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ASSESSMENT OF SOIL EROSION USING RUSLE2 MODEL AND *GIS* IN UPPER EBONYI RIVER WATERSHED, ENUGU STATE, NIGERIA

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Abstract

Soil erosion is a growing problem in Nigeria, particularly in South-Eastern Nigeria. This study focused on the estimation of the rate of soil erosion and soil loss potential using Revised Universal Soil Loss Equation (RUSLE2) and ArcGIS in the Upper Ebonyi River watershed. Soil data, land use inventory, digital elevation model, and climatic data were used as resource data sets to generate RUSLE2 factor values in ArcGIS environment. All factors used in RUSLE2 were calculated for the catchment area using local data. The rainfall erosivity R-factor was calculated from the annual and monthly rainfall data and the soil erodibility K-factor calculated from the soil map. Slopes and overall LS-values in the catchment were obtained from the DEM. The C-factor values were computed using remote sensing (with NDVI). Support practice P-factors were from terraces that exist on slopes. The results of the preliminary soil erosion assessment indicate that the average annual soil loss within the catchment ranges from 0 to 48 tons/ha/yr, the total average soil loss is 24,191.66(ton/yr.) with an average of 14.21(ton/ha/yr.). The values of erosion potential were divided into four (4) risk classes. The results showed that low class of soil loss having a range of soil loss between 0 to 1.4 (ton/ha/year), moderate class having rates between 1.4 to 4(ton/ha/year), high class rates between 4 to 12 (ton/ha/year), and Severe rates from 12 to 48(ton/ha/year) covering 68.3%, 21.135, 9.23% and 1.09% of the watershed area respectively.

Keywords: RUSLE2; ARCGIS; soil loss; erosivity; erodibility

Introduction

Soil erosion by water is a serious environmental problem in many parts of the world (Deniz *et al.*, 2008). Soil erosion is a common cause of soil deterioration around the world and has been accelerated by improper land use practices over the last several decades (Stanley and Pierre, 2000; Vanni`ere et al., 2003; Piccarreta et al., 2006; Szilassi et al., 2006; Feng et al., 2010). It is estimated that 85% of global land degradation is associated with soil erosion (Piccarreta et al., 2006). This has accelerated, especially in developing countries, due to different socio-economic factors, demographic factors and limited resources (Angima et al., 2003; Abate, 2011). Problems caused by soil erosion include loss of soil nutrients, declining crop yields, reduction in soil productivity, loss of vast agricultural land, poor water quality, and environmental degradation (Stacey, 2011). Moreover, soil moved by erosion carries nutrients, pesticides and other harmful farm chemicals into rivers, streams, and ground water resources hence deteriorating our freshwater sources (Nyakatawa et al. 2001). In Africa it is estimated that the decrease in agricultural productivity due to soil erosion is in the range of 2 - 40% with an average of 8.2% for the whole continent and with average of 19% of reservoir storage volumes been silted (Andersson, 2010). The study conducted by Angima et al. (2003) shows that about 5Mg/ha of productive topsoil is annually eroded into lakes and oceans. In addition, excessive sedimentation clogs stream channels and increases costs for maintaining water conveyance structures.

In Nigeria, soil erosion is a common phenomenon, where it causes widespread soil degradation. The soil erosion situation in the southeastern part of Nigeria has become very critical due to increased intensity of cultivation and clearing of forests, rapid human population growth and urbanization, watershed configuration, soil type and intense rainstorms which has led to major soil erosion problems. This is having devastating impacts and has led to land degradation (gullies), infrastructural damage as well as loss of lives and properties (Anejionu et al., 2013). Most of the erosion problems currently being experienced in the southeastern Nigeria are generating a high level of concern among researchers and the populace (Ezezika and Adetona, 2011, Obiadi *et al.*, 2011, Akpokodje *et al.*, 2010, Igbokwe *et al.*, 2008, Ofomata, 1965) in (Anejionu et al., 2013).

Soil erosion patterns in watersheds are patchy, heterogeneous and therefore it is difficult to assess. Mapping soil erosion in large areas is often very difficult using traditional methods. The use of soil erosion model and geographical information system (GIS) techniques makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas (Toy et al. 2002; Schmitt, 2009; Wang et al. 2008). The successful integration of RUSLE2 with GIS can be used to develop a spatial decision support system to estimate soil erosion under different conservation practices and to facilitate soil conservation planning within a watershed (Soo, 2011).

RUSLE2: Model Description

RUSLE2 is hybrid soil erosion prediction (estimation) technology because it is a combination of the empirical, index-based Universal Soil Loss Equation (USLE) and process-based equations for the detachment, transport, and deposition of soil particles (USDA-ARS, 2008). RUSLE2 is likely a better erosion prediction technology that builds on the success of USLE and RUSLE1 (Foster, 2005). Modern theory on soil processes of detachment, transportation and deposition of soil erosion particles by rainfall impacts and surface runoff was used to derive RUSLE2 (Ismail and Ravichandran, 2007). The erosion estimates are based on site specific condition which allows erosion control practices to be tailored to each specific site. RUSLE2, like RUSLE, estimates average annual rill and interrill erosion based on site- specific conditions and aims to guide conservation and erosion control planning at the local field office level. It is computer-based technology that involves a computer program, mathematical equations, and a database, which has a large collection of input data values (USDA-ARS, 2008).

The RUSLE2 computes the Average annual soil loss with Equation 1.

$$A = \frac{\left(\sum_{i=1}^{365N} r_i k_i l_i s_i c_i p_i\right)}{N} \quad . \qquad 1$$

Where: r_i = daily erosivity factor (erosivity unit/year); k_i = daily soil erodibility factor (mass/area·erosivity unit); l_i = daily slope length factor (dimensionless); s_i = daily slope steepness factor (dimensionless), c_i = daily cover-management factor (dimensionless); p_i = daily support practice factor (dimensionless), all long term averages for the *ith* day, and N = number of years in the overall computational period. In practice, a single time-invariant slope steepness S is used instead of a daily s_i slope steepness factor.

