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Assessment of Revised Universal Soil Loss Equation (RUSLE) in Katsina Area, Katsina State of Nigeria using Remote Sensing (RS) and Geographic Information System (GIS)

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Abstract: The Revised Universal Soil Loss Equation (RUSLE) parameters were assessed using Satellite Remote Sensing (RS) and GIS with a view to model soil erosion in Katsina area of Katsina State of Nigeria. Data on parameters such as slope factors, crop cover and management practice support (P) were obtained from obtained for Katsina area for Digital Elevation Model (DEM) and Landsat ETM +, 2002 of the area. The estimated potential mean annual soil loss of 17.35 ton/ac/yr based on the refined RUSLE was obtained for the study area. Also, the potential erosion rates from the erosion classes identified ranged from 0.0 to 4185.12 ton/ac/yr. About 65.47% of the study area was classified under the first class with erosion rate between 0.0 and 10 ton/ac/yr. The most severely eroded area with rates of erosion between 104.80 and 4,185.12 ton/ac/yr accounted for about 1.86% of the study area. On the whole, this study has demonstrated the significance of Satellite (RS) and GIS technologies in modeling erosion.

Key words: Assessment % RUSLE % Satellite Imagery and Potential Soil Erosion

INTRODUCTION

Erosion can be described as the wearing away of the earths surface material by wind, water, ice or gravity. Problems associated with the accelerated erosion persisted for more than a million geologic years ago in almost all parts of the globe. However, the situation is compounded in recent times by man's increasing interactions with the environment and the fact that data collections on soil erosion is usually capital intensive as well as a time consuming exercise. Hence, global extrapolation of a few data collected through various diverse and non-standardized methods often leads to gross error and consequently, it can lead to wrong assessment on critical policy issues. In this regard, remote sensing especially Satellite Remote Sensing provides a convenient technique to solve this problem. Remote Sensing (RS) and Geographic Information System (GIS) enable manipulation of spatial data of various types. The ability to extract overlay and delineate any land characteristics make GIS suitable for soil erosion modeling.

A number of parametric models for predicting soil erosion exist e.g. Universal Soil Loss Equating (USLE), Revised USLE (RUSLE), Modified USLE (MUSLE),Water Erosion Prediction Project (WEPP) and Soil Loss Estimation Model for Southern African (SLEMSA). Both USLE and WEPP by [1], are widely used in North American and even adopted and applied in other regions of the world (e.g. [2] in Southwestern Nigeria; [3] in South eastern Nigeria and [4] in Milewa Catchments, Kenya). For instance, [2] in South western Nigeria substituted the Wischmcier and South's R factor with the [5] rainfall erosivity (R) index which was not adequately modeled by USLE because of high intensity of tropical rainfalls. [6] Examined the relative efficiencies of erosivity indices in the soil loss equation in Southeastern Nigeria.

Also, some published studies existed on the application of RS and GIS technologies to modeling of soil erosion in other parts of the worlds (e.g. [7], [8] and [4]). However, there is little or no known work on the application of GIS to erosion modeling in Northern Nigeria if not in the whole of Nigeria. Thus, the more recent version of the USLE, the Revised Universal Soil applied in

