Formulation of Mechanized Soil Loss Model (MSLM) Verified in Imo River Basin Eastern Nigeria

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Abstract: This study "Formulation of Mechanized Soil Loss Model tested in Imo River Basin in Eastern Nigeria" presented mechanized models to estimate soil loss in gullies and steep terrains applicable to Imo River Basin in Eastern Nigeria. The mechanical properties of soil in the ten sub-catchments in the basin were determined. The model was derived based on continuity principle. MSLM was derived by considering the shear stress of the soil. Equations of gully, rill and interill erosions were incorporated into the model. The derived model was applied in estimating soil loss in the sub-catchment and compared with soil loss estimated from Universal Soil Loss Equation USLE. Model verification was carried out by correlating results from the model and with the USLE values, which gave R^2 values of 0.863 and 0.91 for MSLM and USLE respectively. Test for adequacy showed that there is no significant difference between the MSLM and USLE models at 5% level of significance (4.26) which greater than ANOVA value of 0.42. The total amount of soil loss estimated for the ten sub-catchments using MSLM was 146.4 tons/km^2/month while the USLE gave a lower value of 129.8 tons/km^2/month. The derived models are helpful tools for optimizing soil loss estimation in Imo River Basin. They shall serve as useful tools in planning and design of erosion and sediment control projects in the basin. Finally, it is recommended that further studies be carried out on the universal applicability of the model.
Keywords: Calibration, Catchment, Mechanized, Model, Parameters, Soil Loss, Verification.

Citation: Ibearugbulem, O.H., Okoro, B.C., Osuagwu, J.C. and Nwoke, H.U. 2018. Formulation of Mechanized Soil Loss Model (MSLM) Verified in Imo River Basin Eastern Nigeria. International Journal of Recent Innovations in Academic Research, 2(6): 202-222.

1.1. Introduction

Studies on erosion have over the years contend more on sheet and rill erosion. There have been few studies on nature and extent of development of gullies. Recent studies reveal that gullies are major source of sediment inflow into surface water bodies (Soms, 2001). Consequently, increased rainfall intensity resulting from global warming has worsted the problem of soil erosion. Several hectares of arable Agricultural land are lost as a result of gully development yearly.

In the last quarter of the twentieth (20th) century, the Imo River basin which consists of ten (10) tributaries of different sub-catchments and discharge points with gauging station (G.S), witnessed entrenched valleys in the catchment (AIRBDA, 2014). These channels which gradually eroded into red-earth and unconsolidated geological materials established prominent gullies with near vertical slopes. The Imo River in turn is a tributary and discharge point to the Atlantic Ocean. Those geological materials deposited in the Imo River are transferred to the Atlantic Ocean. The river is about 40km in length with an annual average discharge of $4m^3/s$ with its coverage of 26,000 hectares of wetland (AIRBDA, 2014).

Based on the investigation of this study, history has it that some villages have been split into two or three because their bridges have long ago been destroyed by the effect of excess runoff in their river and widened their riverbank such that the local method of construction of the bridge cannot hold again. While some gully erosion has succeeded in making some communities inaccessible from each other. Some villages now answer different names; e.g. in Umuezegwu; Ihitte/Uboma LGA, we have a town called Umuode and Umuode-ofeugwu. Also in Owerri North LGA, we have a town called Nekede and Nekede Old road.

There are lots of gully erosion problems and continuous soil loses along the tributaries of Imo river drainage basin. More than sixteen gully sites in Imo state have been in sad and unbearable conditions, and reconstructions have commenced on some with little knowledge of River Engineering. People have been employing the use of Universal Soil Loss Equation (USLE) model, and Revised Universal Soil Loss Equation (RUSLE) and measuring method in determining the quantity of soil loss in a chment which cannot be applied in gully and steep regions. The USLE does not predict accurate soil loss in this part of the world because it was primarily developed for United States of America soil. The mechanized model for soil loss in Imo River basin with respect to Interrill, rill, and gully soil loss need to be developed.

1.2 Geology of Imo State

The study area is underlain by the Coastal Plain Sands consisting of the Ogwashi-Asaba and Benin Formations. The Benin Formation (Miocene-Recent) is an extensive Isopach map in the Southern Nigerian Sedimentary Basins. It has been earlier referred to as the Coastal Plain Sands (Simpson, 2000)

Within the study area, the average thickness of the Benin Formation is l000m as shown by the Isopach map of the area (Figure 1).

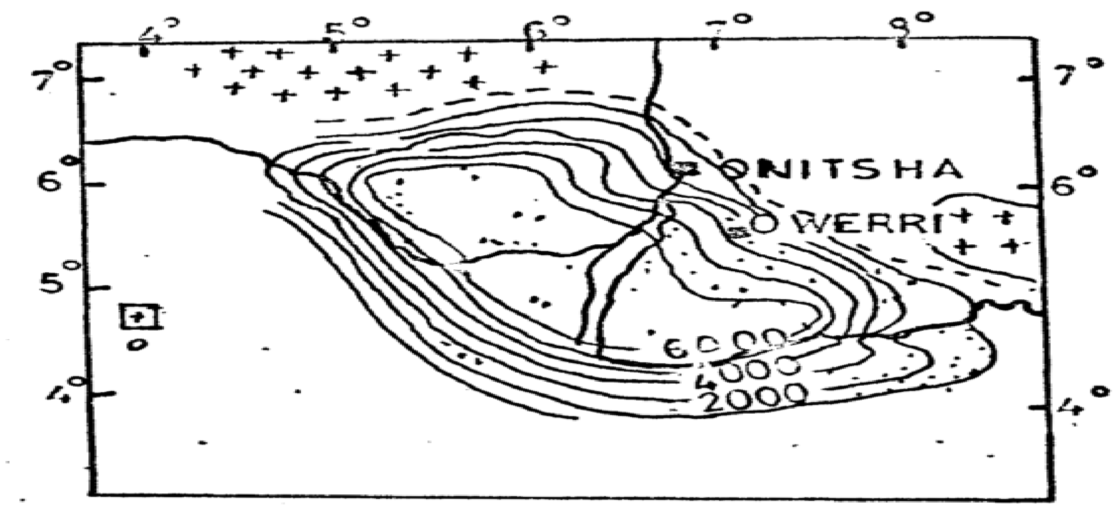

Figure 1. Isopach Map of Benin Formation, Source: Avbovbo (1993)

Volume-2, Issue-6, October-2018: 202-222
International Journal of Recent Innovations in Academic Research ISSN: 2635-3040

The LeGrand (2000), GOD (Foster, 2002), SIGA (Vrba, 1991), and DRASTIC (Allen *et al.*, 2002) were computer models used for vulnerability analysis of the Owerri study area. They were applied to each of the five sub-areas (Blocks A-E) covering the study area (Figure 1). Each subdivision was defined by separate geological, hydrostratigraphic, and land-use criteria.

1.3 Location of Study Area

The study area is located in Imo State, Nigeria. Imo State derives its name from Imo River, which takes its course from the Okigwe, Imo State upland. It lies within latitudes 04°52'N and 05°47'N, and longitude 07°02'E and 07°26'E. The map of Imo river basin is as shown in Figure 2. The Imo River (Igbo: Imo Mmiri) is in southeastern Nigeria and flows 240 kilometres (150 mi) into the Atlantic Ocean. Its estuary is around 40 kilometres (25 mi) wide, and the river has an annual discharge of 4km^3/yr (1.0 cu mi or 126.84m^3/s) with 26,000 hectares of wetland (Russell, 1993).