RUSLE2 Input Factors

RUSLE2 has six parameters, which are (climate) rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and support practice factor (P).

Climate factor

The four basic RUSLE2 climate variables are monthly erosivity, precipitation, and temperature and the 10 year-24 hour precipitation amount (USDA-ARS, 2008). The rainfall erosivity factor (R factor) represents the erosion potential caused by rainfall (Foster, 2003). The EI product for storm erosivity captures the effects of the two most important rainfall variables that determine erosivity; how much it rains (rainfall amount) and how hard it rains (rainfall intensity). Rainfall and Runoff erosivity factor, **R** factor, represents the effect of energy and intensity of rainfall (Kunta and Carosio, 2007).

The average annual erosivity is computed as

$$R = \left[\sum_{m=1}^{M} \sum_{j=1}^{J(m)} (EI_{30})_j\right] / M \qquad 2$$

The erosivity of individual storm (EI_{30}) is calculated as:

$$EI_{30} = (E)(I_{30}) = \left[\sum_{j=0}^{j_m} e_r \Delta v_r\right] I_{30} \qquad 3$$

Where; R = Average annual erosivity; EI_{30} = The erosivity of an individual storm; j = An index for each storm, $J_{(m)}$ = Number of storms in the mth year, and m; an index for year

E = the total storm kinetic energy of the *i*th rainstorm (MJ/ha); $I_{(30)}i$ = the max. 30 min rainfall intensity of the *i*th rainstorm (mm/h); e_r kinetic energy of a storm for the *r* period (MJ /ha/mm); Δv_r = the volume of rainfall registered during the *r* period (mm)

The kinetic energy of a storm is computed by

$$e_r = 0.29[1 - 0.72\exp(-0.05 i_r)] \qquad 4$$

$$i_r = \frac{\Delta v_r}{\Delta t_r} \qquad \mathbf{5}$$

Where e_r = kinetic energy of a storm for the *r* period (MJ /ha/mm); i_r = the rainfall intensity for the *r* period (mm/h),

Δt_r = the duration of the *r* period (min)

Soil Erodibility (K-factor)

The soil erodibility factor (K factor) measures the susceptibility of soil particles or surface materials to transportation and detachment by the amount of rainfall and runoff input (USDA-ARS, 2008). It is known that the most easily eroded soil particles are silt and very fine sand and the less erodible soil particles are aggregated soils because they are accrued together making it more resistible (Kim, 2006). In RUSLE2, the soil erodibility factor (K) measures the average long-term soil and profile response to the erosive power of rainstorm, as influenced by different soil properties (Wachal, 2008). The K-factor represents the combined effect of soil texture, organic matter, permeability, and structure on average long-term erosion. If these soil properties are known for a given soil type, then the K-factor can be read from a nomograph (Foster, 2005).

The equation for standard soil erodibility nomograph is given in Equation 6.

$$K = \frac{(k_t k_o + k_s + k_p)}{100} \qquad 6$$

Where; K = soil erodibility factor (t/ha)/(MJ mm), k_t :soil texture sub-factor; k_o = soil organic matter sub-factor ,k_s = soil structure sub-factor k_p = soil profile permeability sub-factor

The soil texture subfactor equation is given by

$$K_{tb} = 2.1[(P_{sl} + P_{vfs}(100 - P_{cl})]^{1.14}/10000 \qquad 7$$

$$K_{t68} = 2.1[68\ (100 - P_{cl})\ ]^{1.14}/1000 \qquad 8$$

$$K_t = K_{tb} \text{ for } P_{sl} + P_{vfs} \le 68\% \qquad 9$$

$$K_t = K_{tb} - [0{:}67(K_{tb} - K_{t68})^{0.82} \text{ for } P_{sl} + P_{vfs} > 68\% \qquad 10$$

Where; P_{sl} = percentage of silt; P_{vfs} = percentage of very fine sand; P_{cl} = percentage of clay; K_{tb} = base soil texture subfactor; K_{t68} = soil texture subfactor corresponding to 68%

$$P_{vfs} = (0.74 - 0{:}62P_{sd}/100)P_{sd} \quad 11$$

Where; P_{sd} = percentage of sand

The soil organic matter subfactor is given by

$$K_o = (12 - O_m) \quad 12$$

Where; O_m = percentage of inherent soil organic matter

The soil structure subfactor is given by

$$K_s = 3.25(S_s - 2) \text{ if } (K_tK_o + K_s) \geq 7 \quad 13$$

$$K_tK_o + K_s = 7 \quad \text{if } (K_tK_o + K_s) < 7 \quad 14$$

Where; S_s = soil structure class

1 – very fine granular, 2 – fine granular, 3 – medium or coarse granular and 4 – blocky, platy or massive

The soil profile permeability subfactor is given by

$$K_p = 2.5(P_r - 3) \quad 15$$

Where; Pr = soil profile permeability rating

1 – rapid , 2 – moderate rapid, 3 – moderate, 4 – slow to moderate, 5 – slow and, 6 – very slow.

The time to soil consolidation refers to the soil becoming resistant to soil erosion over time after a mechanical soil disturbance and not to mechanically increase the bulk density of the soil (USDA-ARS, 2008).