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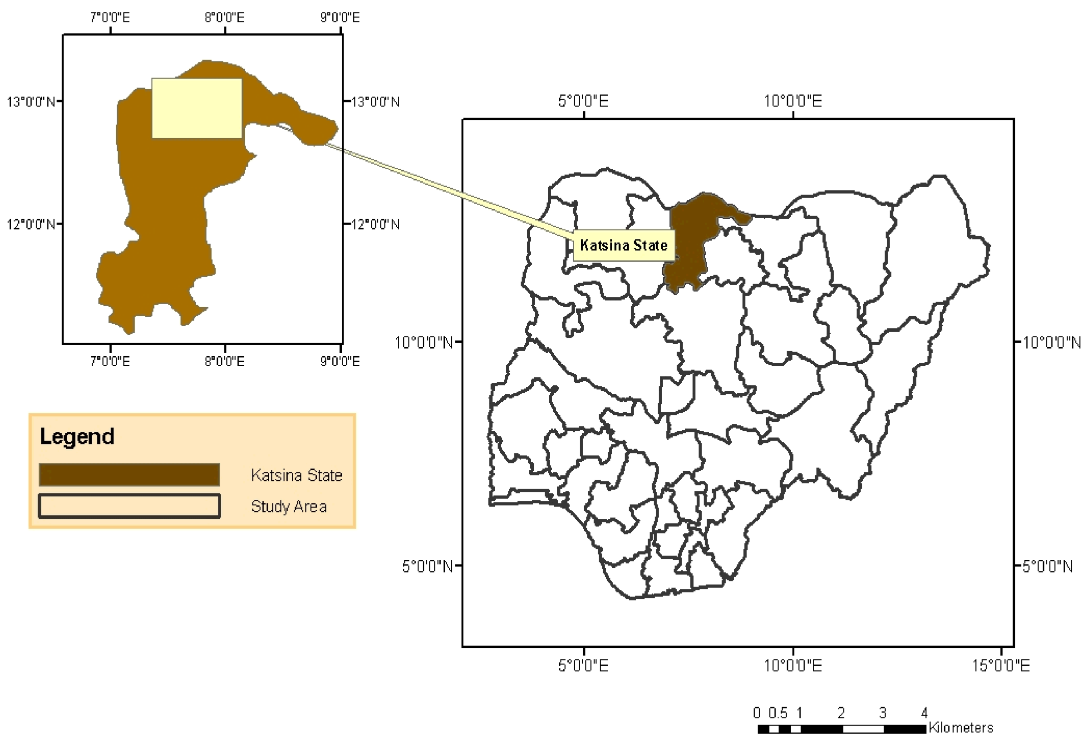

Fig. 1: Map of Katsina State showing the study area

this study to erosion modeling in Katsina area of Katsina State of Nigeria. RUSLE uses the same empirical principles as the USLE but includes improved rainfall erosivity factor ®, incorporation of the influence of profile convexity / concavity using segmentation of irregular slopes and improved empirical equation for computing slope factor (LS).

The RUSLE can be expressed as:-

$$A = RXKXLSXCXP \quad (1)$$

Where A = average soil loss (ton/ac/yr); R = rainfall erosivity factor (MJ.mm / ha.hr.yr); soil erodibility factor (ton/ac/unit R). LS = slope factor (dimensionless); C = cover factor (dimensionless) and P = prevention practices factor (dimensionless). The effective determination of the RUSLE factor is fundamental to estimation of soil loss from cropland and rangeland. Specifically, interfacing GIS analysis capabilities with the RUSLE provides the resource specialist with a tool to visualize quickly the soil erosion potential area based on several major environmental parameters for large areas. Therefore, the eroded area in Katsina area will be categorized into various classes using RS and GIS techniques.

Study Objective:

The specific objectives of this study are to:

- Identify areas that have been affected by soil erosion
- Estimate the potential soil loss from the affected area using RUSLE
- Generate Erosion Hazard Map for the study area.

Study Area: Katsina area in Katsina State of Nigeria constitute the study area. It lies between Latitude 12°30'N and 13°N and Longitude 7°30'E and 8°East of Greenwich Meridian (Fig. 1). It covers an area of about 3,025km^2. The area is bordered to the south by Musawa and to the north by Dankama. The area is further bordered to the West by Ruma and to the East by Kazuare (Jigawa State). The area also covers Rimi, Kanya, Charanchi and Batagarawa. Local Government Areas as well as Bindawa, Mane and Mashi. The area is drained by major rivers such as the Koza, Sabke, Tagwai and Gada System in the northern part of the state.

The area is characterized by Tropical Continental Climate (Sudan Type). The mean annual rainfall ranges between 600 and 1100mm. The temperature during Harmattan season ranges from 18° to 27°C. Also, the maximum temperature ranges between 29° and 38°C.

Most parts of the study area are underlain by light sandy soils of low-medium fertility. The vegetation of the area consists of trees characterized by long tap roots and thick barks (e.g. *Acacia sp.* and *Eucalyptus sp.*). This makes it possible for them to withstand the long dry season and bush fire. Specially, Katsina area plays a leading role in the production of a lot of cash and food crops (e.g. *Gossypium sp. Arachis hupogaea, Phaseoulus sp., Penisetum americanum and Oryza sativa*) for the country.

The dramatic population growth, overgrazing and large dependency on agriculture as well as the use of wood as fuel are responsible for land use /cover dynamics in the area. Land degradation is quite common in the area and in fact, large area of the land surface is under the threat of desertification. This consequently exposes the soil to erosion.

