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Estimation of Annual Erosion in Six Soil Series of the Federal University of Agriculture Abeokuta Nigeria using Rusle in Map Algebra

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ABSTRACT: Anthropogenic activities such as deforestation, bush burning and extensive opening of farmlands in the 10,000 hectares at the Federal University of Agriculture, Abeokuta (FUNAAB) have increased vulnerabilities of the seven soil series in the campus to agents of erosion. Therefore it is important to evaluate the rate and locations of soil erosion in the study area inorder to develop erosion control intervention programme using standard methods. The results show that overall soil erosion ranges from 0 to 167.8 tons per hectare per annum. 10% of University land now has high risk of soil erosion being grasslands exposed to annual fires. Soil erosion is pronounced in the two soil series (Oke-imesi and Apomu) that are found along river fringes with topographic factors (Slope length and steepness) playing major role in the soil erosion

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The soil is described as a multifunctional and non-renewable environmental resource (Várallyai, 2015; Lal, 2015; Cooke, 2020). It may become lost irretrievably where proper evaluation and management practices are missing (Sharda, *et al.,* 2002, Walin, 2013). The annual loss of productive soil is therefore not inconsistent with sustainable agriculture (AfDB, 2013). As such, for an African country like Nigeria, maximum soil conservation Various aspects of the soil of attributes have been documented at the University of Agriculture, Abeokuta Nigeria (Ajiboye, *et al*., 2011; Ajiboye and Aduloju, 2013; Ajiboye, *et al*., 2014; Ajiboye *et* al., 2015a; Abatan, *et al.,* 2016; Alabi, *et al*., 2017). Soils of the University have been characterized by their series and structures (Aiboni, 2001) and a few studies have also been conducted to examine rainfall erosivity and rainfall kinetic energy of the Soils (Salako *et al.,* 2006b; Salako, 2007; Salako, 2008; Salako *et al.,* 2008). Changes in morphogenetic and physicochemical properties of an Alfisol in charcoal production area were also recently examined (Ajiboye, *et al.,* 2019). Notwithstanding, only a few efforts have rested on the prediction of annual soil loss of the entire campus and where such studies existed, the geographical scope of the study has been narrowed to manageable land areas. Meanwhile, continuous cropping of the University land from year to year was found to be leading to fertility loss (Dada, *et al*., 2016). This aligns with the assertion that constant tillage operations increase porosity and macro-porosity in soils (Veiga *et al*., 2008). This also reduces soil bulk density and consequently increasing the vulnerability of soils to erosion (Tavares and Tessier, 2009). The University land mass is comprised of six soil series of which is imperative to calculate the rate their erosion and the precise locations to direct soil conservation and management practices.

Theoretical Underpinning: Wischmeier and Smith (1978) developed an equation to determine soil erosion of an area by combining five factors that contributes to soil erosion in a simple algebraic model. All of the five factors are multiplied together as in the equation below:

$$A = R \times K \times LS \times CM \times P \ldots\ldots\ldots\ldots\ldots (1)$$

A is amount of soil lost to erosion in a year (tons/ha), R is the erosivity of rainfall (accounting for the erosive power of rainfall), K is the soil erodibility (tons/ha) of given soils" (Barrena-González *et al*., 2020). Soil erodibility values differ from soil to soil (< 0.1 to 1.0). "The LS represents the length and steepness of the slope" (Vijith *et al*., 2018); "longer slopes produce larger run-off volume while steeper slopes produce higher run-off velocities" (Ghosh and Guchhait, 2012). This is significant in the removal of large quantities of

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soil particles. C is soil cover factor which accounts for the "protective effects natural vegetation and crop, including their leaf litter and residues" (Kassam *et al.,* 1993). P is factor for physical protection of soil from erosion (particularly accounting for the effects of soil conservation measures). The first equation was revised by separating the two elements of "the cover and management factor to give the Revised Universal Soil Loss Equation (RUSLE)" (Morgan and Nearing, 2016) as follows:

$$: A = R \text{ x } K \text{ x } LS \text{ x } C \text{ x } P \ldots\ldots\ldots.(2)$$

*Soil-erodibility determination in nomograph (*Wischmeier and Smith, 1978*):* Direct measurements taken on plots with natural runoffs have been argued as best way to obtain soil-erodibility (Cassol *et al*., 2018). Simulation of rainfall on plots and predictive relationships are other ways of obtaining soil erodibility, but these methods have been proved to be less accurate (Renard *et al*., 1997).

