.00134)} \quad (2)$$

Where, e is exponential, I is rainfall intensity, S is catchment slope, D is duration of the water drop, ρ is soil density, A is catchment size, O is organic matter content, and C is clay content in the soil.

c. Universal Soil Loss Equation (USLE) Model:

Universal Soil Loss Equation (U. S. L. E.) (Wischmeier, and Smith, 1993), is presented herein with its six factors given mathematically as shows in Equation (3);

$$A = K * R * P * C * (LS) \quad (3)$$

R is runoff/erosivity factor; K is soil erodibility factor, L is slope length factor, S is slope steepness factor, C is lower and management factor, and P is soil conservation practices factor (Wischmeier and Smith, 1993) (Foster *et al.*, 2003).

II. Experimental Parameters

Imo river basin has sub-catchments. On the average of the sub-catchments in the basin, the following parameters were studied; rainfall intensity I, slope S, density ρ, catchment area A, organic content O and clay content C.

A Rainfall Intensity I

Is the ratio of the summation of rainfall depth that fall over a period of time to the duration of the same period and it is expressed in unit depth per time mm/hr, (Raikes and Partners, 1971). Statistical we have high-intensity short duration rainfall and low-intensity long duration rainfall, and the cause different case of flooding and damage. The computation is differ from region to another region and is a secondary data obtain from AIRBDA (2014), and SCS unit hydrograph was employed in the computation.

B. Slope

The topographic land slope of Imo river basin starts from Northeast pass through Anambra and Imo finally to Atlantic Ocean, (Gordon, 2019). It is a highland with small steep slope, (Okoro *et al.*, 2014). The slope is summation of different slopes from various terrains in the catchment divide by their number, which is the average slope. They are average slope of the roads, channels, gully sites, flat terrains etc.

C. Determination of Soil Bulk Density

The core cutter method of determining soil bulk density was used. The height and internal diameter of the cylindrical core cutter was measured and recorded, and the volume (V) of the core cutter was computed.

The mass of the core cutter was measured and recorded as M_1 in grams. The cylindrical core cutter was pressed into the ground soil to its full depth with the help of a steel rammer.

The soil around the cutter was removed by a spade and the cutter was lifted up. The top and bottom surface of the soil sample in the cutter was trimmed carefully, and the outside surface of the cutter cleaned. The mass of the soil + with the cutter was measured as M_2 in grams. The sample in the core cutter was then dried in an oven at 105^0C over night, and then measured as M_3 and was used in moisture content calculation (Garg, 2013).

The bulk density or wet density ρ is calculated using Equation (4).

$$\rho_b = \frac{M_2 - M_1}{Vol.of\ Cylinder} \quad (4)$$

Where M_1 is mass of core cutter in (g)
M_2 is mass of cutter + soil core in (g)
V is volume of cutter in (cm^3)

And Moisture content computation was embarking on Equation (5).

$$\theta_V = \frac{M_2 - M_3}{M_3 - M_1} * 100 \quad (5)$$

Where M_3 is mass of cutter + soil core after drying (g)

D. Catchment Area

Catchment area is a secondary data obtained from the ministry, Anambra-Imo River Basin Development Authority, Agbala Owerri. (AIRBDA (2014). The data was used to compute the average sub-catchment of the basin used in this study.

E. Organic and Clay Content

Organic matter content is the percent of humus present in a soil sample likewise clay which is not humus but finely-grained from natural rock, (Michael, 2007). That is the smallest particles of soil that posses the characteristics of vegetation because of it slippery properties. 150g of soil was collected in three locations on each erosion site; it was stirred vigorously with 100ml of hot water and salt and allowed 24hrs to settle in a beaker and soil layered, (Venkatramaiah, 2012) for clay content determination. While organic matter content was in accordance to ASTM 2974 method, (Garg, 2013).

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III. RESULT OF SOIL LOSS AND PARAMETERS

This section enveloped the results of experimental and the computation of soil loss in the catchment of Imo river basin. The result of parameters used in the prediction of soil loss in the average Imo river basin is presented in Table I.