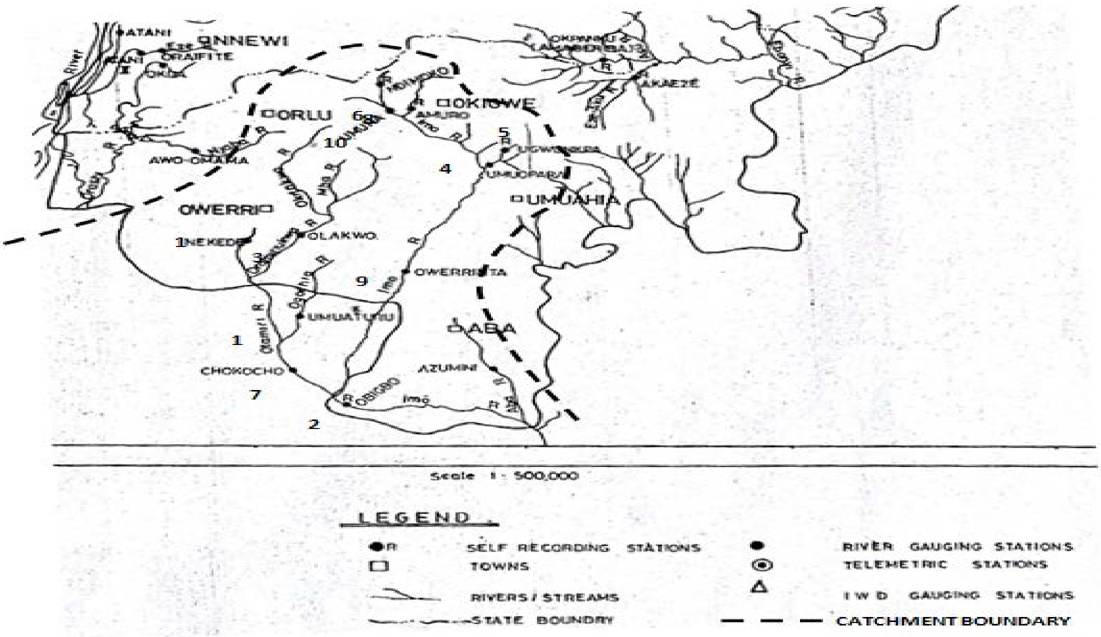

Figure 2. Location of gauging station along rivers in Imo River Basin Sources: AIRBDA (2014)

2.0 Design Study

This study concentrated on the formulation of mechanized soil loss model (MSLM) of Imo River basin with respect to Interrill, rill, and gully soil loss. The parameters used in the model development include, rainfall intensity, slope of the catchment, catchment area, duration of rainfall, watershed length, density of soil, organic matter content in the soil, clay content in the soil and runoff. The runoff was by the help of Soil Conservation System (SCS).

The study covered Erosion site investigation and laboratory soil test and determination of hydraulic depth R. This was done in each of the various sub-catchment of the basin.

The total soil loss of each sub-catchment was determined by the Mechanized Soil loss Model (MSLM) and Universal Soil loss Equation (USLE). The two results were compared with the statistical tool ANOVA.

2.1 Determination of mechanical properties of Soil in the catchment

Here the soil properties including angle of internal friction, cohesion, clay content, density and organic content were determined. Soil samples were collected from the three difference holes from each gully site (Owerri West, Achara Obowo, Uturu Okigwe, Agbaghara Nsu, Umuopara – Nzerem, Ibeafor Umunumu, Ihitte Ubi/Oparanadim of Ahiazu L.GA, Emekuku Owerri North, Afor Ukwu–Afor Nta Market, Isiekenesi–Dikenafai and Agbaghara–Umuopara) for laboratory tests.

2.1.3 Determination of Soil Bulk Density

Soil Sample was collected in the catchment and compacted into a cylinder and placed in a weighing container and weighed. The weight of the wet soil + container + cylinder was recorded as W_1. The weight of the container was recorded as W_2 and the weight of the cylinder as W_3. These weights (W_2 and W_3) were measured before sampling and after drying. The Samples were then dried in an oven at 1050C overnight. The weight of the oven dry sample, container and cylinder was W_4. The wet weight W_1 was used to calculate the moisture content at time of sampling. (Garg, 2013).

Calculation of the bulk density.

$$D_b = \frac{W_4 - W_2 - W_3}{Vol. of\ Cylinder} \qquad (1)$$

And Moisture content

$$\theta_V = W_1 - \frac{(W_4 - W_2 - W_3)}{W_4 - W_2 - W_3} * D_b \qquad (2)$$

2.1.4 Angle of Internal Friction and Cohesion

A disturbed soil sample was used in tri-axial machine and the major principal stress σ_1 and the minor principal stress σ_3 were obtained. Then Mohr circle diagrams were used in obtaining the failure plane as shown in Figure 3. The circle diameter is taken as the difference between the major and minor principal stresses (σ_1 - σ_3).

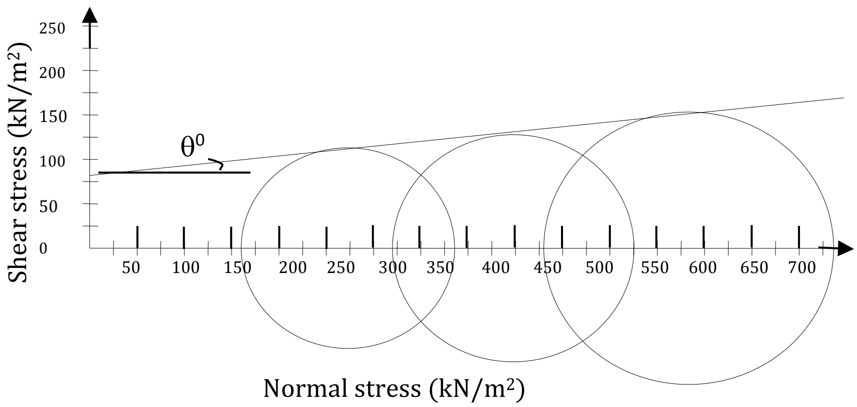

Figure 3. Typical Mohr Circles

The first point along the horizontal axis for each circle is the minor principal stress, σ_3, and the last point along the horizontal axis is the major principal stress, σ_1 along horizontal axis. This envelop cut the vertical axis at a point called the cohesion of the soil. After drawing the circles, a straight line that touched the circles at tangents (this is called envelop) was drawn. The inclined plane (envelop) made angle,θ, (called angle of internal friction) with the horizontal axis. (Ibearugbulem *et al.* 2017).

2.2 Determination of Discharge per unit rainfall depth in the Catchment

2.2.1 SCS Dimensionless Unit Hydrograph

The Soil Conservation Society (SCS) method develops a synthetic dimensionless hydrograph. Under this approach the peak discharge, q_p is computed thus:

$$q_p = \frac{CA}{T_p} \qquad (3)$$

where: C is runoff coefficient, A is the catchment area in (km^2), T_p is Time to peak on rising side.

The peak discharge and lag time, the unit hydrograph is estimated the synthetic hydrograph for the basin.

2.2.2 Time To Peak of Discharge, T_P

Time to peak of discharge, T_p is calculated using Equation (4).

$$T_p = \frac{D}{2} + 0.6T_c = \frac{2}{3}T_c \qquad (4)$$

Where D is the average duration of excess rainfall given as:

$$D = 0.133T_c \qquad (5)$$

And T_c is time of concentration in minutes.

Time of concentration, T_c is determined from equation for lag time, T_L given as:

$$T_L = 0.6T_c \qquad (6)$$

Equation for calculating lag time in (hours) is also given as:

$$T_L = \frac{L^{0.8}((S+1)^{0.7})}{1900\sqrt{y}} \qquad (7)$$

Where L is hydraulic length of watershed in feet.
S is maximum retention in the watershed in inches
y is watershed slope in percent.

Two other ways of determining time of concentration are by the Kirpich formula and the SCS lag formula. The Kirpich Formula is;

$$T_c = 0.0195\, L^{0.77} S^{-0.385} \qquad (8)$$

L is maximum length of flow in meters.
S is the watershed gradient in m per m or the ratio of the difference in elevation between the outlet and the most remote point to the length between them.

The Soil Conservation Society (SCS) method Lag Formula is given as:

$$T_c = 0.00526\, L^{0.8}(1000\,/CN\, - 9)^{0.7} S^{-0.5} \qquad (9)$$

Where L is watershed length (m).