Slope length and Slope Steepness (LS) Factors

The slope length and slope steepness are important factors that control the rate of soil erosion and are therefore critical in the modeling of erosion at the watershed scale (Angima *et al.*, 2003). From a geomorphological perspective, slope length and steepness partly determine the erosive energy of surface runoff and the depth and velocity of flow, which also influence the transport capacity of runoff and its ability to transport the eroded sediment (Toy et al. 2002).The effect of topography on soil erosion is accounted for by the LS factor in RUSLE2, which combines the effects of a slope length factor (L) and a slope steepness factor (S). Investigation by kim(2006) shows that the amount of runoff increases due to the continuous accumulation down the slope as the slope length (L factor) increases; the velocity of runoff increases as the slope steepness (S factor) increases.

The slope length factor in RUSLE2 is given by

$$L = (m+1)\left({x}/{\lambda_u}\right)^m \quad 16$$

Where; L = slope length factor; x = Distance from the origin of over land flow path (m); λ_u = Length of unit plot (22.13 m); m = slope length exponent which is given by

$$m = \frac{\beta}{1+\beta} \quad 17$$

In which

$$\beta = \frac{k_r}{k_i}\frac{C_{pr}}{C_{pi}}\frac{exp(-b_r f_{ge})}{exp(-0.025 f_{ge})}\frac{\left({sin\theta}/{0.896}\right)}{3(sin\theta)^{0.8}+0.56} \quad 18$$

$\frac{k_r}{k_i}$ = Rill to interill erodibility ratio in Equation 17; $\frac{C_{pr}}{C_{pi}}$ = Rill to interill prior land use soil erodibility ratio

$\frac{exp(-b_r f_{ge})}{exp(-0.025 f_{ge})}$ = Rill erosion surface cover effect to interrill erosion surface cover effect ratio

$\frac{\left({sin\theta}/{0.896}\right)}{3(sin\theta)^{0.8}+0.56}$ = Slope effect for rill erosion to slope effect for interrill erosion

$$\frac{C_{pr}}{C_{pi}} = 0.45 + 1.55(s_c s_b)^2 \quad 19$$

S_c = soil consolidation subfactor; S_b = soil biomass subfactor; b_r = coefficient for conformance of ground cover that describes the relative effectiveness of the ground cover for reducing erosion. The value ranges from 0.05–0.06.

f_{ge} = effective ground cover

$$f_{ge} = f_{gn}(0.4 + 0.6\delta) \quad 20$$

Where, $\delta = {(b_r - 0.05)}/{0.01}$ 21

The slope steepness factor is given by:

$$S = 10.8sin\theta + 0.03 \qquad s_p < 9\% \quad 21$$

$$S = 16.8sin\theta - 0.5 \qquad s_p \geq 9\% \quad 22$$

$$where\ \theta = tan^{-1}\left({s_p}/{100}\right) \quad 22$$

S_p = steepness of the overland flow path (%), S = steepness factor; s = overland flow path steepness (sine of slope angle)

Cover Management Factor(C)

The C-factor is very important in the modeling process because it partly reflects the effect of ground cover (i.e., the combined effect of vegetation, litter, etc.), which arguably exerts a critical influence on the rate of erosion because a high percentage of ground cover translates to lower erosion rates even if all other factors are favorable (Vanacker et al. 2007, Morgan and Duzant 2008, Vahabi and Nikkami 2008, Wang et al. 2008, Zhou et al. 2008). A sub-factor method used in RUSLE2 to compute values for the cover-management factor C gives RUSLE2 its land use independence. RUSLE2 computes Cover management C factor as the product of subfactors as

$$C = c_C g_c s_r r_h s_b s_c s_m \qquad 23$$

Where: c = daily cover-management factor; c_c = daily canopy subfactor; g_c = daily ground (surface) cover subfactor, s_r =soil surface roughness subfactor; r_h = daily ridge height subfactor, s_b = daily soil biomass subfactor, s_c = daily soil consolidation subfactor, s_m = daily antecedent soil moisture subfactor which is 1

Support Practice (P Factor)

The support management factor represents the protection offered by the erosion control structure and practices such as terracing, contouring, ridging, strip cropping, and subsurface drainage, as well as other runoff and erosion control structures that reduce the rate and amount of runoff and erosion by modifying gradient, surface flow pattern, and velocity of runoffs (Foster, 2005).The Support Practice Factor (P) in RUSLE2 is defined as the ratio between soil loss with a specific support practice and the corresponding loss with upslope and downslope tillage. The conservation practices factor P is given by

$$P = a(s_m - s_c)^4 + p_{bm} s_c < s_m \qquad 24$$

$$P = a(s_c - s_m)^{1.5} + p_{bm} s_m \le s_c \le s_{be} \qquad 25$$

$$p = 1 \qquad s_{be} < s_c \qquad 26$$

Where

$$a = \left(1 - p_{bm}/{s_c}^4\right)$$

$P_b = 1$ at $S_c = 0$

$P_b = P_m$ at $S_c = S_m$

$P_b = 1$ at $S_c = S_{be}$

$$p_{bm} = 0.05 + 0.95 exp(-0.5512 h_e)\ if\ h_e > 8, h_e = 8 inches \qquad 27$$

$$s_m = 4[1 - exp(-0.1903 h_e)] + 4 if\ h_e > 8, h_e = 8 inches \qquad 28$$

$$s_{be} = sin\left\{tan^{-1}\left[{{(9 + 53.09 h_e)}/{8}}/{100}\right]\right\} if\ h_e > 8, h_e = 8$$

S_m = land steepness, S_c = scaled land steepness (sine of the slope angle); a = coefficient used to compute values for base contouring subfactor values; S_{be} = steepness that the contouring subfactor reaches 1, h_e = effective ridge height (maximum value is 8 inches); P_b = base contouring subfactor, P_m = minimum base contouring subfactor

The supporting mechanical practices include the effects of contouring, strip cropping, or terracing for different slope%.