TABLE I. Parameters Values on Average Imo River Basin

PERIOD	RAIN DEPTH	S_L	I	S_o	D	ρ	A	O	C	SL
Months	CM	kg	Mm/min	%	s	kN/m^3	m^2	%	%	(Kg)
JAN	2.1	0.612	1.82037736	3.945	15021	19.73	1374100	24.97	11.25	0.659456
FEB	3.2	2.860	2.77510294	3.945	22899	19.73	1374100	24.97	11.25	3.266922
MAR	15.6	1.508	13.5762995	3.945	112026	19.73	1374100	24.97	11.25	1351.701
APR	18.6	1.200	16.2368790	3.945	133980	19.73	1374100	24.97	11.25	2665.886
MAY	27.8	3.900	24.2622455	3.945	200202	19.73	1374100	24.97	11.25	12241.03
JUN	29.0	0.323	25.3093169	3.945	208842	19.73	1374100	24.97	11.25	14369.98
JUL	31.3	0.518	27.2747573	3.945	225060	19.73	1374100	24.97	11.25	19086.37
AUG	37.5	0.660	32.7609755	3.945	135165	19.73	1374100	24.97	11.25	20887.03
SEP	43.0	0.304	37.5069723	3.945	133200	19.73	1374100	24.97	11.25	30618.73
OCT	31.3	0.612	27.3445621	3.945	225636	19.73	1374100	24.97	11.25	19272.42
NOV	10.3	0.576	9.0240836	3.945	74463	19.73	1374100	24.97	11.25	286.886
DEC	1.0	0.542	0.85510836	3.945	7056	19.73	1374100	24.97	11.25	0.037485

A Verification of study model (ESLRM and MSLM) with USLE

The three models called ESLRM, MSLM and USLE model were used for soil loss prediction in the river basin on the average sub-catchment and tabulated in Table II, for model verification.

TABLE II. Soil Loss Predicted in Average Sub-catchment of Imo River Basin using ESLRM, MSLM and USLE

PERIOD	RAIN DEPTH	ESLRM MODEL	MSLM MODEL	USLE MODEL
Months	cm	ton	ton	ton
JAN	2.1	0.000659	1.114036	1.066695
FEB	3.2	0.003267	1.963459	1.538241
MAR	15.6	1.351701	8.495948	7.593762
APR	18.6	2.665886	11.62304	9.08193
MAY	27.8	12.24103	15.2021	13.82215
JUN	29.0	14.36998	18.12963	15.1186
JUL	31.3	19.08637	17.09233	16.78144
AUG	37.5	20.88703	23.47289	20.03674
SEP	43.0	30.61873	23.51193	22.84856
OCT	31.3	19.27242	19.58909	16.17729
NOV	10.3	0.286886	5.638293	5.238
DEC	1.0	3.75E-05	0.584877	0.501072

The result of the prediction of soil loss in average sub-catchment in Imo river basin which has the following soil and other experimental parameters like, catchment area is $1374.1km^2$, SCS intensity of $19.983068(m^3/s)/1cm$, $S = 0.0343$, that is the average road slope of the catchment and the gully or slope leading to natural channel, $S_f = 0.0446$ the soil density $\rho = 19.73\ kN/m^3$ and organic content of 24.97% and clay content of 11.25% as obtained in Table II above. This ESLRM model was used to predict the value of soil loss of the catchment and compared it with MSLM and USLE as presented in Table II.

Their graphical verification were shown as follows, the soil loss predicted from the three models were plotted against monthly period in the year in Figure 1.

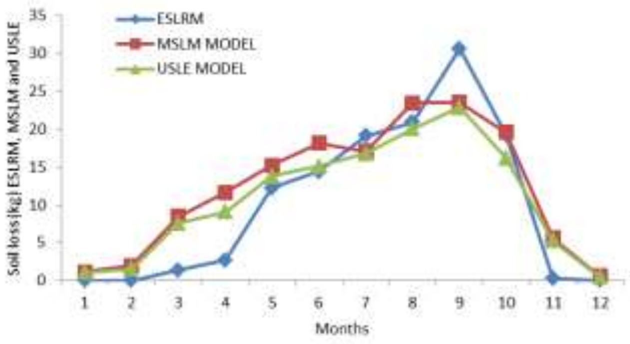

Figure 1: Comparison of Soil Loss from study models

And the soil loss value for the three model are plotted as follows, as shown in Figure 1 showing the shape of the soil loss predicted for the three model against the annual period in months that is January to December. MSLM and USLE suggested the same pattern of soil loss, why ESLRM suggest low or small amount of soil loss during January to April, which is not a threats to the environment but from May to August a substantial amount of soil loss in line with MSLM and USLE occur. But at September ESLRM give a very sharp and high value of soil loss more than MSLM and USLE suggesting a big or high risk to the environment, which shows the period, that cannot be control in time of damages and gullies can easily occur during this time. In a place if not well prepared for such upcoming flood. And at this point ESLRM is highly recommended for soil loss prediction for a catchment and environmental erosion.