S is watershed slope (m/m)
CN is SCS curve number for the watershed given as: CN is 92 Michigan (2011).

2.2.3 The peak discharge, Q_p

The peak discharge, Q_p in cubic meters per seconds per cm depth of rainfall is given by the relation;

$$Q_p = \frac{2.78C_pA}{T_p} \quad (10)$$

A is area of basin in km^2
C_p is Coefficient which depends upon the retention and storage characteristics of basin. Its value varies from 0.3 to 0.93
.

3.1 Formulation of Mechanized Soil Loss Model

The mechanized model for soil loss was based on the governing Sediment Continuity Equation by Okoro, *et al.* (2013) given as in Equation (11);

$$\int_0^A \frac{dq_{sb}}{dA} = \int_0^A \frac{q_{ie}}{dA} + \int_0^A \frac{q_{re}}{dA} \quad (11)$$

where
A is 2D horizontal distance down slope (Area of Catchment) (m^2).
q_{sb} is sediment load (kg s^{-1} m^{-2}).
q_{ie} is interrill erosion rate (kg s^{-1} m^{-2}).
q_{re} is rill erosion rate (kg s^{-1} m^{-2}).

Integrating Equation (11), with respect to A as independent variable, the sediment load is model transport capacity and the equation is as shown in Equation (12);

$$q_{sl} = q_{ie}A + q_{re}A + C \quad (12)$$

C is constant of integration ($kgkm^{-2}$)
q_{re} is rill erosion rate (kg $s^{-1}km^{-2}$)
q_{ie} is interrill erosion rate (kg $s^{-1}km^{-2}$)
A is integration independent value (s)

C is amount of soil loss on gully erosion, measured in kg/km^2 and is denoted as q_g. In the similar way $q_{re}A$ is soil loss on rill erosion, measured in kg/km^2 is denoted as q_r, while $q_{ie}A$ is amount of soil loss on interrill erosion, measured in kg/km^2 is denoted as q_i. Substituting these terms into Equation (12) gives the model equation as shown in Equation (13).

$$q_{sl} = q_g + q_i + q_r \quad (13)$$

Where q_{sl} is Amount of soil loss in the catchment, measured in kg/km^2.
Treating Equation (13) term by term we have the following processes;

First term: Take q_g as the first term in the Equation (13), which serve as the volume of soil loss in gully channel and are unpredictable, more especially in alluvium soil mass. According to Okoro *et al.*, (2013) is given as;

$$q_g = K_t\tau_fV_c \quad (14)$$

Where $\tau_f = \gamma SR\left(\frac{f_s}{f_t}\right)$ *and* $V_c = \sqrt{gR}$
Substituting the values of τ_f and V_c into Equation (14) yield Equation (15) as follows;

Volume-2, Issue-6, October-2018: 202-222
International Journal of Recent Innovations in Academic Research ISSN: 2635-3040

$$q_g = K_t * \gamma_w S_f R \left(\frac{f_s}{f_t}\right) * \sqrt{gR} \qquad (15)$$

Second term: The second term q_r is the soil loss due to rill erosion were the runoff have increase more than the sheet flow and its flow is moving in gully channel where the flow will finally develop into a full tributary flow to the natural channel river. This channel is considered as rill channel because it is less than 1m deep. Okoro *et al.* (2013) gave the equation for this as;

$$q_r = q_c \left[1 - \frac{q_{sb}}{q_g}\right] \qquad (16)$$

where $q_{sb} = \phi * \omega * d(1 - \mu)$ and $q_c = K_r(\tau_f - \tau_c)$

From the empirical model variable, putting the values of q_{sb}, q_c and value of q_g in Equation (15) will yield to us Equation (17) as follows;

$$q_r = k_r(\tau_f - \tau_c) * \left[1 - \frac{\phi\omega d(1-\mu)}{K_t * \gamma_w S_f R\left(\frac{f_s}{f_t}\right) * \sqrt{gR}}\right] \qquad (17)$$

where $\phi = K_e\left\{\frac{1}{\psi} - \frac{1}{\psi_c}\right\}$

Substituting the values of τ_c, τ_f and ϕ into Equation (17) gives:

$$q_r = k_r\left(\gamma_w S_f R\left(\frac{f_s}{f_t}\right) - \gamma_w RS\right) * \left[1 - \frac{k_e\left\{\frac{1}{\Psi} - \frac{1}{\Psi_c}\right\}^p \omega d(1-\mu)}{K_t * \gamma_w S_f R\left(\frac{f_s}{f_t}\right) * \sqrt{gR}}\right] \qquad (18)$$

Ψ_c according to Okoro *et al*. (2013) is negligible and p is a constant given as 3. With these, Equation (18) becomes:

$$q_r = k_r \gamma_w R\left(S_f\left(\frac{f_s}{f_t}\right) - S\right) * \left[1 - \frac{k_e\left\{\frac{1}{\Psi}\right\}^3 \omega d(1-\mu)}{K_t * \gamma_w S_f R\left(\frac{f_s}{f_t}\right) * \sqrt{gR}}\right] \qquad (19)$$

Third term: The third term is the sheet erosion value q_i, which was given in the works of Okoro *et al*. (2013) as:

$$q_i = k_i I_e^2 C_e G_e \left(\frac{R_s}{w}\right) \qquad (20)$$

Then substituting Equation (15), (19) and (20) into Equation (13) gave Equation (21);

$$q_{sl} = K_t \gamma_w S_f R\left(\frac{f_s}{f_t}\right)\sqrt{gR} + k_i I_e^2 C_e G_e\left(\frac{R_s}{w}\right) + k_r \gamma_w R\left(S_f\left(\frac{f_s}{f_t}\right) - S\right) * \left[1 - \frac{k_e\left\{\frac{1}{\Psi}\right\}^3 \omega d(1-\mu)}{K_t \gamma_w S_f R\left(\frac{f_s}{f_t}\right)\sqrt{gR}}\right] \qquad (21)$$

Where K_t is gully erodibility or sediment transport erodibility, K_r is rill erodibility (sm^{-1}) factor, K_i is interrill erodibility, k_e is effective saturated conductivity, ω is the fall velocity of the sediment grains, d is the sediment grain size, μ is alluvium porosity, γ_w is unit weight of the water, g is acceleration due to gravity, f_s/f_t for a wide channels, is taken as 0.7, R is the hydraulic radius, S_f is slope along the wide channel, Ψ is a dimensional parameter, I_e is effective rainfall intensity, C_e is the effect of canopy on interrill erosion, G_e is the effect of ground cover on interril erosion, R_s is the average spacing between one rill and the other, S is

slope along the channel either rill or interrill or gully, and w is the average width of the rill in the catchment.
Equation (21) is the general mathematical model for soil loss used in this study. The variables vary in the different sub-catchment in Imo river basin and for the ten sub-catchments, simplified mechanized models was developed.

Soil characteristics, dimensionless factor of soil erodibility and erosion coefficient determination of soil in this work were from ASAE and manning's rainfall simulator plots from Engman and Stone, (2002).

3.2 Universal Soil Loss Equation (USLE) Model:

There is therefore the need the developed mathematical relation that develops the erosion process and prevents losses resulting there from. Control measures applied against surface erosion are derived from Universal Soil Loss Equation (U. S. L. E.) by Wischmeier, and Smith, (1993). The soil loss quantity, A (measured in ton/acre) on a slope from sheet erosion, according to U. S. L. E is as a result heavy shower within a period (normally in years). This is defined by six factors and given mathematically as:

$$A = K * R * P * C * (LS) \qquad (22)$$

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

Using of appropriate conservative farming practices helped in mitigating soil losses in farm lands. On no account should expected reduction on P (in contouring) be greater than 0.25. However, vegetation cover factor and topography factor are the only two factors that can be totally modified.