Study Area

Study Area Description

The study area is the Upper Ebonyi River Watershed (Figure 2) catchment located on the western border of the Cross River plains, bounded by the Udi-Nsukka escarpment. The entire catchment of the Ebonyi River covers approximately 1702.3ha or 17km^2 and it is geographically located between latitude 6° 52$'$ N to 6° 56$'$ N and longitude 7° 33$'$ E to 7° 37$'$ E in Obollo-Etiti community, Udenu local government Area of Enugu State in South Eastern Nigeria (Fig. 1). The watershed ranges in Slope between 0^0 and 71^0 with elevation between 650m and 1650 m above Sea level (Fig 3). The mean annual rainfall is 1500mm and exhibits a wet climatic condition with a mean minimum and maximum temperature of 22.6 $^\circ$C and 30.7 $^\circ$C, respectively. The basin has a rural setting and is used extensively for agriculture (Agbo, 1991).

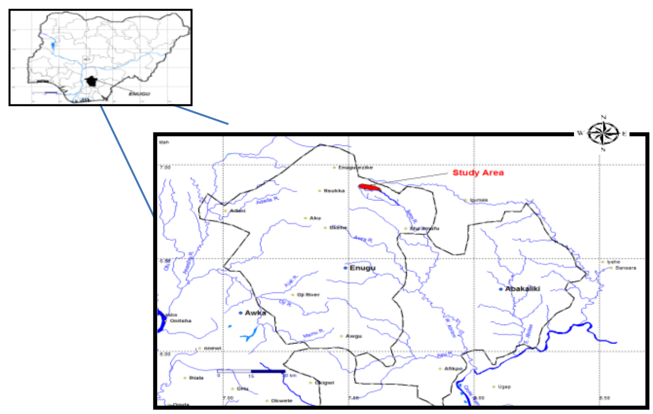

Figure 1: Map of Nigeria Showing the Study Area

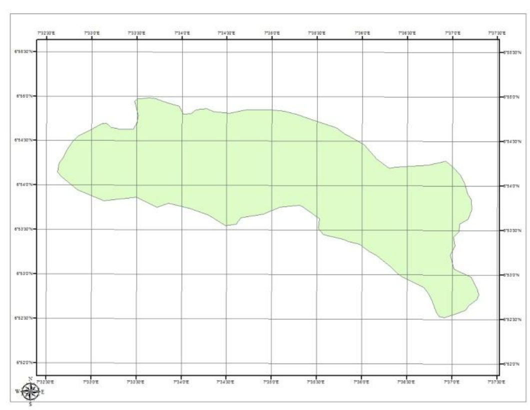

Figure 2: Delineated Upper Ebonyi river watershed in South-eastern Nigeria.

Method

In this study, the watershed area was delineated by a cartographer and a location map for the area was produced. The different types of data sets that are used for the calculation of soil loss within the watershed area include: Digital elevation model (DEM), Land use map, soil map, and climatic information. The overall methodology adopted in this study involves the development of RUSLE2 factor in a GIS environment, with RUSLE2 input parameters like climatic data obtained from meteorological stations, soil data from soil map, digital elevation map from topographic maps and land use map from the USGS Global land cover characterization (GLCC) as shown in Fig. 3. An individual GIS file was prepared for each factor in the RUSLE2 and combined by cell-grid modeling procedure in ArcGIS to predict soil loss in a spatial domain.

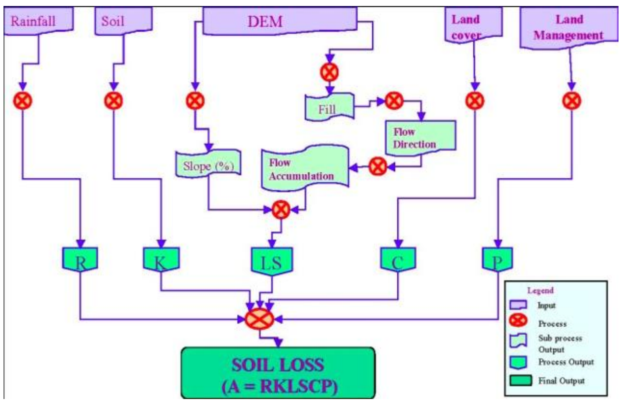

Figure 3: Procedures of RUSLE2 integrated in ArcGIS (Omar, 2010)

Data Inputs

Digital Elevation Model (DEM)

In this study, the watershed geographic coordinate was extracted from a contour map (1: 50,000 Igumale NW Topographic Sheet) and a ground-truthing survey was also carried out using a geographical positioning system (GPS) to develop the digital elevation model (DEM) (Figs. 4) of the watershed. The elevation range of the Upper Ebonyi river watershed is from 650 m - 1650 m. The DEM was used to estimate slope gradient, flow direction, catchment area, flowlength and flow accumulation for the study. Using ArcGIS 9.3, the slope length and slope steepness (LS) factor required by RUSLE2 was calculated.

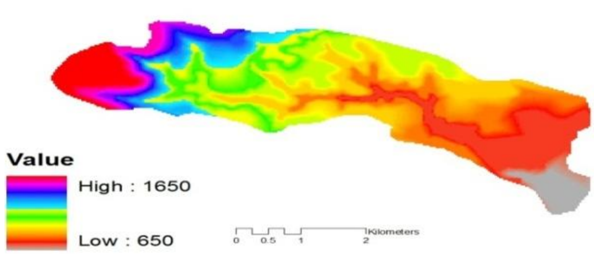

Figure 4: DEM of the Watershed in Raster Form

Soil Data (Soil Classification Map)

The soil map was downloaded from the Digital Soil Map of the World (http://www.fao.org/catalog/what_new-e.htm. Using the Harmonized World Soil Database (HWSD) viewer software (FAO, 2012) at the scale of 1:5000000, the required Soil parameters at two layers of 30 cm and 100 cm were derived. From the HWSD classification, the soils in the watershed are Nitisols, Acrisols and Phlinthosols covering 53.03%, 30.58% and 16.38% of the study area respectively. From the soil map the soil erodibility of the watershed was calculated.