Study Method: Data used for evaluation of RUSLE factors and generation of Erosion Hazard Map in this study were obtained from Secondary sources. These data were processed using the maximum likelihood classification algorithm in ERDAS Imagine and the spatial analyst and 3D analyst extensions of ARC GIS 9.2 software for spatial analysis.

The materials used include topographic sheets, Landsat ETM+2002 (resolution of 30m and path /Row of P189R51) obtained from the Global Land Cover facility (GLCF) website, rainfall distribution and soil erodibility shape file were collected from African Regional Centre for Space Science and Technology Education (ARCSSTEE), OAU,Ile-Ife, Nigeria.

Rainfall Erosivity Factor (R): The average annual rainfall data of the study area for the period of 25 years (1982-2006) was obtained from the Nigeria Metrological Agency (NIMET). Although the annual R index is not directly linked to annual rainfall, however, [9] in West Africa has shown that:

The main annual rainfall erosivity over 10years = mean annual rainfall *a….(2)

Where a = 0.05 in most cases ± 0.05
= 0.6 near the sea (<40km)
= 0.3 to 0.2 in tropical mountain areas
= 0.1 in Mediterranean mountain area

The rainfall pattern of the study area is such that rainfall increases southward with the northern parts receiving an average of 600mm of rainfall annually while the southern parts experience an average of 1000mm annually.

These values are inputted into equation 2 to derived R factor for the study area (Table 1).

Slope Factor (LS): Derivation of slope factor (LS) for the area involved generation of Digital Elevation Model (DEM) for the study area from the topographical sheet. The contour data were extracted from a topo sheet (1:100,000) of the study area through scanning and manual digitizing using Arc Map. The DEM generated was converted to a raster file with resolution set at 30m.[10] Slope layer was derived from the DEM. The LS factor was determined using equation developed. [11]

$$LS = (As/22.13)^m (\text{Sin } 2 /0.09)^n \quad (3)$$

Where As = upslope contributing areas per unit width of cell spacing; 2 =slope angle (degrees), m and n are exponent of slope parameters for slope length and gradient and the typical values of m and n are 0.4 - 0.6 and 1.0 - 1.4, respectively. Lower values of m = 0.4 and n =1.1 were used for the study area because of the undistributed nature of the area.

Land Cover Factor (C): The classification of a Landsat ETM + image was done using ERDAS IMAGINE software which was used to prepare land use/ land cover map of the study area. The result of the classification was used to derive the C-factor for each of the land cover identified (Table 2).

Table 1: C factor and Areal Coverage for Classes Derived from LandSat Image

Land-Use/Cover Classes	Areal Coverage(Acres)	C Factor
Town	23,407.5	0.99
Degraded Forests	24247.5	0.02
Savannah/Grassland	323,651	0.11
Agriculture (sparse)	362,440	0.16
Water bodies	15,286.6	0
Bare land	17,510.6	0.99

Table 2: K values for different soil textures

	Organic matter content (%)		
Textural class	0.5	2.0	4.0
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand Loamy	0.12	0.10	0.08
Very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Very fine sandy loam Silt loam	0.47	0.41	0.33
Clay loam	0.48	0.42	0.33
Silty clay loam	0.28	0.25	0.21
Clay	0.37	0.32	0.26
	0.25	0.23	0.19