The models were compared, by plotting soil loss value predicted by MSLM and USLE against ESLRM predicted soil loss values as shown in Figure 2.

However, Figure 2 shows the comparison of ESLRM with MSLM and USLE were MSLM and USLE was plotted against ESLRM. And it reflects what we have in Figure 1 in a scattered graph with a linear trend progression. Now cutting the two related models MSLM and USLEM at less than 5kg soil loss, which shows the period when MSLM and USLE have started recording soil loss. That is January to April were

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ESLRM say no soil loss has occurred. And the graph has a linear relation for the two models with ESLRM.

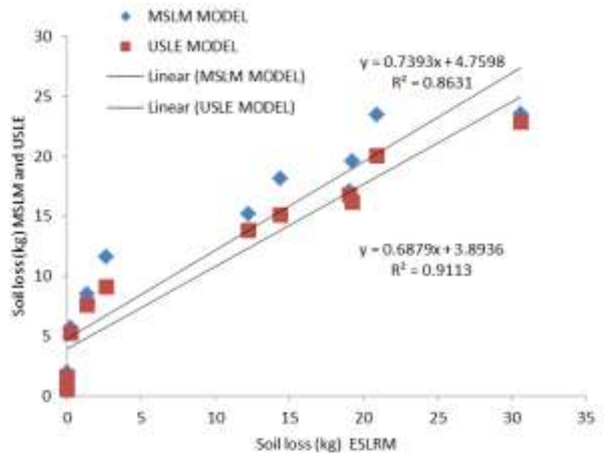

Figure 2: Comparison of ESLRM with MSLM and USLE

MSLM, yield $Y = 0.739x + 4.759$, $with\, R^2 = 0.863$
USLE, yield $Y = 0.687x + 3.893$, $with\, R^2 = 0.911$
Where; x is the independent variable ESLRM.

Take them one by one the soil loss value predicted with MSLM was plotted against soil loss values predicted by ESLRM as shown in Figure 3.

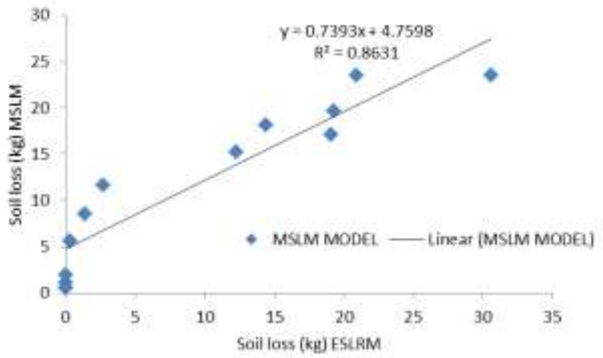

Figure 3: Comparison of Soil Loss from ESLRM and MSLM

Finally, the soil loss values predicted with USLE was plotted against soil loss value predicted by ESLRM as presented in Figure 4.

The graph of Figure 2 was duplicated into Figure 3 and Figure 4 for more clarification and, how their values were represented.

USLE and ESLRM were highly correlated than MSLM and ELSRM. And their percentage error can be expressed as follows;

$$\%error = \frac{0.911 - 0.863}{0.911} * 100 = 5.2\% \approx 5\%$$

Three model are good, but ESLRM is the best and better than others and provide more confident and helpful result in dealing with gully risks etc.