Climate Data

This file was created using recorded rainfall data from the Centre for Basic Space Sciences (CBSS), University of Nigeria, Nsukka. Break-point precipitation data in five (5) minutes was summed up to annual rainfall in millimeter and used to calculate the annual rainfall erosivity value.

Land Use and Land Layer

The land use map was developed from L andsat spectral satellite image of December 17, 2011. Five major types of land use: settlement, water body, riparian vegetation, cultivated area and upland vegetation, were identified in the watershed and classified using ENVI 4.7 software. ENVI is the ideal software for the visualization, analysis, and presentation of all types of digital imagery. The land use map of the watershed is shown in Fig.5. Water body covered 1.38% of the watershed, with settlement, cultivated land, riparian vegetation and forest covering 12%, 28.24%, 10.38% and 47.82% of the study area respectively.

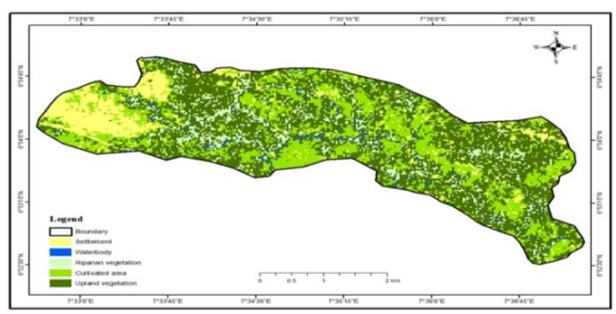

Figure 5: Land Use Map of the Study Area

Calculation of RUSLE2 Factors

Rainfall Erosivity Factors(R)

Rainfall is a driver of soil erosion processes and its effect is accounted for by the Rainfall-Runoff Erosivity factor (R) in the RUSLE2 equation (Pal and Al-Tabbaa, 2009). The R-factor accounts for the effect of raindrop impact and also shows the amount and rate of runoff associated with precipitation events (Stacey, 2011). Most of the time rainfall intensity and storm kinetic energy data are not available at meteorological stations. In the absence of rainfall intensity and storm kinetic energy data for this study area, the mean annual and monthly rainfall data (Fig.6) was used to estimate the R factor. Rainfall data of 7 years (2007-2013) collected from Centre for Basic Space Sciences (CBSS), University of Nigeria, Nsukka were used for calculating R-factor using the following relationship developed by Wischmeier and Smith (1978) and modified by Arnoldus (1980):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5 log \frac{P_1^2}{P} - 0.8188\right)} \qquad 30$$

Where: Pi = is the monthly amounts of precipitation and

P = is annual precipitation.

The annual summation of Pi^2/p is called the Fournier equation

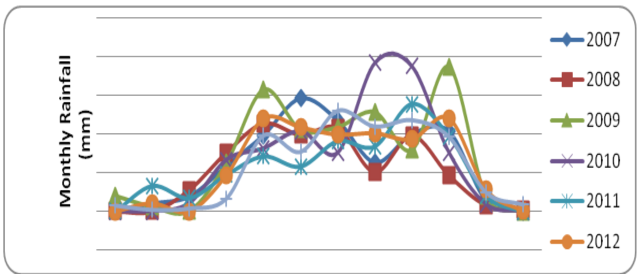

Figure 6: Monthly Rainfall distributions within the watershed

In order to apply the relationship in Equation (30) above, the monthly and annual rainfall depth are required to be prepared in raster format. Thus, the original rainfall data which distributed in daily form from the climate station was extracted and summed up to monthly rainfall and annual rainfall depth. The position of the station and the corresponding rainfall depth values were imported to ArcGIS as point vector data. Afterwards, Inverse Distance Weighting (IDW) interpolation with second power calculation was applied and used to construct rainfall erosivity maps.

Soil Erodibility factor

Usually, soil erodibility factor is obtained from erodibility index map which derived from soil map of the area by the help of ArcGIS. But, due to the absence of erodibility index map, the soil erodibility factor was calculated by using Soil erodibility values estimated based on the Harmonised world soil database, which contains the soil classification according to FAO standards. There are totally three types of soil classified in the study area; Nitisols, Acrisol and Plinthosols. To obtain the K-factor values for the different soil types, the percentages of clay, silt, sand and organic matters were determined for each major soil type using Harmonized World Soil Database (HWSD). The ERFAC (Proposed Alternative soil Erodiblity Factor) equation 31 was used. The result is shown in Table 1, from the table, the spatial distribution of the K-factor was computed in ArcGIS 9.3 at 30m resolution.

$$ERFAC = 0.32 * \left(\frac{\%\,Silt}{\%Sand + \%Clay}\right) \qquad 31$$

Table 1: Distribution of the k-factor**:** Culled from Ashiagbor et al. (2013).

Soil Type	Clay (%)	Silt (%)	Sand (%)	ERFAC (k)
Acrisols	24	27	49	0.255
Lixisols	24	20	56	0.234
Phlinthosols	22	29	49	0.261
Solenetz	38	60	2	0.351
Nitisols	23	33	44	0.251

Slope Factors (LS)

The effect of topography on erosion in RUSLE2 is accounted for by the LS factors (Foster et al., 2006). Erosion increases as slope length and slope steepness increases. The LS-factor is a combination slope steepness and slope length. The slope length factor (L) is defined as the distance from the source of runoff to the point where either deposition begins or runoff enters a well-defined channel (Ashiagbor et al., 2013). The steepness factor (S) reflects the influence of slope steepness or elevation on erosion (Foster et al., 1997). For this study, the combined LS-factor was computed for the watershed by using spatial analyst extension in ARCGIS 9.3. The slope of the watershed range in value between 0 – 71.7 degree and was derived from the DEM (Fig. 7). Sink in the DEM was identified and filled. The filled DEM was used to determine the flow direction and flow accumulation in grid form. The flow accumulation denotes the contribution upslope for a given cell and the cell size is 30m.