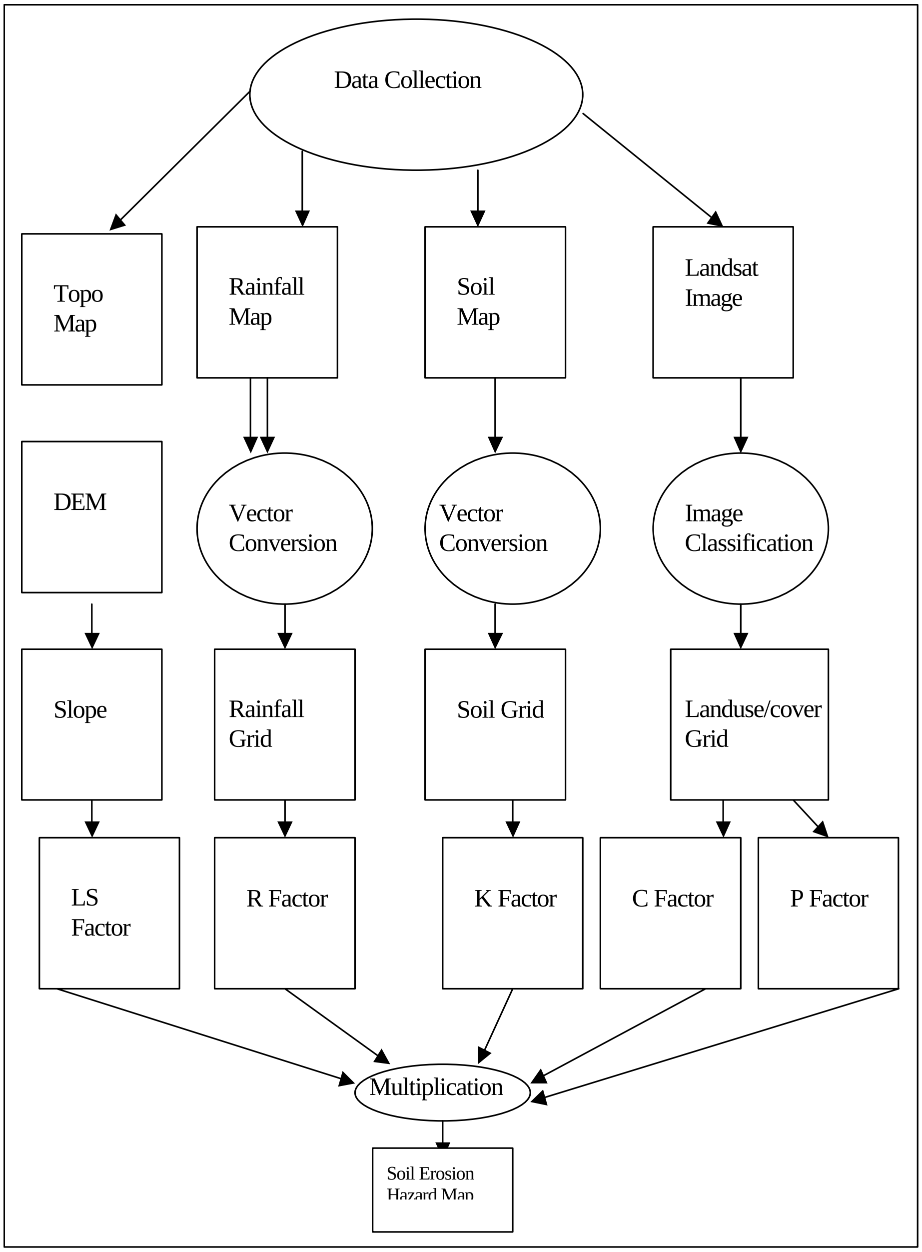

Fig. 2: Flow Chart of Study Methodology

Soil Erodibility Factor (k): A descriptive soil map of the study area was obtained from previous Food and Agricultural Organization (FAO) survey in Nigeria. The description in the Attribute Table enabled us to compute k factor for each textural class using the values in Tables 3.

Practice Management Factor (P): The P factor map was prepared from land use/cover map. [11] method was employed in this study to assign the P –values for the study area.

Table 3: R factor Values

Average Annual Rainfall	R factor
600mm	270
1000mm	450

Determination of Potential Annual Soil Loss: The estimated annual soil loss was computed by multiplying the grid layers of the factors described above in the GIS environment using Arc Map. The summary of the study method employed in this study is shown in Figure 2.

RESULTS AND DISCUSSION

The erosion values obtained through RUSLE can vary considerably due to varying weather conditions. The results obtained for the RUSLE factors are shown in Table 2-4 and Figure 3-10.

Rainfall Erosivity Factor (R): The distribution of the average annual rainfall distribution of Kastina over 22years period is shown in Fig.3. It is quite evident from Fig.3 that rainfall in the study area increases southwards with the northern part experiencing an average of 600mm of rainfall annually while the southern parts receive a mean of 1000mm annually. The map of rainfall erosivity index (R) derived for the study area is shown in Fig.4. The R factor values obtained (see Fig.4) compared favourably with those obtained by [4] in Malewa Catchments, Kenya. Although, [4] employed the erosivity regression equation proposed by [12] for Kenya hinterland, this R factor values of between 274.40 and 314.75 N/h for areas with average annual rainfall values between 600 and 800mm compared closely with values obtained in this study.