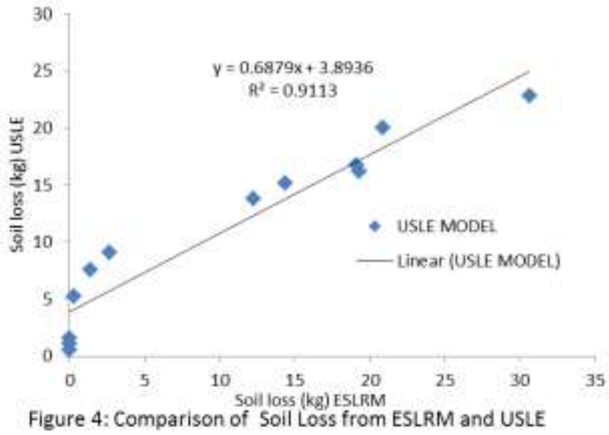

Figure 4: Comparison of Soil Loss from ESLRM and USLE

The results presented as shown in Figures 1 to 4 for the verification of the three models called ESLRM, MSLM and USLE which is used for soil loss prediction in the average sub-catchment of Imo river basin were summarized in Table III. Showing how the model related to each other.

TABLE III. Comparison of Study Models for Soil Loss Prediction

Station Average	Area sqkm	SCS $(m^3/s)/1cm$	ESLRM Similarity Linear Equation	R^2
MSLM	1374.1	19.983068	y = 0.739x + 4.759	0.863
USLE	1374.1	19.983068	y = 0.687x + 3.893	0.911

The periodic amount of soil loss was further studied and the results were plotted against months each and further calibrated it, to get their perfect coefficient of determination R^2 at 6 orders of polynomial trends.

Graphical calibration of the individual models result of soil loss plotted against months of annual soil loss were shown in Figures 5 to 7. ESLRM soil loss result against month was presented in Figure 5.

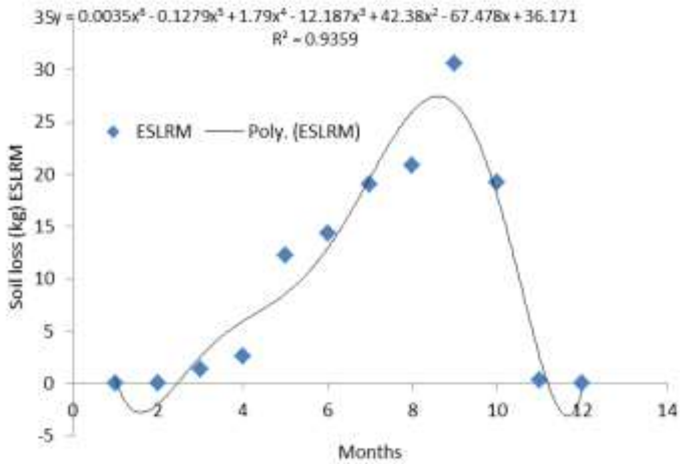

Figure 5: Calibration of ESLRM of 6 Order Polynomial

However, predicted results of soil loss by MSLM plotted against Months were shown in Figure 6.

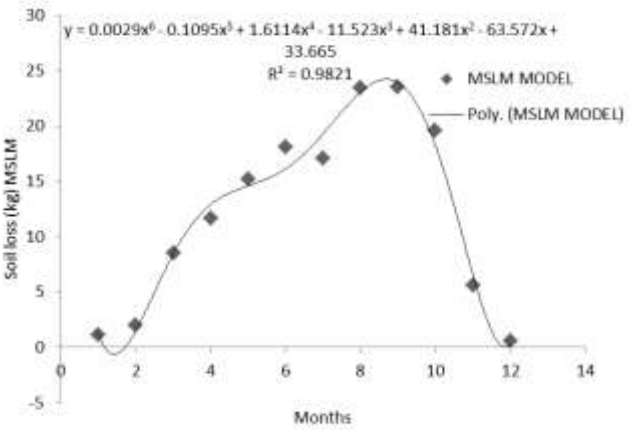

Figure 6: Calibration of MSLM of 6 Order Polynomial

Finally, the predicted soil loss result in the average sub-catchment of Imo river basin with USLE model was plotted against months as shown in Figure 7.