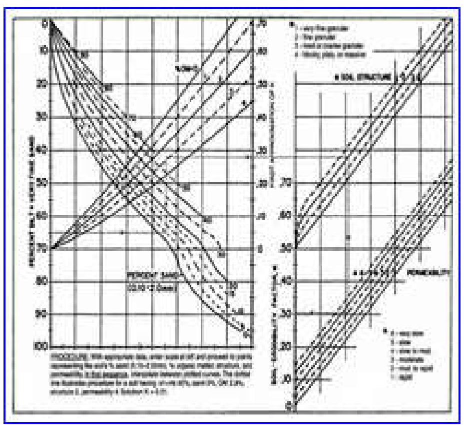

Fig. 1. The nomograph for soil-erodibility (adapted from Wischmeier and Smith, 1978)

Many and varied properties of the soil (physical, chemical, mineralogical) and their interactions affect erodibility (K-factor) values. To accurately describe erodibility values for each soil series, more soil characteristics will be needed. In the several past studies attempts at measuring soil-erodibility (K) values have referenced the nomographs (Arab *et al*., 2013; Addis and Klik, 2015). The figure below is the nomograph for five soil parameters namely: "percent modified silt (0.002 to 0.1 mm), percent modified sand (0.1 to 2 mm), percent organic matter (OM), and structural classes (s) and permeability (p)".

K value is in U.S. unit of tons per acre (to convert it to the SI unit, the K values are divided by 7.59)

A useful algebraic approximation of the above nomograph for cases where silt fraction is not more than 70% is"

$$\text{K} = 2.1 * 10 - 4(12 - OM)M1.14 + 3{,}25(s - 2) + 2.5(p - 3)]/100 \ldots\ldots\ldots..(3)$$

Where M is the product of the primary particle size fractions:

$$(\%\text{ modified silt or the } 0.002 - 0.1\text{mm size fraction}) * (\%\text{ Silt} + \%\text{ Sand})$$

$$\%\text{ modified silt or the } 0.002 - 0.1\text{mm size fraction}) * (\%\text{ Silt} + \%\text{ Sand})$$

To supply values that will fit into the above expressions, it was necessary to carry out particle size analysis, permeability test as well as Organic matter content determination.

Erodibility (k factor): The erodibility is measured on a scale from 0 to 1 for any soil type. The values 0 is for soils with the least predisposition to erosion, while the value of 1, refers to soils that are highly susceptible to water erosion.

Description of study area: The University of Agriculture, is situated on a 9,800 ha of land between latitudes 7^{0} 13' 30' N and 7^{0} 19' 00" N and longitudes 3^{0} 20' 15" E and 3^{0} 27' 30" E. along Alabata Road in Abeokuta southwest Nigeria. The landmass generally described as Lixisol by the Harmonized World Soil Database (HWSD, 2009) is further disaggregated into seven soil series namely: Apomu, Egbeda, Ekiti, Iseyin, Iwo, Jago and Oke-Imesi. The area forms part of the transition zone between the humid lowland rain forest of Nigeria and its southern guinea savanna agro-ecological zone (Adepoju *et al*., 2019). It is described in the literature as derived savanna (Oyenuga, 1967; Greig-Smith, 1991; Omokhafe, 2017). The vegetation comprises of a mixture of secondary forest regrowth of smooth-barked trees and scaly barked savanna trees with sub-dominant grasses. The general land use is both intensive and extensive rain-fed agriculture.