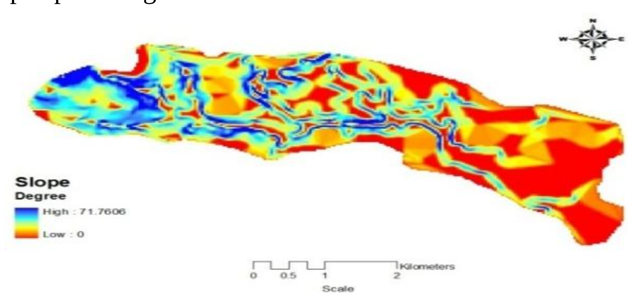

Figure 7: Slope of the Watershed in degrees

The LS factor was calculated using the raster calculator in ARCGIS. The expression in equation 16, 17 and 18was written in ARCGIS as

$$m = \frac{\left(\frac{[slope] * 0.01745}{0.0896}\right)}{3 * pow(\sin([slope] * 0.01745)\,, +0.56)} \qquad 32$$

m is the slope length exponent

The L factor with upslope drainage contributing area was computed as

$$L = (pow(([FlowAcc] + 900, ([m]+1)) - \frac{Pow(([FlowAcc], [m]+1))}{(pow(30, [m]+2) * pow(22.13, [m]))} \quad 33$$

The S factor was computed using equation 41 and 42 and rewritten in ArcGIS as

$$S = Con\left(\left(\tan([slope] * 0.01745) < 0.09, \left(\frac{10.8 * \sin([slope] * 0.01745) +}{0.03}\right), (16.8 * \sin([slope] * 0.01745)) - 0.5\right)\right) \quad 34$$

$$LS = [L] * [S] \quad 35$$

Where; Sine slope in degree, cell size in meters, FlowAcc is flow accumulation, Con is condition and Pow which means power is a function in the ArcGIS spatial Analyst.

Cover Management Factor (C)

The cover management factor 'C' in RUSLE2 represents how landuse and management affect soil loss. The parameters which are universally important in the impact of cover management systems on erosion are: above ground vegetative material, ground cover directly in contact with the soil surface, soil-surface roughness and ridge height created randomly by mechanical disturbance, soil biomass and consolidation introduced by the mechanical disturbance or roots grown there, and in some cases impact of antecedent soil moisture on reduction of runoff (USDA-ARS, 2008). The cover management factor is related to the vegetation cover percentage and it is the factor that is most readily changed by human activities (Karaburan A, 2010).

As management-cover situations can vary a lot from one place to another, a subfactor approach to estimate C values was proposed in the Revised Universal Soil Loss Equation (Foster, 2003, USDA-ARS, 2008). However in this study, the ETM + image classification was and use to prepare a land use/ land cover map for the study area. The watershed was classified into five land use pattern namely; cultivated land covering 28.34%, water covering 1.38%, Settlement covering12.86%, forest covering 47.82% and Raparain vegetation covering 10.38% of the watershed. This classification was used to derive the C-factor for each of the land use/ land cover identified.

Support Practice Factor (P)

By definition, the support practice factor *P* in RUSLE2 is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage (USDA-ARS, 2008). These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff. For cultivated land, the support practices considered include contouring, strip-cropping, terracing, and subsurface drainage. *P* stands for erosion inhibition effect and reflects partly human's effort not to allow soil erosion (Stacey, 2011). This is considered a useful strategy to reduce runoff and collect the soil moved by sheet erosion along the slope. A "P" factor map was derived from the landuse/ land cover maps and each value of P was assigned to each land use/ covers type and slope.

Table 2: P-value (Wischmeier and Smith (1978)

Land use type	Slope (%)	P-factor
Agricultural land	0-5	0.1
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other Land	All	1.00

According to Adediji et al., (2010), practice management factor map can be prepared from land use/ cover map and (Moore and Wilson, 1992) method of LS estimation employed in the study area to assign the P values for the Watershed. This same procedure will be adopted to derive the value of the P factor in this study see table 2.

Result and Discussion

The raster maps developed for K, LS, R, C and P factors of RUSLE2 model was combined with the help of raster calculator option in ArcGIS spatial analyst in other to estimate, evaluate and provide the maps of soil loss and severity map for the Upper Ebonyi River Watershed. The results for the RUSLE2 computed are presented below.

Rainfall Erosivity R-Factor

The distribution of the average annual rainfall of the study area for 7 years period (2007-2013) was used to calculate the erosivity value using Equation 30. The result showed that the value of R factor also vary according to rainfall distribution and elevation. As it is shown in Fig. 8 below, the value of R factor for the entire watershed found to vary between 743.1-830MJ.mm$ha^{-1}h^{-1}yr^{-1}$ with an average of 786.55MJ.mm$ha^{-1}h^{-1}yr^{-1}$.

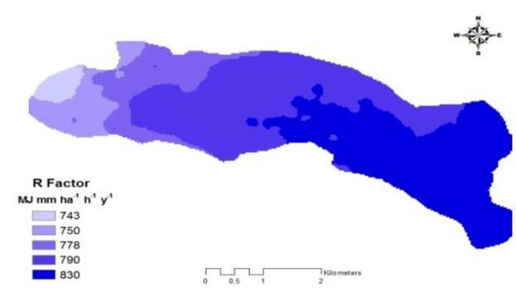

Figure 8: Rainfall Erosivity Map

Soil Erodibility K factor

The K factor reflects the ease with which the soil is detached by splash during rainfall and/or by surface flow, and therefore shows the change in the soil per unit of applied external force of energy. With the help of reclassification tool in ArcGIS, the cell values which indicated the soil types were replaced by using the K-values shown in Table 3.1 above. Three different K-values are obtained; 0.251, 0.255 and 0.261ton.ha.h.ha^{-1} MJ^{-1} mm^{-1}. The map of soil erodibility factor is shown in Fig. 9.