Table 4: P Factor Values (Wischmeier and Smith, 1978 (MCMLXXVIII))

Land Use Type	Slope %	P-Factor
Agriculture	0-5	0.10
	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

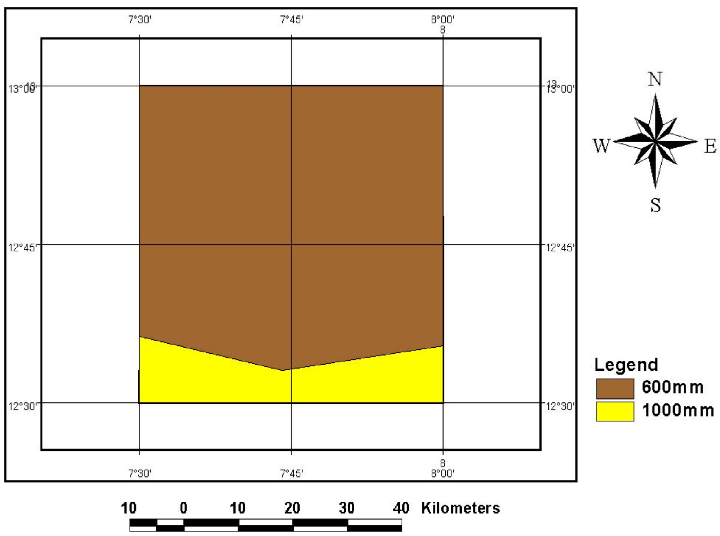

Fig. 3: Annual Rainfall Distribution in the Study Area