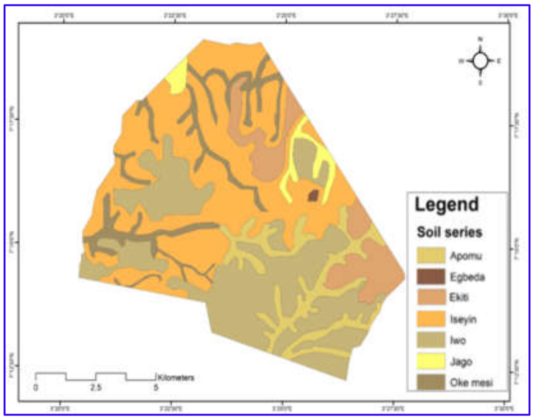

Fig. 2. The map of the FUNAAB boundaries showing the seven soil series

The land area is drained by a network of tortuous rivulets ramifying the landscape and all draining into the Ogun River in the northern and eastern portions of the campus area. The climate is tropical with wet season commencing in March and ending in October, while the dry seasons begin in November and ending in February. Rainfall distribution graph is bimodal; the first peak is in July and the second is in September. There is a short break in rainfall in August. Average annual rainfall is 1113.1 mm. Rainfall is sometimes intense with lightning and thunderstorm at the beginning and end of the season (Ufoegbune and Fabiyi, 2016). Average monthly temperature of the area is between 22.9^{0}C to 36.32^{0}C.

Data type and acquisition: The study relied on data from both primary and secondary sources including data obtained from previous studies and satellite-derived remote sensing data. The data from the primary source are mainly the representative soil samples obtained in replicates from each soil series. Data from secondary sources include: Rainfall intensity distribution was derived from the Climate Hazards InfraRed Precipitation Station (CHIRPS) data. Digital Elevation Models (DEM) data obtained from the Shuttle Radar Topographic Mission (SRTM) was subjected to spatial analysis to derive slope length and steepness (Karan *et al*., 2019). The soil series map was retrieved from the archive of the University Physical Planning Unit (PPU). The PPU archive also contains the baseline data in the original master plan of the University. The Land use and Land cover (LULC) types (Dastagir, *et al*., 2020) was produced from supervised classification (Bewket and Teferi, 2009) of Landsat TM image of the University.

Soil Sample collection and analysis: Undisturbed samples were collected (using Core sampler's method) from "two depths (0-15 cm and 15-30 cm) in each of the six soil series". The geographic coordinates of soil sample locations were obtained with the aid of a handheld GPS receiver.

Method for producing annual soil loss map: The algebraic functions in GIS were deployed in producing a composite map of annual soil loss. A set of algebraic operations in a GIS permits two or more raster layers ('map') of similar dimensions to produce a new raster layer (map) using the multiplication or other operators such as additions, subtraction, and division in the raster calculator.

Rasterization of maps and soil loss parameters: The hard copy map of the seven soil series in FUNAAB namely Jago, Apomu, Iseyin, Ekiti, Egbeda, Iwo, and Oke-Imesi (Ufoegbune and Fabiyi, 2016) was geo-referenced, digitized ('heads-up'), and converted to the grid using 0.0028 as grid cell size. Each grid cell was assigned a uniform value of 1. The soil the series map was however symbolized (using unique ID numbers 1 to 7) to distinguish the boundaries of each soil series as shown in figure 1.

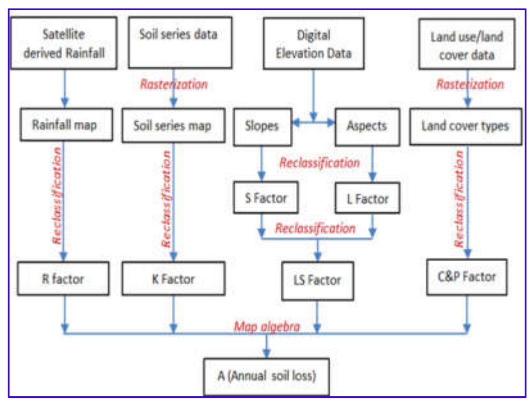

Fig. 3. Flow chart diagram showing the steps followed for the annual soil loss map