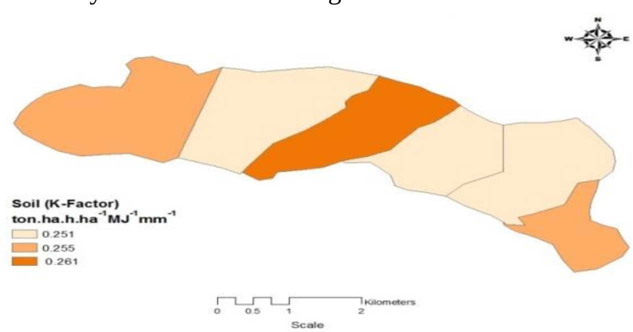

Figure 9: Soil Erodibility Map

Slope length and Steepness LS Factor

As mentioned in the Chapter Three, the slope angle and slope length (overland flow length) were generated using ARCGIS 9.3. The mean slope is 12.60 in percent with standard deviation of 11.26 and a maximum and minimum value of 71.76 and zero (0) respectively. The LS factor was calculated by using equation 72.The mean slope length and steepness factor of the study area is 0.202 with standard deviation of 0.20 and maximum and minimum value of 4.02 and 0.003 respectively Fig. 10. For both cases (flow length and slope gradient), The result is the average of the entire study area.

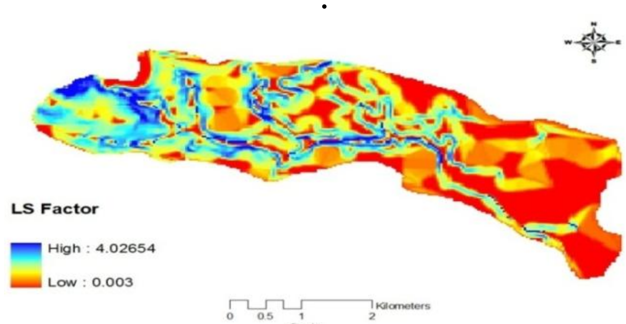

Figure 10: Slope length and steepness factor Map

Cover Management Factor(C)

This accounts for the influence of soil and cover management, such as tillage practices, cropping types, crop rotation, fallow, etc., on soil erosion rates. C factor ranges in Figure 11 were from 0 - 0.3.The C-factor was applied from the NDVI map. Cultivated land values were 0.3, 0.004in forests and 0.03 in Built up area. Water body has 0.0.The result indicates that the effects of forest and grassland on soil erosion is approximately uniform.

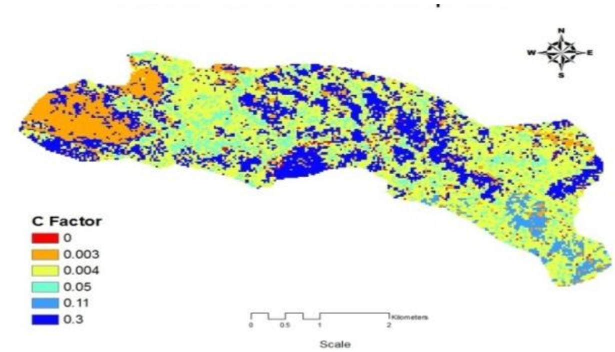

Figure 11: Cover Management Factor

Support Practice (P Factor)

Support practices factor (P factor) accounts for the impact of the land use on the average annual erosion rate. In the present study the P-factor map was derived from the land use/land cover and support factors. The values of P-factor ranges from 0 to 1, in which the highest value is assigned to areas with no conservation practices (forest and water body) about 72% of the total watershed; the minimum values correspond to built-up-land and cultivated area with contour and mould cropping occupying 28% of the watershed area. The lower the P value, the more effective the conservation practices. The P value in the study area ranged from 0.33 to 0.11 in cultivated and built up areas. The P factor values was 1 for other areas as there was no erosion control structures in these areas. The P factor map is shown in Fig. 12 below.

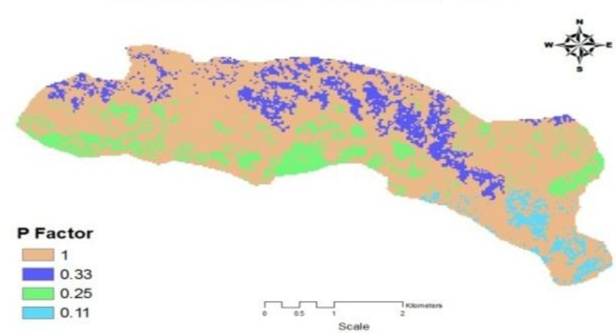

Figure 12: Support Practice Map

Annual Average Soil loss (A)

From this study, rainfall factor, soil erodibility factor, slope length and steepness factor, cover management factor, and support practice factor were calculated as shown above. The RUSLE2 calculated the annual average soil loss for the Upper Ebonyi River Watershed from Eq. (36). Since all the factors necessary for executing the RUSLE2 are created already, the map Raster calculator in ArcGIS Spatial analyst was used to execute equation 36 and shown in fig. 13.