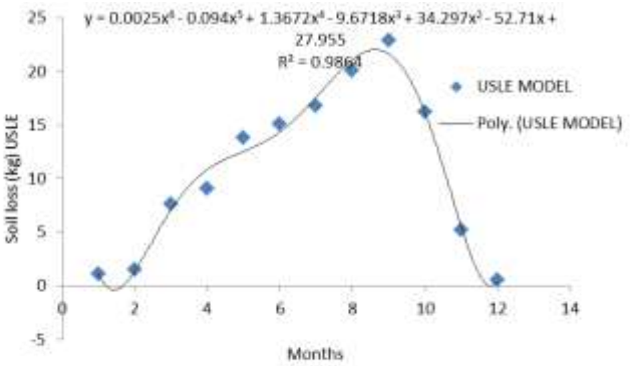

Figure 7: Calibration of USLE of 6 Order Polynomial

However, Figure 5 showing the calibration of ESLRM against months at 6 order of polynomial and that gives 6 order polynomial equations as $y = 0.003x^6 - 0.127x^5 + 1.79x^4 - 12.18x^3 + 42.38x^2 - 67.47x + 36.17$ and R^2 0.935.

Secondly, Figure 6 showing the 6 order polynomial relationship of soil loss value of MSLM against months with 6 order polynomial equation as $y = 0.002x^6 - 0.109x^5 + 1.611x^4 - 11.52x^3 + 41.18x^2 - 63.57x + 33.66$ and R^2 of 0.982.

Finally, Figure 7 shows the calibration of Soil loss predicted with USLE model against month at 6 order polynomial and equation of the relation as $y = 0.002x^6 - 0.094x^5 + 1.367x^4 - 9.671x^3 + 34.29x^2 - 52.71x + 27.95$ and R^2 of 0.986.

The results presented in Figures 5 to 7 for the calibration of the three models called ESLRM, MSLM and USLE as used for soil loss prediction in the average sub-catchment in Imo river basin were summarized in Table IV. The figure shows how the model related to the period of soil loss in year with their calibration equation of 6 orders of polynomial, R^2 values and total amount of soil loss for each model.

And Table IV shows the total amount of soil loss of each model and the R^2 and yield equation of soil loss of 6 order polynomial.

Looking at their R^2 as 0.935, 0.982 and 0.986 for ESLRM, MSLM and USLE model respectively USLE has the perfect uniform curve followed by MSLM and ELSRM which have irregular shape because it is true natural occurrence of soil loss, which is highly recommended, for soil loss prediction to any catchment in erosion study.

TABLE IV. Calibration of study Models for Soil Loss Prediction

Station AVERAGE	Area sqkm	SCS (m^3/s)/1cm	Calibrated Equation of 6 order of polynomial	R^2	Total amount of Soil Loss ton/km^2/year
ESLRM	1374.1	19.983068	$y = 0.003x^6 - 0.127x^5 + 1.79x^4 - 12.18x^3 + 42.38x^2 - 67.47x + 36.17$	0.935	120.784
MSLM	1374.1	19.983068	$y = 0.002x^6 - 0.109x^5 + 1.611x^4 - 11.52x^3 + 41.18x^2 - 63.57x + 33.66$	0.982	146.4176
USLE	1374.1	19.983068	$y = 0.002x^6 - 0.094x^5 + 1.367x^4 - 9.671x^3 + 34.29x^2 - 52.71x + 27.95$	0.986	129.8045

IV. CONCLUSION

The field parameters were well studied and their values obtained. The three models ESLRM, MSLM and USLE were used for the soil loss prediction in the average Imo river basin sub-catchment, on monthly bases and their summation give the total amount of soil loss per annual. The amount of soil loss per annual from the three models are 120.784 ton/km^2/year, 146.4176 ton/km^2/year and 129.8045 ton/km^2/year respectively while on September as the month we have highest rainfall as a reference point when is expected risk to occur the models yields the following amount of soil loss; 30.61873 metric tones km^{-2} $month^{-1}$, 23.521 metric tones $km^{-2}month^{-1}$, and 22.701 metric tones km^{-2} $month^{-1}$ respectively.

The R^2 on comparison of MSLM and USLE against ESLRM give 0.863 and 0.911 respectively in liner progression meaning USLE and ESLRM give high correlation than MSLM on the average sub-catchment. But MSLM is on the approximately +/- 5% error which means that they are all within the region of their test of significant but ESLRM is the best helpful tool in dealing with gullies. It shows that on September when a risk is expected to occur, ESLRM is the model that gave high value making it more natural in real life situation.

The coefficient of determination R^2 of the three models with six orders of polynomial of monthly amount of soil loss are 0.935, 0.982 and 0.986 for ESLRM, MSLM and USLE respectively while the area of the average sub-catchment and SCS unit runoff are the same.

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