4.0 Results And Discussions

4.1 River Basin soil's Mechanical Properties

The summary of the results of the catchment and the soil in the gully sites like Slope S, Increase Slope S_f, Organic Content %, Clay Content %, Friction ϕ^0, Cohesion C (kN/m^2), Density (kN/m^3); are presented on Table 1.

Table 1. Soil characteristics of different gully locations

Location	Slope S	S_f = 130% S	Organic content %	Clay content %	Friction $\phi(^0)$	Cohesion C (kN/m^2)	Density (kN/m^3)
Owerri West L.G.A (Chokocho and Oyigbo G.S.)	0.0320	0.0416	34	13.5	24	21	19.8
Achara Obowo Erosion Site (Owerrinta G.S)	0.0250	0.0325	10	4.8	24.65	7.50	19.9
Uturu Okigwe (Ndimoko G.S)	0.0510	0.0663	14	6.89	30.92	10.75	20.1
Agbaghara Nsu (Ulakwu G.S.)	0.0350	0.0455	18	9.2	28.32	15.3	20.1
Umuopara–Nzerem (Ulakwu G.S)	0.0160	0.0208	13	12.2	25.2	21.3	19.9
Ibeafor Umunumu	0.0317	0.0412	32.5	13.5	23.75	20.67	18.9

(Umuopara and Ugwunkpa G.S.)							
Ihitte Ubi/ Oparanadim of Ahiazu L.GA (Umuaturu and Umuopara G.S.)	0.0620	0.0806	34	13.25	24.5	21.25	18.9
Emekuku Owerri North LGA (Nekede G.S)	0.0352	0.0458	22.7	14.4	24	21	19.8
Afor Ukwu – Afor Nta Market (Amuro G.S.)	0.0100	0.013	31.5	14.5	23.75	21.67	19.9
Isiekenesi – Dikenafai (Umunna G.S.)	0.0172	0.0224	32.5	13.4	23.75	20.7	19.8
Agbaghara – Umuopara (Ndimoko G.S)	0.0620	0.0806	32.5	13.6	23.75	20.67	19.9
Average values (Oyigbo G.S.)	0.0343	0.0446	24.97	11.75	25.14	18.35	19.73

Where G.S. = Gauging Station

4.2 Discharge Per Unit Rainfall Depth

The geographical location parameters of the Gauging stations are presented on Table 2, with the discharge per unit rainfall depth using SCS method.

Table 2. Catchment and Gauging Station with SCS discharge

River System	River/station	Station	Area sqkm	LAT.	LONG	SCS (m^3/s)/1cm
Imo 1	Otamiri	Nekede	100	$05^{0}26^{1}$N	$07^{0}02^{1}$E	4.974478
Imo 2	Imo	Oyigbo	5600	$04^{0}52^{1}$N	$07^{0}11^{1}$E	74.11396
Imo 3	Oramiriukwu	Ulakwo	795	$05^{0}25^{1}$N	$07^{0}07^{1}$E	9.519669
Imo 4	Imo	Umuopara	1450	$05^{0}33^{1}$N	$07^{0}25^{1}$E	19.52488
Imo 5	Eme	Ugwunkpa	230	$05^{0}35^{1}$N	$07^{0}26^{1}$E	7.102296
Imo 6	Imo	Umunna	490	$05^{0}47^{1}$N	$07^{0}18^{1}$E	8.421503
Imo 7	Otamiri	Chokocho	2700	$04^{0}59^{1}$N	$07^{0}03^{1}$E	35.80209
Imo 8	Law-law	Amauro	63	$05^{0}47^{1}$N	$07^{0}13^{1}$E	1.403483
Imo 9	Imo	Owerrinta	2263	$05^{0}09^{1}$N	$07^{0}06^{1}$E	35.10194
Imo 10	Imo	Ndimoko	50	$05^{0}47^{1}$N	$07^{0}13^{1}$E	3.866385
Average Area And Discharge			1374.1			19.983068

Table 3, shows the flood discharge based on 1 cm drop of water multiplied by monthly rainfall intensity in cm (m^3/sec) that occurred at the ten (10) gauging station sub-catchment of the basins in Nekede, Oyigbo, Ulakwo, Umuopara, Ugwunkpa, Umunna, Chokocho, Amauro, Owerrinta and Ndimoko.

Table 3. Flood Discharge based on 1 cm depth of water multiplied by monthly rain intensity in cm (m^3/sec)

Month	NEK	OYI	ULA	UMP	UGWU	UMN	CHO	AMA	OWE	NDI
Jan	10.38	154.62	19.86	40.73	14.82	17.57	74.69	2.93	73.23	8.07
Feb	15.82	235.71	30.28	62.10	22.59	26.78	113.87	4.46	111.64	12.30
Mar	77.40	1153.15	148.12	303.79	110.51	131.03	557.05	21.84	546.16	60.16
Apr	92.57	1379.14	177.15	363.33	132.16	156.71	666.22	26.12	653.19	71.95
May	138.32	2060.80	264.70	542.91	197.49	234.17	995.51	39.03	976.04	107.51
Jun	144.29	2149.74	276.13	566.34	206.01	244.27	1038.47	40.71	1018.16	112.15
Jul	155.49	2316.68	297.57	610.32	222.01	263.24	1119.11	43.87	1097.23	120.86

Aug	186.77	2782.67	357.42	733.08	266.66	316.19	1344.22	52.69	1317.93	145.17
Sep	213.83	3185.79	409.20	839.28	305.29	362.00	1538.95	60.33	1508.86	166.20
Oct	155.89	2322.61	298.33	611.88	222.57	263.92	1121.98	43.98	1100.04	121.17
Nov	51.45	766.49	98.45	201.93	73.45	87.10	370.27	14.51	363.03	39.99
Dec	4.87	72.63	9.33	19.13	6.96	8.25	35.09	1.38	34.40	3.79
Ann.	1247.08	18580.03	2386.54	4894.82	1780.52	2111.23	8975.43	351.85	8799.91	969.32

Legend: NEK = Nekede; OYI = Oyigbo; ULA = Ulakwo; UMP = Umuopara; UGWU = Ugwunkpa ; UMN = Umunna; CHO = Chokocho; AMA = Amauro; OWE = Owerrinta; NDI = Ndimoko

4.3 Soil Loss Models

4.3.1 Mechanized Soil Loss Model (MSLM)

The Mechanized Soil loss Model (MSLM) was formulated as shown on Equation (21):

4.3.2 Universal Soil Loss Equation, U. S. L. E.

Slope length factor equation in USLE model is presented herein as:

$$LS\ factor = 1.4\left(\frac{As}{22.13}\right)^{0.4} * \left(\frac{Sin\beta}{0.0896}\right)^{1.3} \qquad (23)$$

The Soil classification and model parameters of the eleven (11) gully site locations in the basin are presented in Table 4.

Table 4. Soil classification and model parameters of gully locations

	Location	Soil parameter	k_i	k_r	k_t	ψ	Density (kN/m^3)
1	Owerri West L.G.A (Chokocho and Oyigbo G.S.)	CLSSi	908719	0.00329	0.0935	150	19.8
2	Achara Obowo Erosion Site (Owerrinta G.S)	CS	1306278	0.00400	0.0851	180	19.9
3	Uturu Okigwe (Ndimoko G.S)	CS	1306278	0.00400	0.0853	180	20.1
4	Agbaghara Nsu (Ulakwu G.S.)	SCSi	1306278	0.00400	0.0853	225	20.1
5	Umuopara – Nzerem (Ulakwu G.S)	SCSi	1306278	0.00400	0.0851	183	19.9
6	Ibeafor Umunumu (Umuopara and Ugwunkpa G.S.)	SiSC	1306278	0.00400	0.0911	225	18.9
7	Ihitte Ubi/ Oparanadim of Ahiazu L.GA (Umuaturu and Umuopara G.S.)	SiSC	1306278	0.00400	0.0911	225	18.9
8	Emekuku Owerri North LGA (Nekede G.S)	CLS	134308	0.00359	0.0935	120	19.8
9	Afor Ukwu – Afor Nta Market (Amuro G.S.)	SiSC	1306278	0.00400	0.0851	225	19.9
10	Isiekenesi – Dikenafai (Umunna G.S.)	SiSLC	908719	0.00329	0.0935	168	19.8
11	Agbaghara – Umuopara (Ndimoko G.S)	SCSi	1306278	0.00400	0.0935	225	19.9
12	Average values		1127451.82	0.00383	0.0893	191.45	19.73

Legend: G.S. = Gauging Station, C = Clay, S = Sand, Si = Silty, L = Loam

Volume-2, Issue-6, October-2018: 202-222
International Journal of Recent Innovations in Academic Research
ISSN: 2635-3040

The Universal soil loss equation (USLE) variables for the sub-catchments and Mechanized Soil Loss Model (MSLM) variables for the same sub-catchments are presented on Table 5.