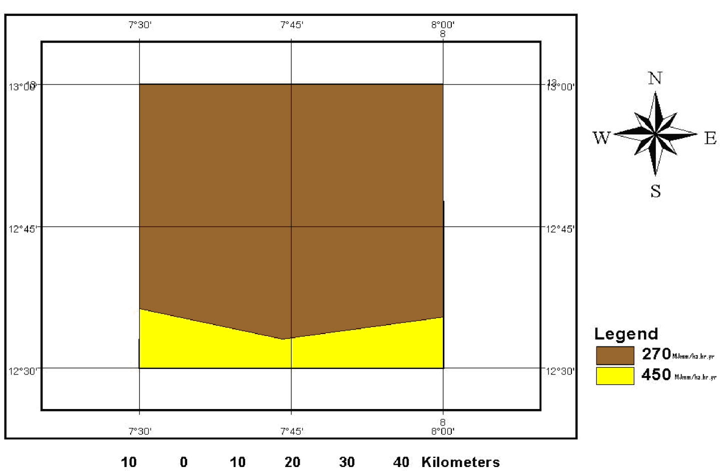

Fig. 4: Rainfall Erosivity, R, Map of the Study Area

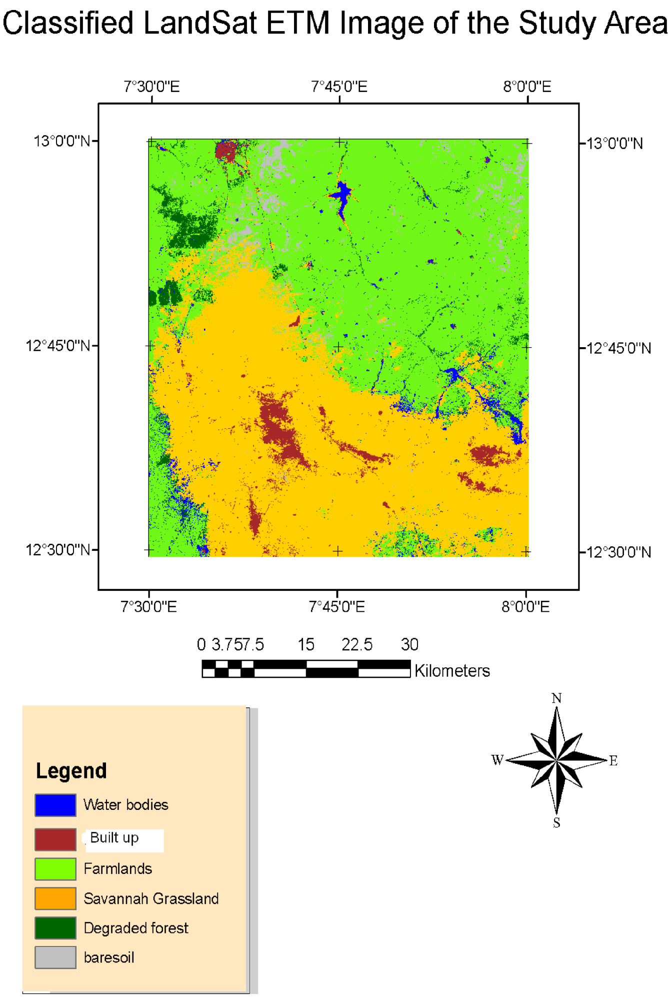

Fig. 5: Land-Cover/Land-Use Classes of the Study Area

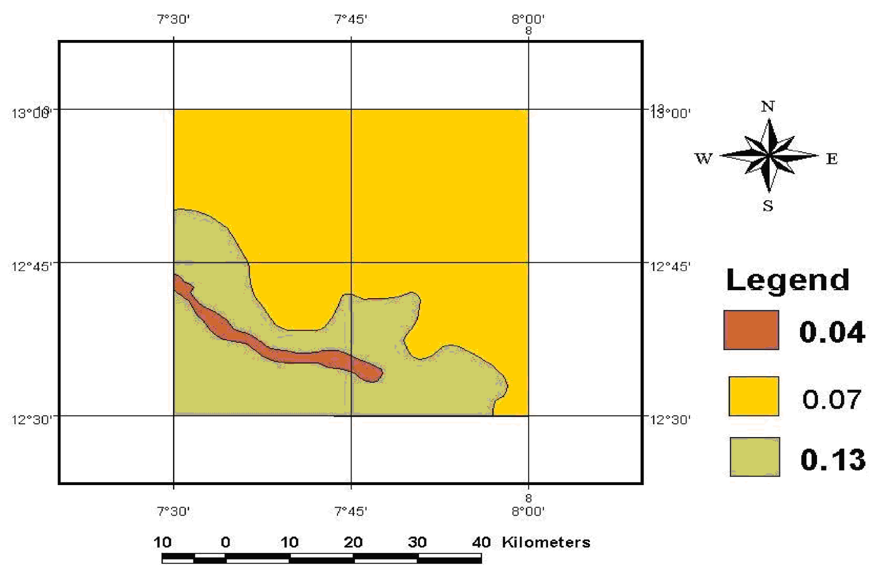

Fig. 6: Soil Erodibility, K factor Map of the Study area