$$A = ([R - factor] * [LS] * [K - factor] * [C - factor] * [P - fac$$

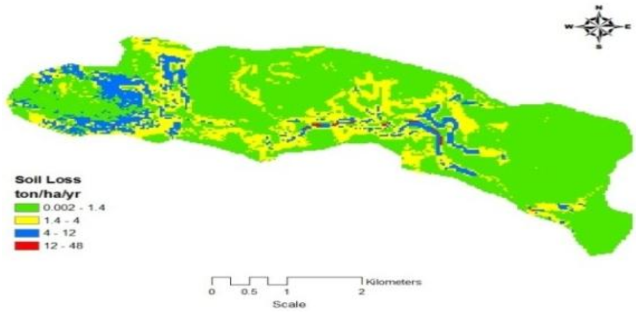

Figure 13: Annual Predicted Average Soil Loss Map

The annual soil loss (A) caused erosion ranges from 0 to 48(ton/ha/yr.), the total average soil loss is 24,191.66(ton/yr.) with an average of 14.21(ton/ha/yr.). The values of erosion potential were divided into four (4) risk classes as shown in Fig. 14 and tabulated in Table 3. The results showed that very low class of soil loss having a range of soil loss from 0 to 1.4 (ton/ha/year), moderate class having rates from 1.4 to 4(ton/ha/year), high class rates from 4 to 12 (ton/ha/year), and Severe rates from 12 to 48(ton/ha/year). Generally, the estimated value of soil loss in the RUSLE2 model highly depends on LS factor next to R factor. This implies that the DEM information, which is directly transformed to L and S factors, and rainfall data are crucial in calculating soil loss.

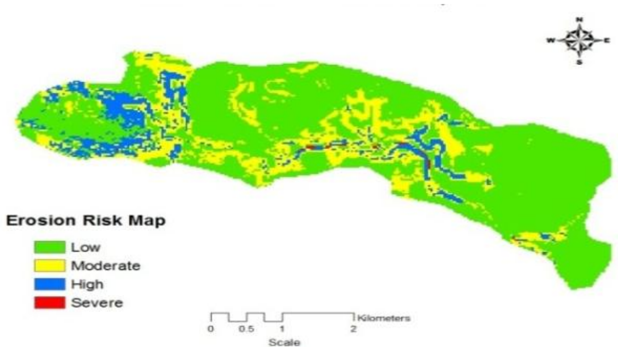

Figure 14: Erosion Risk Map

Table 3: Annual Soil loss Rate and Risk Categories

Soil Loss Range (t/ha/yr)	Risk Categories	Area (ha)	Area (%)
0 – 1.4	Low	1162.7	68.3
1.4 – 4	Moderate	359.8	21.13
4 – 12	High	158	9.23
12 - 48	Severe	18.6	1.09

Discussion

In the calculation of soil erosion based on RUSLE2 model and GIS, the rainfall erosivity factor (R) plays an important role as the driver of erosion. The result showed that the annual R value ranges between 743-830MJ/ha.mm/yr with an average value of 797MJ/ha.mm/yr. The highest value of R was found on the lower area of the watershed and the lowest value found in the high elevation area north of the watershed. The R factor value as shown in Fig. 8 compares favorably with the one obtained by (Ezemonye and Emeribe, 2012) who reported values of 800MJmm/ha/yr for Enugu State. The soil erodibility values K for this area are presented in Fig. 9; the soil erodibility varies between 0.251 and 0.261 t ha h ha^{-1} MJ^{-1} mm^{-1}. Previous studies for the eastern state have found K values that vary between 0.022 and 0.040 t ha h ha^{-1} MJ^{-1} mm^{-1}(Anejionu et al., 2013). Figure 10 presents the results of modelling the slope length and steepness. It is noted that the longer the slope length, the greater the amount of cumulative runoff. The soil erosion susceptibility with slope categories shows that the steeper the slope of the land the higher the velocities of runoff which contribute to erosion. With higher slope exceeding 20 degrees, soil erosion increases. The LS value for this watershed are similar to those reported by Agele et al. (2013) which was found to vary between 0 – 25. Similarly, the land cover management factor was modelled and the results are shown in Figure 11 The results indicate that the vegetation cover has an impact in the erosion by intercepting the rainfall thus reducing the rainfall energy and increasing the infiltration.

The final soil loss model (Figure 13) predicts that approximately 68.3%of the watershed covering 1162.7 hectares as low erosion risk (i.e., erosion with very gentle runoff speed.) and 21.13% moderate covering 359.8ha of the watershed (i.e., shallow to deep hills mainly found around agricultural lands and moderate forest class). But the erosion risk is high (i.e., very deep hills and some gullies) on 9.23% (158ha) and severe on 1.09% (18.8ha) of the watershed area. The results of the preliminary soil erosion assessment indicate that the average annual soil loss within the catchment ranges from 0 to 48 tons/ha/yr, the total average soil loss is 24,191.66(ton/yr.) with an average of 14.21(ton/ha/yr.). The values of erosion potential were divided into four (4) risk classes. The results showed that low class of soil loss having a range of soil loss from 0 to 1.4 (ton/ha/year), moderate class having rates from 1.4 to 4(ton/ha/year), high class rates from 4 to 12 (ton/ha/year), and Severe rates from 12 to 48(ton/ha/year) covering 68.3%, 21.135, 9.23% and 1.09% of the watershed area respectively.

Conclusion

The modeling of soil erosion potential for Upper Ebonyi River Watershed provides several insights such as which areas to be first conserved based on the severity level of soil loss. This study indicated that using GIS technologies for erosion risk mapping, based on the RUSLE2 model, resulted in assessment of soil erosion in a considerably shorter time and at low cost for large watersheds. The present study showed that erosion risk expressed as annual soil loss rates were mainly determined by high LS factor values.

Based on the results of this study, it is recommended that ground survey be undertaken on areas showing high risk of soil erosion and depending on the outcome of the survey immediate action should be taken to curb acceleration of the soil erosion and degradation. It is important to note that the steepest slopes show high risk of soil erosion, it is therefore recommended that further study be undertaken to establish the suitable soil and water conservation measures that should be implemented in these areas as well as the whole watershed.

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