Table 5. Catchment model variables of MSLM and USLE

Station	Area (sq km)	As	LS	S	S_f	k_i	k_r	k_t	ψ	K	C	P	SCS $(m^3/s)/1cm$
Nekede	100	8862.27	6.433	0.0352	0.0458	134308	0.00359	0.0935	120	0.33	0.45	0.5	4.974478
Oyigbo	5600	66319.15	13.9	0.0343	0.0446	1127451.82	0.00383	0.0893	192	0.69	0.6	0.6	74.11396
Ulakwo	795	24987.83	6.3952	0.0255	0.03315	1306278	0.00400	0.0852	204	0.44	0.28	0.6	9.519669
Umuopara	1450	33746.52	15.9024	0.0469	0.0609	1306278	0.00400	0.0911	225	0.61	0.3	0.6	19.52488
Ugwunkpa	230	13440.29	6.6201	0.0317	0.0412	1306278	0.00400	0.0911	225	0.33	0.4	0.6	7.102296
Umunna	490	19617.47	3.488	0.0172	0.0224	908719	0.00329	0.0935	168	0.36	0.4	0.6	8.421503
Chokocho	2700	46049.70	10.9711	0.0320	0.0416	908719	0.00329	0.0935	150	0.68	0.45	0.6	35.80209
Amauro	63	7034.21	1.141	0.0100	0.0130	1306278	0.00400	0.0851	225	0.33	0.3	0.5	1.403483
Owerrinta	2263	42158.70	7.6832	0.0250	0.0325	1306278	0.00400	0.0851	180	0.61	0.55	0.6	35.10194
Ndimoko	50	6266.561	10.3452	0.0565	0.07345	1306278	0.00400	0.0894	203	0.33	0.4	0.5	3.866385
Average	1374.1	32851.44	10.62	0.0343	0.0446	1127451.82	0.00383	0.0893	191.45	0.61	0.41	0.5	19.983068

4.4 Chart Comparison of MSLM and USLE

Soil losses predicted from MSLM and USLE were plotted as presented on Fig. 4 to 14.

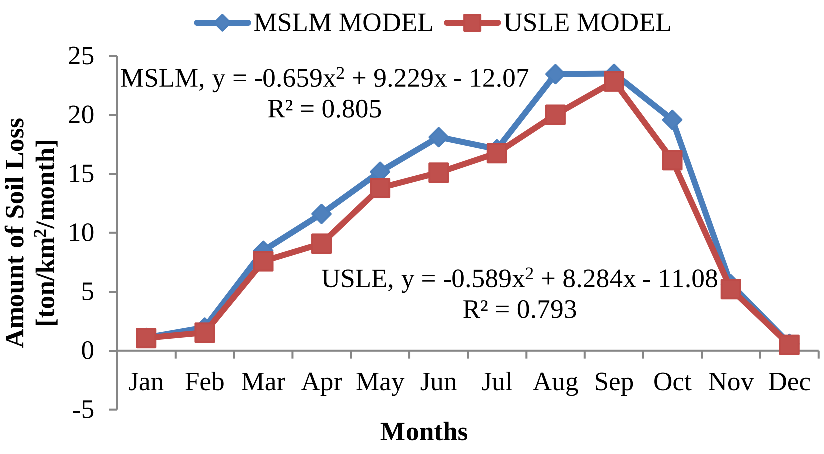

Figure 4. Average Monthly Amount of Soil loss on Catchments predicted from MSLM and USLE Model

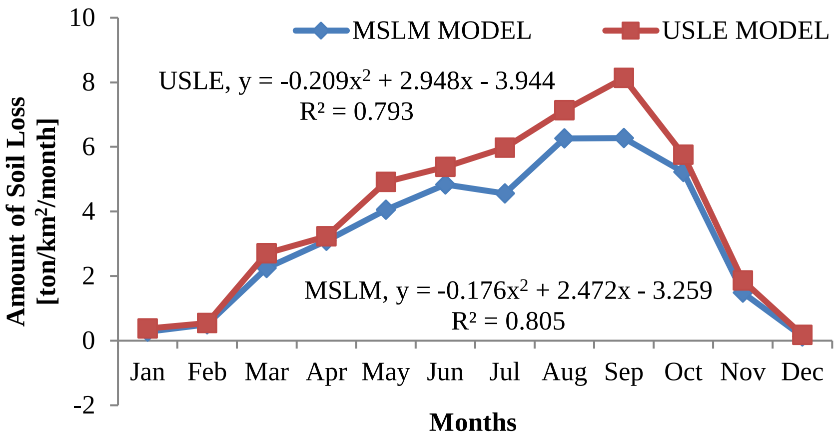

Figure 5. Monthly Amount of Soil loss on Nekede G.S. Catchment predicted from MSLM and USLE Model

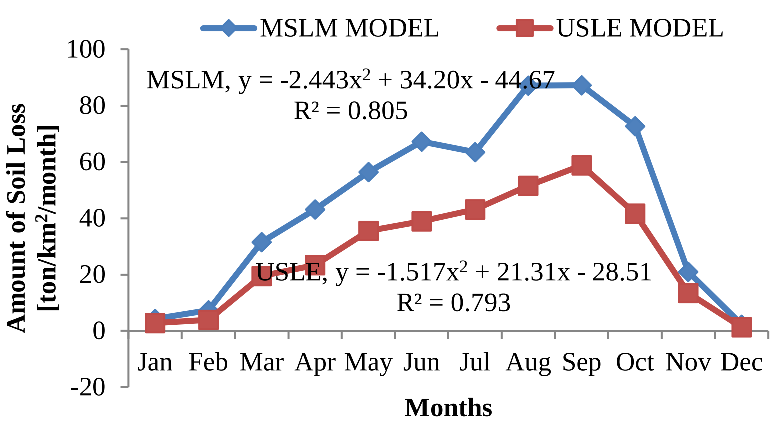

Figure 6. Amount of Soil loss on Oyigbo G.S. Catchment predicted from MSLM and USLE Model

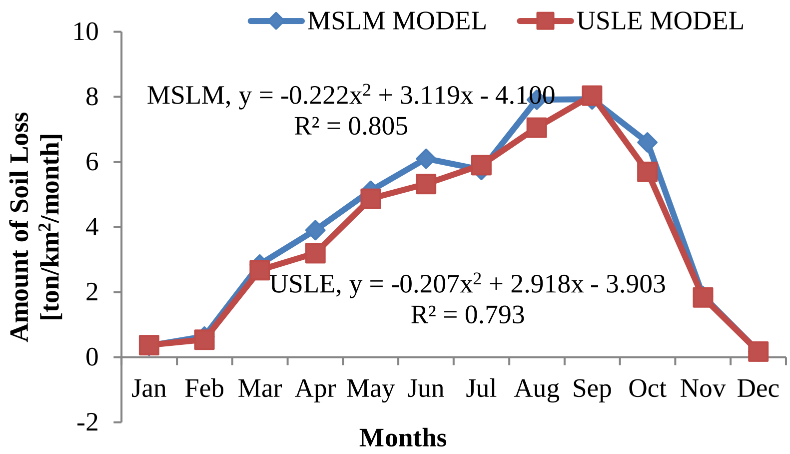

Figure 7. Amount of Soil loss on Ulakwo G.S. Catchment predicted from MSLM and USLE Model