Maps of RUSLE Components: All factors of soil erosion in the RUSLE (equation 2) are prepared as a grid map with the same grid cell size. With the grid map of all soil loss factors prepared on the same scale and cell size, map algebra was then easy, using the multiplication operator in the map calculator. Each component of the soil loss namely "erosivity" (R), "erodibility" (K), "slope length" (L, S), "conservation practice" (C), and "physical protection" factor (P) were expressed in raster map format. The same grid cell size used for the soil series map was used for all

RUSLE component maps. This allowed for alignment and easy overlay operations. The procedures for producing the map for each soil, loss factor are presented in figure 3

Total erosivity of rain (R factor): Annual Rainfall data obtained from the CHIRPS (covering 2009 to 2018) were imported into a GIS environment. The raster calculator was used to obtain the total rainfall in the 11 year period. The average values for the period was then computed by dividing the total with 11 using the Spatial Analyst raster calculator in ArcGIS. The equation below is the mathematical model for "rainfall erosivity" (Lee and Lee, 2006):

$$R = 38.5 + 0.35 * Pr \ldots\ldots\ldots..(4)$$

Here, "Pr is the annual average rainfall/number (Ganasri and Ramesh, 2016) of years (mm/yr)" as shown in figure 3. The computed R from the equation above was transformed to rainfall intensity map.

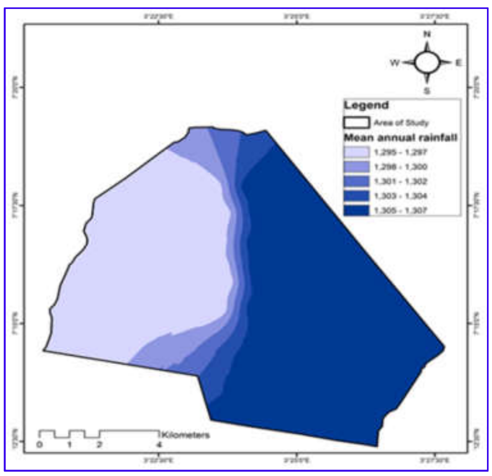

Fig. 4. Rainfall intensity variability distribution across FUNAAB campus area

Erodibility (k factor): The respective K values for each soil series from laboratory experiments and reference to nomograph was translated into a raster map. Each soil series (with uniform cell value of 1) was multiplied by the respective soil-erodibility values earlier calculated.

Topographic factor ("Slope length and steepness-LS"): "The effect of length and steepness of slope on soil erosion" (Angima, *et al*., 2003) (LS factor) was computed from a 30 m resolution DEM data derived from the SRTM data. Two major factors were combined to calculate the length of the slope, which include: the slope degree and the flow accumulation. The DEM was used to calculate the slope degree and also flow accumulation using ArcGIS spatial analyst extension.

The flow accumulation and slope degree were combined with equation 4 below using the raster calculator in ArcGIS" (Bewket and Teferi, 2009).

$$LS = \left(FA \times Cell\frac{size}{22.1}\right) 0.4 \times \left(sin\left(\frac{slope\ x\ 0.01745}{0.09}\right) 1.4 \ldots (5)$$

Where FA = flow accumulation.

The outcome is presented in figure 9 as a map with same cell size and parameters as previous maps.

Cover and Management factors (C&M): Each land cover types were reclassified (as shown in figure 54) to produce the cover (C) factor map, [Lee and Lee, 2006; Ganasri and Ramesh, 2016).

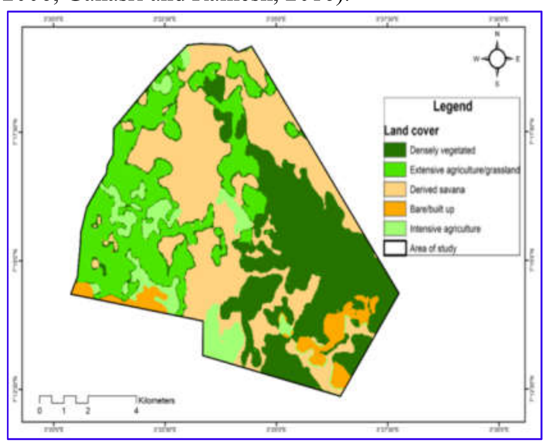

Fig. 5. Land use / land cover categories of FUNAAB

Supervised classification of 2018 Landsat imagery (using maximum likelihood classifier) produced the five major land use/ land cover classes (Densely vegetated, Extensive agriculture, Intensive agriculture, Derived Savanna and Bare-land /built-up environment) were produced as shown in figure 5

Overall annual soil loss: Overall erosion map of the University (see figure 10) was produced by multiplying the raster maps of erosivity by the map of erodibility by the map of conservation practice/management and by the map of slope length and steepness. The annual soil was therefore obtained as a single map showing five distinct class ranges with the least as 0-16 ($t^{-1}Ha^{-1}yr^{-}1$). The largest erosion range in the University is 98 – 203 ($t^{-1}Ha^{-1}yr^{-}1$). The map appears to depict that, the University does not have serious issues with soil loss yet since not more than 10% of the 10,000 hectares loses up to 1.6 tons of soil per hectare per year.

EXPERIMENTAL

Particle size determination: The soil samples from the locations of the 6 major soil series were subjected to particle size analysis (% fine sand, silt, clay) and organic matter content determination using the hydrometer method (Bouyoucos, 1962).

The values obtained were used to estimate the erodibility (k factor). 50 g of (2mm) sieved soil sample was measured into 250 ml conical flasks and 50 ml of sodium hexametaphosphate solution (calgon solution) was added with 100 ml of distilled water. The samples were left overnight to allow the soil to soak properly before mechanical dispersal.

The soil was transferred into a dispersing cup and dispersed using a mechanical stirrer for 5 minutes. The mixture was immediately transferred to 1000 ml measuring cylinder. The dispersing cup was rinsed into the measuring cylinder until there was no trace of soil particle in the cup. Thereafter water was added to fill the 1000 ml cylinders up to 900 ml mark and a soil hydrometer was inserted into the cylinder before adding water to mark. With the mouth covered, the cylinder was inverted several times to ensure that the soil was properly suspended. The dispersed soil was placed on a flat table – top and allowed to rest.

The first hydrometer reading was taken 40seconds after the suspension was set down and temperature was also taken using a thermometer. Both the hydrometer and temperature readings were recorded (first readings). Just before 2 hrs, the hydrometer was inserted again into the soil suspension and the second hydrometer readings were taken again at 2 hours.

The temperature was equally taken. Both the HR and temperature readings were recorded as 2nd reading. The percentage sand, clay and silt in the soil were calculated using the formula below:

$$(\%\,sand + \%\,silt + \%\,clay) = 100 \ldots\ldots..(6)$$

$$\%\,sand = 100 - (\%\,silt + \%\,clay) \ldots\ldots..(7)$$

$$\%\,(silt + clay) = 100\,(1st\ reading + corrected\ temp\ reading) \text{ x } 100 \div weight\ of\ soil \ldots (8)$$

$$\%\,clay = +\,(2nd\ reading + corrected\ temp\ reading) \text{ x } 100 \div weight\ of\ soil \ldots..(9)$$

$$\%\,silt = 100 - \%(silt + clay) - (\%\,clay) \ldots\ldots (10)$$

Permeability test: The permeability test was conducted using Reynolds constant head soil core method (Basile *et al.*,, 2020) in line with Darcy equation for vertical flow of liquid. "Saturated Hydraulic Conductivity (Ks) was determined using undisturbed soil samples collected with core samplers at different soil depths" (Ajiboye *et al*., 2015). A constant water head was maintained on each core sample. The amount of water that passed through the soil in the core at set time was recorded. Saturated hydraulic conductivity (Ks) is given by the equation below:

$$Ks = \frac{Qw \text{ x } d}{h \text{ x } A \text{ x } t} \ldots\ldots\ldots\ldots..(11)$$

Qw is the quantity of water (cm^3) that flowed through a cross-sectional area A (cm^2) in time (t), and h is the hydraulic head difference (cm) imposed across the sample length d (cm)."