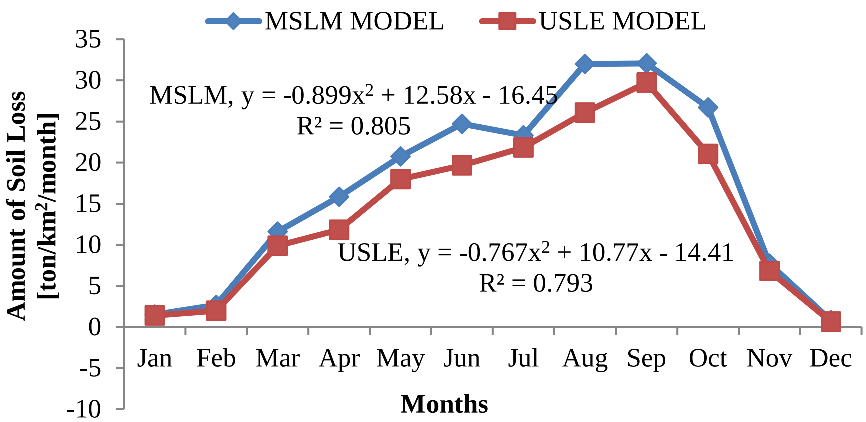

Figure 8. Amount of Soil loss on Umuopara G.S. Catchment predicted from MSLM and USLE Model

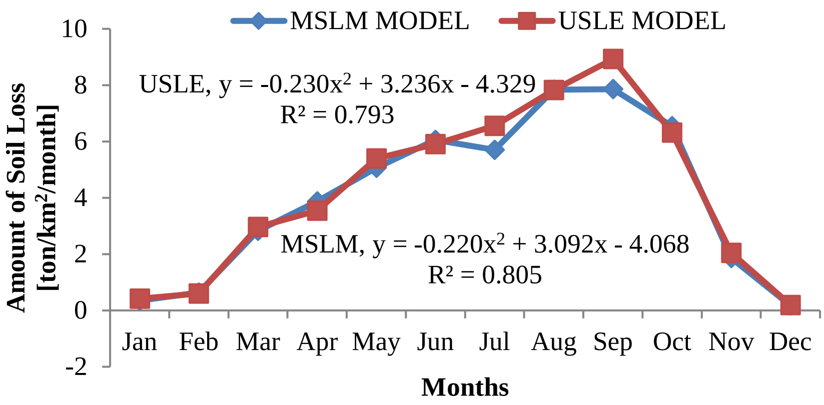

Figure 9. Amount of Soil loss on Ugwunkpa G.S. Catchment predicted from MSLM and USLE Model

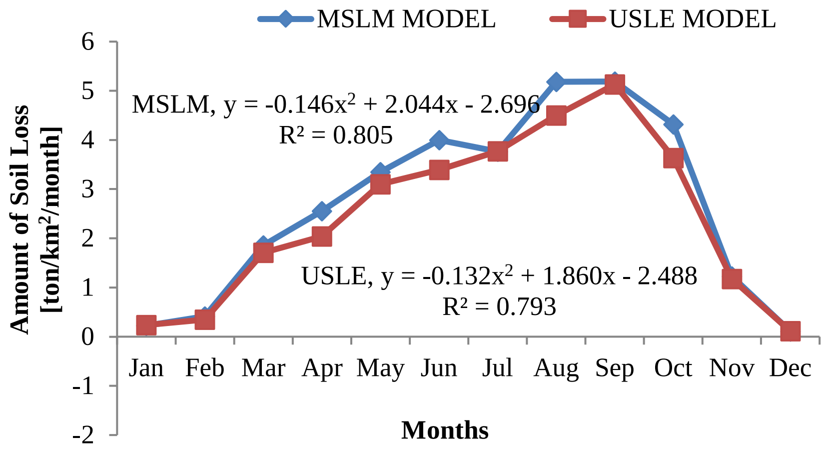

Figure 10. Amount of Soil loss on Umunna G.S. Catchment predicted from MSLM and USLE Model

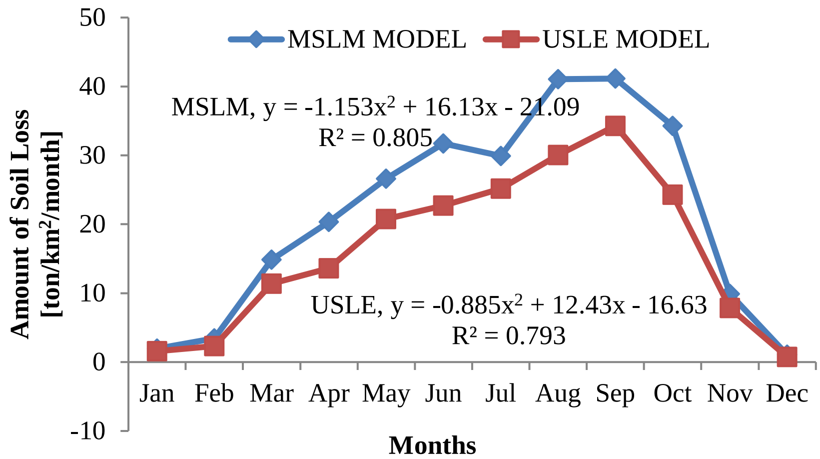

Figure 11. Amount of Soil loss on Chokocho G.S. Catchment predicted from MSLM and USLE Model

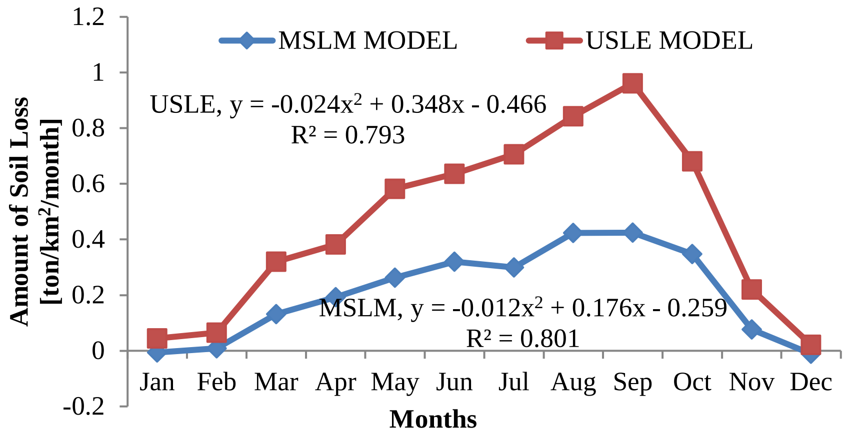

Figure 12. Amount of Soil loss on Amauro G.S. Catchment predicted from MSLM and USLE Model

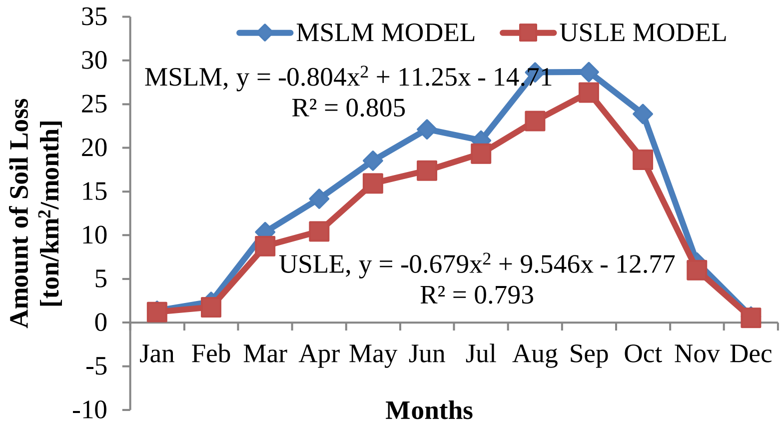

Figure 13. Amount of Soil loss on Owerri-nta G.S. Catchment predicted from MSLM and USLE Model

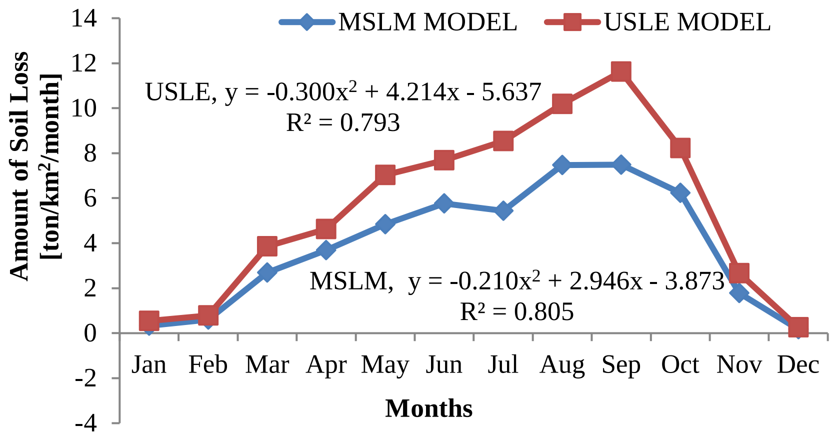

Figure 14. Amount of Soil loss on Ndimoko G.S. Catchment predicted from MSLM and USLE Model

The amount of soil losses from calibrated model equations for different catchments were present on Table 6.

Table 6. Comparison of MSLM and USLE model

Station	Area sq km	MSLM Calibrated Model	R^2	USLE Calibrated Model	R^2	Total amount of Soil Loss MSLM|USLE		% Diff.
Nekede	100	$y = -0.176x^2 + 2.472x - 3.259$	0.805	$y = -0.209x^2 + 2.948x - 3.944$	0.793	38.9	46.2*	-18.77
Oyigbo	5600	$y = -2.443x^2 + 34.20x - 44.67$	0.805	$y = -1.517x^2 + 21.31x - 28.51$	0.793	543.7	333.9	38.59
Ulakwo	795	$y = -0.222x^2 + 3.119x - 4.100$	0.805	$y = -0.207x^2 + 2.918x - 3.903$	0.793	49.3	45.7	7.3
Umuopara	1450	$y = -0.899x^2 + 12.58x - 16.45$	0.805	$y = -0.767x^2 + 10.77x - 14.41$	0.793	199.7	168.9	15.42
Ugwunkpa	230	$y = -0.220x^2 + 3.092x - 4.068$	0.805	$y = -0.230x^2 + 3.236x - 4.329$	0.793	48.8	50.7*	-3.89
Umunna	490	$y = -0.146x^2 + 2.044x - 2.696$	0.805	$y = -0.132x^2 + 1.860x - 2.488$	0.793	32.2	29.1	9.63

Chokocho	2700	$y = -1.153x^2 + 16.13x - 21.09$	0.805	$y = -0.885x^2 + 12.43x - 16.63$	0.793	256.3	194.8	24
Amauro	63	$y = -0.012x^2 + 0.176x - 0.259$	0.801	$y = -0.024x^2 + 0.348x - 0.466$	0.793	2.5	5.4*	-116
Owerrinta	2263	$y = -0.804x^2 + 11.25x - 14.71$	0.805	$y = -0.679x^2 + 9.546x - 12.77$	0.793	178.7	149.6	16.28
Ndimoko	50	$y = -0.210x^2 + 2.946x - 3.873$	0.805	$y = -0.300x^2 + 4.214x - 5.637$	0.793	46.5	66.0*	-41.94
Average	1374.1	$y = -0.659x^2 + 9.229x - 12.07$	0.805	$y = -0.589x^2 + 8.284x - 11.08$	0.793	146.4	129.8	11.34

The Monthly Amount of soil loss from different sub-catchment of Imo River basin using MSLM model and USLE model by Wischmeier and Smith (1993), as presented in graphical forms of Figure 4 to 14 accordingly, which shows the graphical representation of soil loss amount in the Average catchment and other ten sub-catchment showing on the graphs was the single regression calibrated model equation and R^2 of each of the model for their soil loss prediction.

4.5 F-test validation of formulated model

In carrying out the experiment, errors were introduced. These errors cause the variations between amount of soil loss predicted with Mechanized Soil Loss model and the Universal Soil loss Equation models. They are due to variations in some factors assumed or neglected and ambient weather conditions.

The parameters for the determination of standard error of replicates were given in Table 7, and a multiple regression calibration, R^2, and F-test with ANOVA variance Analysis. Multiple regressions approximated these real-life problems, where it measures the relationship existing between MSLM and USLE Model variables.

For the multiple regression, as in simple regression; This model describing the relationship between the dependent variable, y as amount of soil loss and two sets of ‘x’ independent variables as soil losses in MSLM and USEL x_1, x_2 respectively, and the soil loss value used (the average of the catchment) is expressed as:

$$y_i = B_0 + B_1 x_{i1} + B_2 x_{i2} \qquad 24$$

For i = 1, 2 ,3 ... n.

Table 7. F-Statistics of MSLM and USLE soil loss results

	Y	X_1	X_2	Y^2	x_1^2	x_2^2	x_1y	x_2y	x_1x_2
Jan	1	1.114	1.067	1	1.241076	1.137838	1.114036	1.066695	1.188337
Feb	2	1.963	1.538	4	3.855171	2.366185	3.926918	3.076482	3.020273
Mar	3	8.496	7.594	9	72.18113	57.66522	25.48784	22.78129	64.51621
Apr	4	11.62	9.082	16	135.0951	82.48145	46.49216	36.32772	105.5596
May	5	15.2	13.82	25	231.1038	191.0518	76.0105	69.11075	210.1257
Jun	6	18.13	15.12	36	328.6835	228.5721	108.7778	90.7116	274.0946
Jul	7	17.09	16.78	49	292.1477	281.6167	119.6463	117.4701	286.8339
Aug	8	23.47	20.04	64	550.9766	401.4709	187.7831	160.2939	470.3202
Sep	9	23.51	22.85	81	552.8109	522.0567	211.6074	205.637	537.2137
Oct	10	19.59	16.18	100	383.7324	261.7047	195.8909	161.7729	316.8984
Nov	11	5.638	5.238	121	31.79035	27.43664	62.02122	57.618	29.53338
Dec	12	0.585	0.501	144	0.342081	0.251073	7.018524	6.012864	0.293065
Ann.	78	146.4	129.8	650	2584	2058	1046	931.9	2300

Using Equations of ANOVA in the computation and substituting into the tabulated values in Table 7, we have:

$$\sum y^2 = \sum y^2 - \frac{(\sum y)^2}{n} = 650 - \frac{(78)^2}{12} = 650 - 507 = 143$$
$$\sum x_1^2 = \sum x_1^2 - \frac{(\sum x_1)^2}{n} = 2584 - \frac{(146.4)^2}{12} = 2584 - 1786.08 = 797.92$$
$$\sum x_2^2 = \sum x_2^2 - \frac{(\sum x_2)^2}{n} = 2058 - \frac{(129.8)^2}{12} = 2058 - 1404 = 653$$
$$\sum x_1 y = \sum x_1 y - \frac{(\sum x_1)(\sum y)}{n} = 1046 - \frac{(146.4)(78)}{12} = 1046 - 951.6 = 94.4$$
$$\sum x_2 y = \sum x_2 y - \frac{(\sum x_2)(\sum y)}{n} = 931.9 - \frac{(129.8)(78)}{12} = 931.9 - 843.7 = 88.2$$
$$\sum x_1 x_2 = \sum x_1 x_2 - \frac{(\sum x_1)(\sum x_2)}{n} = 2300 - \frac{(146.4)(129.8)}{12} = 2300 - 1583.56 = 716.44$$
$$\hat{B}_1 = \frac{94.4 * 653 - 88.2 * 716.44}{797.92 * 653 - (716.44)^2} = -0.1995$$
$$\hat{B}_2 = \frac{88.2 * 797.92 - 94.4 * 716.44}{797.92 * 653. -(716.44)^2} = 0.354$$
$$\hat{B}_0 = \frac{78}{12} - 0.1995 * \frac{146.4}{12} + 0.354 * \frac{129.8}{12} = 6.5 - 2.4339 + 3.829 = 7.895$$