Organic Matter determination: Organic matter was determined from Organic carbon estimation. Air dried soil samples were sieved using 0.5 mm mesh screen" (Angima *et al*., 2003). 0.5 g of the sieved soil was weighed on a sensitive scale balance. The weighed soil was poured into a "conical flask"; then 10mls of potassium dichromate was added along with concentrated Sulfuric acid. The mixture was swirled and left for half of an hour. "50mls of distilled water was then added with five drops of Orthophenatrolein solution as indicator". The solution was then titrated against Ammonium ferrous sulphate solution. The formula below was used in the calculation:

$$\%\,OM = \%\,OC \text{ x } 1.724N \ldots\ldots.(12)$$

Where OM = organic matter, OC =organic carbon, N is Normality of Ferrous sulphate; Normality of Ferrous sulphate = volume of K2CrO7 used for blank/Titre value for blank" (Nath and Krishna, 2014).

RESULTS AND DISCUSSION

In table 1, the four parameters used to determines soil-erodibility namely; soil structure, soil texture, permeability and organic matter are presented. The texture of the soil is determined by the relative percentage composition of sand, silt or clay" (Kusumandari, 2014). Textural analysis of the six series reveals high sand percentage (77.94 to 94.95%) in the soil series in the University. Clay content ranged from 4.06 to 15.06% and silt content from 0.99 to 6.99%, respectively. The general implication of these is that most of the soils are highly erodible if they are bare. "Clay-rich soils with a low shrink-swell capacity have low erodibility value, since clay particles mass together and form large aggregates that resist detachment and transport processes unlike sandy soils" (Kusumandari, 2014). Organic matter content in soils influences its physical and chemical properties by building up aggregation. Normally, soil organic matter affects soil erodibility, infiltration, water detention, and shear strength of soil. The results of soil organic content analysis showed values varying from 0.07 to 3.29% which can be considered to be moderate; "preventing soil particles from detachment by the kinetic energy of rainfall and providing very low threshold of soil erodibility" (Yusof *et al*., 2011). The grain size distribution of soil determines the level of ease with which a particular fluid flows through the interconnecting voids of soil. From the nomograph calculations, the relative soil-erodibility values for the soil series is as presented in the table 2. The values inTable 2 was translated into raster map by multiplying the soil series with their respective erodibility (K-factor) values to produce the erodibility map as shown in the figure 6

Table 1. The physical and chemical characteristics of the soil series

LOCATION	SILT	SAND	CLAY	O C	OM	KS	K	SC
APOMU	1.99	92.95	5.06	0.40	0.69	93.09	0.4	2
EKITI	1.99	92.95	5.06	0.84	1.44	24.25	0.1	2
ISEYIN	0.99	94.94	4.06	0.04	0.07	78.72	0.4	2
IWO	0.99	94.95	4.06	0.04	0.07	22.51	0.2	2
JAGO	0.99	91.94	7.06	1.92	3.29	8.83	0.1	2
OKEMESI	6.99	77.94	15.06	0.68	1.17	28.64	0.2	2

Table 2. The relative "soil-erodibility values" for the series

SOIL SERIES	K-factor Value ($ton.acre^{-1}$)	K-factor Value in SI unit ($t.ha.ha^{-1}$)	Remarks
APOMU	0.04	0.0052	Low
EKITI	0.05	0.0066	Low
ISEYIN	0.20	0.013	Moderate
IWO	0.23	0.017	Moderate
JAGO	0.22	0.015	Moderate
OKEMESI	0.21	0.014	Moderate

The result shows that soil erodibility in the university is relatively low; with values ranging from 0.04 to 0.23 t/ha as shown in table 2.

Areas with moderate erodibility in the series have a higher amount of sand than areas with higher silt contents. Areas with low erodibility also have low permeability and higher resistance to particle detachment.

Proper land management and presence of high vegetation cover in the some parts of the university probably contributes to low erodibility. Similarly, the presence of high organic matter increases cohesion of soil particles thereby lowering erodibility. Okemesi and apomu series are moderately rich in clay particles. They are able to form stable aggregates, which makes them less susceptible to erosion than other soil types. These soils are still moderately erodible. Ekiti State falls in areas with minimal anthropogenic activities.

The area occupied by ekiti soil series have not been released by the aborigines, it consist of community sacred grove. The portion covering almost 1,000 ha is reported as the most viable agricultural land in the University.

Erosivity of Rainfall (R factor): Variability distribution of the erosive power of rainfall is presented in fig 7.

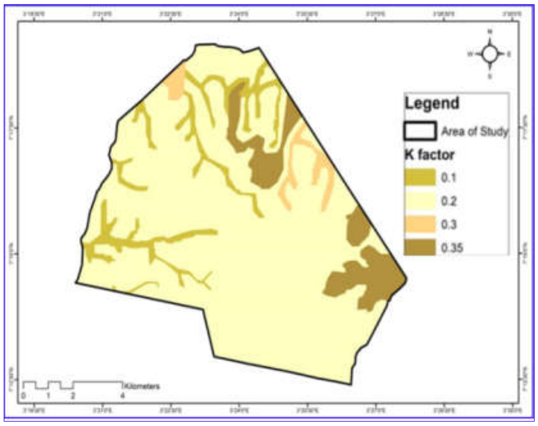

Fig.6. Erodibility distribution across the university

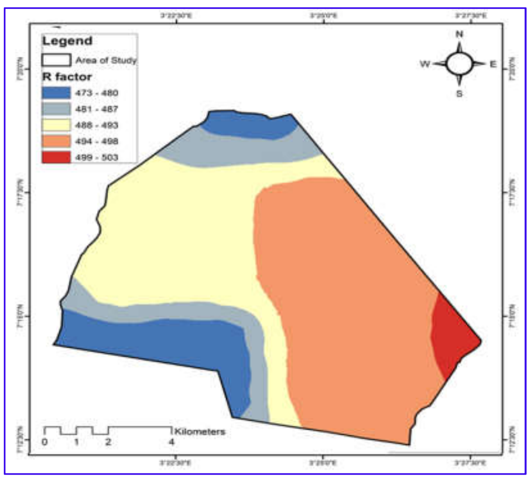

Fig. 7. Erosivity of rainfall (R-factor) across the University land

The detaching power of raindrops and scouring influence of runoffs are important considerations in soil erosion (Morgan e*t al*., 1994).

Land cover and Land management (C&M) factors: To produce the cover and management (C-factor) map; which gives the relative influence of "vegetation cover and management practice" (Krasa *et al*., 2009) on erosion of soil, each land cover types were reclassified as shown in table 3 in line with Lee and Lee, (2006) and Ganasri and Ramesh, (2016).

The values in table 3 is presented as a map in figure 8

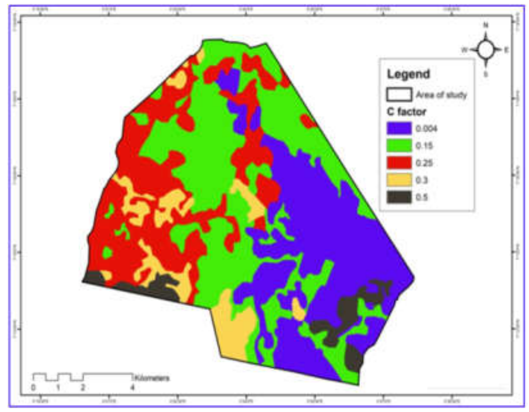

Fig. 8. Cover and management (C & M) factors in FUNAAB land area

Table 3: Land use types and corresponding C-factor values

Land Use	C Factor
Densely Vegetation	0.004
Derived Savanna	0.15
Intensive Agriculture	0.3
Extensive Agriculture	0.25
Bare/Built-up lands	0.5

Topographic factors: The effect of landscape on erosion in soils can be assessed through length and steepness of slope of an area. The potential for soils to be washed away by any agent of erosion increases length and steepness of the slope in that area (Ferreira *et al*., 2015; Gaubi *et al*., 2017). In FUNAAB soil series, elevation value ranges from 50 m to 700 m. Most of parts of the soil series are characterized by low LS factor values which consequently favor low to moderate soil loss. The University land area according to topography (LS factor) can be classified into five as shown on the map in figure 9. About ninety per cent of the University land has LS values of less than 0.02 percent; indicating that imperceptible erosion. Locations where LS values exceed 5 percent are almost inconsequential.