Thus, upon substitutions of these parameters into Equation (24); gives the estimating regression model as:

$$y = 7.895 - 0.1995 x_1 + 0.354 x_2 \qquad 25$$

The mean amount of Soil loss between the two models of MSLM and USLE denoted as A can be used to replace the amount of soil loss, y in Equation (25). x_1 shall replace MSLM Model, and x_2 replaces USLE Model. This shall give:

$$A = 7.895 - 0.1995 MSLM + 0.354 USLE \qquad 26$$

This MSLM model for soil loss shows that the amount of soil loss, A or y increases or decreases by 0.1995 for every one unit increase or decrease of MSLM or x_1 which is against 0.354 for that of USLE where the difference is not much. Without further test, I can say from here that x_1 or MSLM is less significant to the amount of soil loss from this catchment. So in taken decision on computation of soil loss, the MSLM and USLE Models will be considered for amount of soil loss. Test of significance of the model.

H_O: $\hat{B}_1 = \hat{B}_2 = \hat{B}_1 - \hat{B}_2 = 0$. The difference between the MSLM and USLE Models is not significant.

H_A: $\hat{B}_1 \neq \hat{B}_2$. There is a significant difference between the MSLM and USLE.

$$\hat{B}_1 - \hat{B}_2 = 0.1699 - 0.32 = 0.1 \approx 0$$

So Null Hypothesis is highly accepted H_O:

Proceed in carrying out F-test using ANOVA ,

$$R^2 = \frac{\hat{B}_1 \sum x_1 y + \hat{B}_2 \sum x_2 y}{\sum y^2} = \frac{-0.1995 * 94.4 + 0.354 * 88.2}{143} = 0.087$$

The value of R^2 = 0.087 means that MSLM and USLE models predicted soil loss in the catchments without much significant difference. That is each of the models could be used to predict the soil loss in the catchment. The ANOVA was calculated as presented in Table 8.

Table 8. Analysis of variance table ANOVA

Source of variation	Sum of Squares (SS)	Degrees of freedom	Mean Square	F-ratio	Table value
Due to x_1, x_2	SSR = $R^2\sum y^2$ 12.441	K = 2	$MSR = \frac{SSR}{K}$ $\frac{12.441}{2} = 6.221$	$\frac{6.092}{14.535}$ = 0.42	
Due to Error	SSE = SST – SSR = 130.559	N – K – 1 12–2 -1 = 9	$MSE = \frac{SSE}{n-k-1}$ = 14.51		F(2,9)
Total	$\sum y^2$ = 143 = SST	9			0.05= 4.26

For the null and alternative hypothesis, Nwaogazie (2006) for 5% level of significance and 2,9 degrees of freedom, we obtain $F_{0.05}(2{,}9)\ to\ be$ 4.26. That is the result is significant at 5% level, the F_c = 0.42, since the value of t (that is 4.26) as obtained from the standard statistics Tables is more than the calculated value of t, then Null hypothesis H_0 is accepted.

Since the models have been verified, the results will be further analyzed in single comparison of each catchment to fully understand at what point the two models have advantage over the other so that the justification and objectives of this study will be highly clarified. Table 6 shows the catchment calibration model, R^2, total soil loss amount and the percentage difference of the models.

4.6 Model Calibration and Verification

The Equations and R^2 are arranged in Table 6, for further comparison. Under multiple regression model calibration and verification where the two model variables for F-test computation are shown in Table 7, the multiple model regression and calibration yield the equation or expression of soil loss amount as $A = 7.895 - 0.1995MSLM + 0.354USLE$, which is the Equation (26) of this study. As you can see the equation for every unit increase or decrease of model variable MSLM will be reduces by -0.1995 and USLE model increase by 0.354 to the calibration equation that why in their individual or single regression trained line MSLM line is above the USLE in the Fig. 4 and others except the four sub-catchment named Nekede, Ugwunkpa, Amauro and Ndimoko, between the two models no significant different results was found and null hypothesis is accepted and the ANOVA analysis variance is shown in Table 8 and all the single calibration was displayed in Table 6. On this all R^2 values for MSLM model was found to be 0.805 expect Amauro which was 0.801 and is the catchment with smallest slope of 0.01 and R^2 values of USLE model was found to be 0.793 through, which meaning that MSLM has a more reliable regression than USLE. On the side of percentage difference (%diff.), we have a negative %diff. in four sub-catchment of -18.77, -3.89, -116 and -41.94 of the total soil loss in Nekede, Ugwunkpa, Amauro and Ndimoko with catchment Area of 100km^2, 230km^2, 63km^2 and 50km^2 respectively. Which is less than 490km^2 of Umunna where we start having a positive %diff. meaning that for catchment above 490km^2 area MSLM model has more good results of soil loss than USLE and less than that Area USLE start having good amount of soil loss more than MSLM model which is a good Justification for the study beat the claim the European stated in my literature review about USLE model "Europe indicated the USLE-based empirical models provided poor predictions of observed stream sediment delivery (Van Rompaey *et al.*, 2003)".

5.0 Conclusions

Based on the results of this work and in line with specific objectives, the conclusions were drawn. The soil characteristics for the eleven gully sites visited were determined, the parameters include; density, cohesion, friction, clay content, organic content and catchment slope and the average values are 19.73kN/m^3, 18.35kN/m^2, 25.14^0, 11.75%, 24.97% and 0.0343 or 3.43% respectively.

The amount of runoff at the gauging stations of each sub-catchment was computed using SCS Unit-Hydrograph at a depth of 1cm. The values of runoff for the following gauging stations: Nekede, Oyigbo, Ulakwo, Umuopara, Ugwunkpa, Umunna, Chokocho, Amauro, Owerrinta, Ndimoko and their Averages are, 4.98, 74.11, 9.52, 19.53, 7.10, 8.42, 35.80, 1.4, 35.1, 3.87 and 19.98m^3/s respectively. It had been observed that Sheet, Rill and Gully erosion the major contributors to the gross amount of soil loss. Hence, to optimize the soil loss amount, the Mechanized Soil Loss (MSLM) Model was formulated. From the results using September as a reference point for the year the amount of soil loss is 23.521 metric tones km^{-2} month^{-1} based on the Mechanized Soil Loss (MSLM) Model comparatively Universal soil loss equation (USLE) gave a value of 22.701 metric tones km^{-2} month^{-1}.

Multiple Regression ANOVA and Fisher's test was used to compare the results from the Mechanized Soil Loss and Universal Soil Loss Models. The comparison indicated that the difference between the two is not significant. This comparison was done at 95% confidence level. Hence, the model as formulated is sufficient for predicting soil loss at 95% confidence level. For the single regression on the figures, R^2 values for MSLM model was found to be 0.805 except for Amauro, whose value was 0.801 and has the catchment with least slope of 0.01. R^2 value of USLE model was found to be 0.793 all through, which means that MSLM has a more reliable regression than USLE

For catchment areas greater than 490 km^2, MSLM model gave better results of soil loss than USLE. When the area is less than 490 km^2, soil loss predicted by USLE model was higher than that predicted by MSLM model. The fact that the R^2 of MSLM is greater than R^2 of USLE, does however not imply it should be recommended for smaller catchment areas. Since the R^2 of USLE is lower than that of MSLM, we recommend MSLM for soil loss prediction in larger catchment areas.

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