The overall annual erosion map: The RUSLE equation is the product of all factors that contribute to soil erosion, hence the maps in figures 5, 6, 7, 8 and 9 were multiplied in turns to give the overall erosion map in figure 10. The resulting map show that the overall soil erosion ranges from 0 to 167.8 tons per hectare per annum.

The least value ranges between 0-1.3 tons $ha^{-1}yr^{-1}$, while the highest range of value is from 87.6 to 167.8 tons $ha^{-1}yr^{-1}$. Juxtaposing the map of annual soil loss with that of the soil series helped in identifying locations where potential soil loss is pronounced.

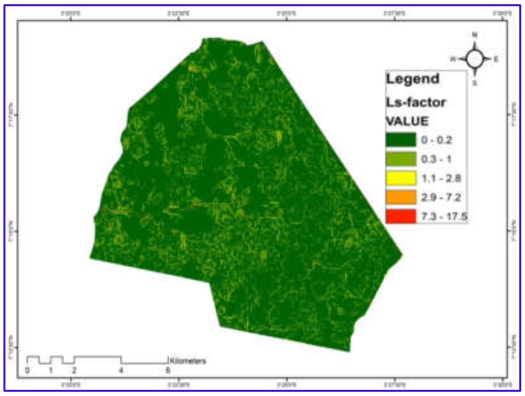

Fig. 9. Topographic factors (LS) of FUNAAB land area

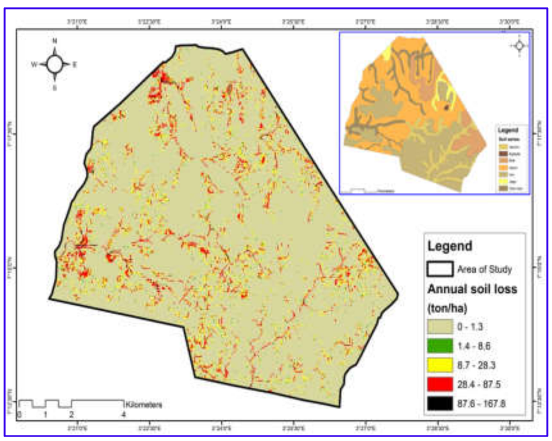

Fig. 10. The map of annual soil loss (Inset: FUNAAB soil series)

For example, Egbeda, Ekiti, Iseyin and Iwo series does not have serious soil loss problems because of favourable cover and slope factors. This is evident from figure 9 that the location of the four soil series have 0 to 1.3 ton/ha of soil loss. Areas with noticeable soil loss ranging between 28.4 to 87.5 tons /ha (in yellow, red and black colours) include Jago, Oke-imesi and Apomu soil series. Incidentally, these three series are along river fringes; where topography (Slope length) play major role. Locations with potential soil loss above 100 tons per hectare are pockets within these three series. It will also be noticed that the soil series with pronounced erosion are those at the fringes of river banks. Generally, the annual soil loss map does not depict that large portions of the University land have serious issues with soil loss yet. particularly since not more than 10% of the 10,000 hectares loses up to 1.3 tons of soil per hectare per year

Conclusion: The study reveals variation amongst the soil series with regards to erodibility and other factors of erosion. Topography has the strongest influence on soil loss. Meanwhile, less than 10% of the 10,000 hectares are vulnerable to erosion; losing up to 1.3 tons of soil per hectare per year. Of the several factors required for soil conservation; proper land management, adequate land cover (vegetation) and good drainage system would be useful in keeping soil loss rate below 10 tons/ha.

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