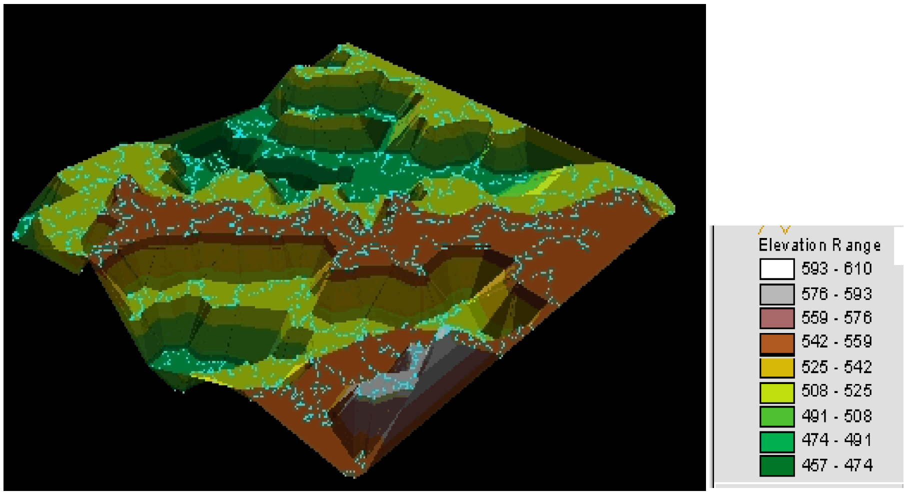

Fig. 7: DEM of the Study Area

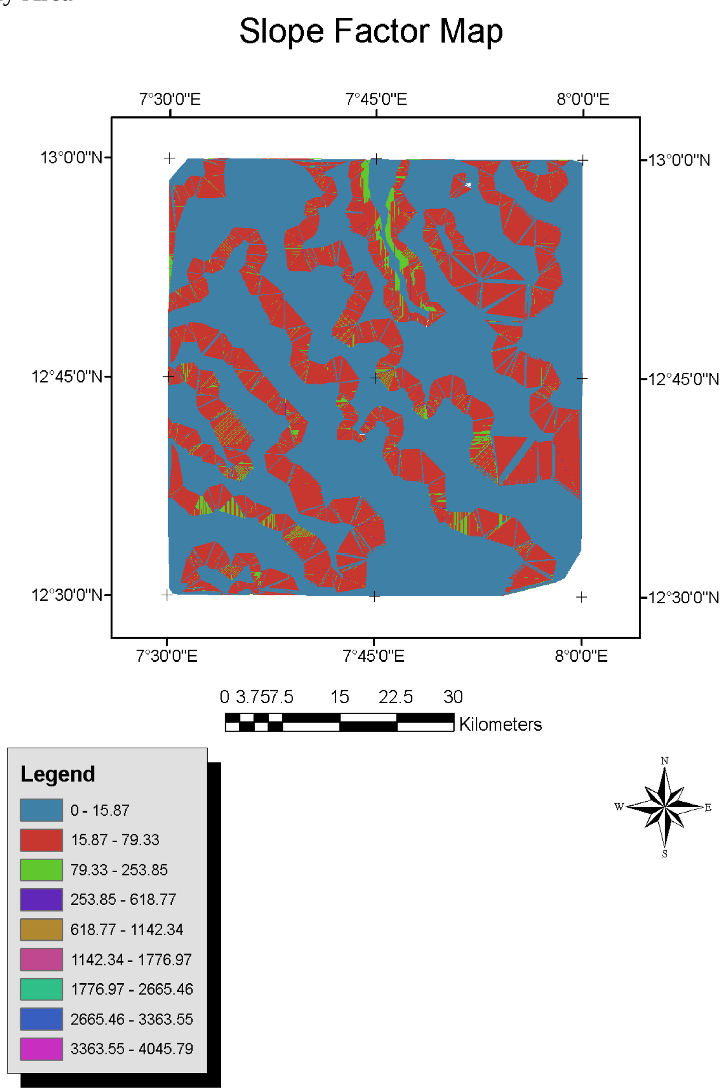

Fig. 8: Slope factor Map

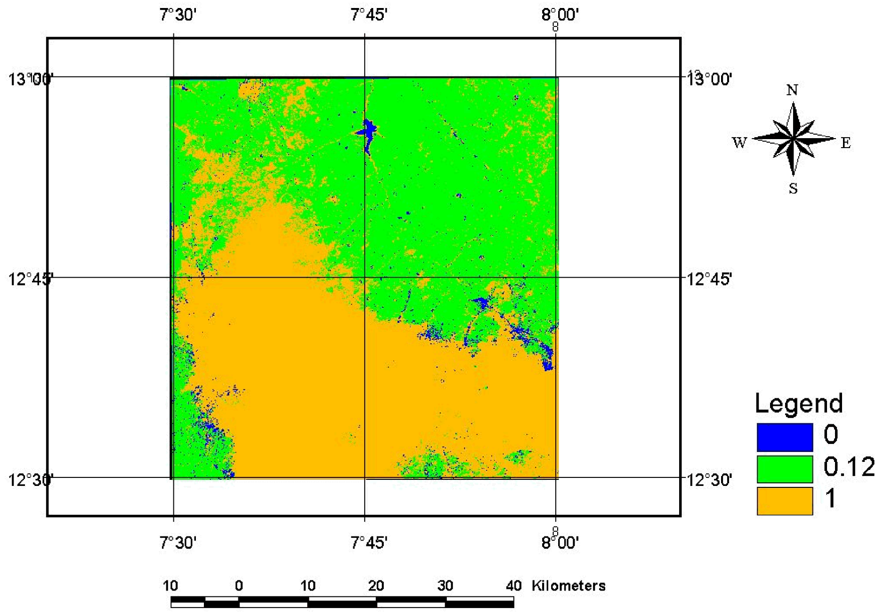

Fig. 9: Support Practices Factor, P, Map of the Study Area

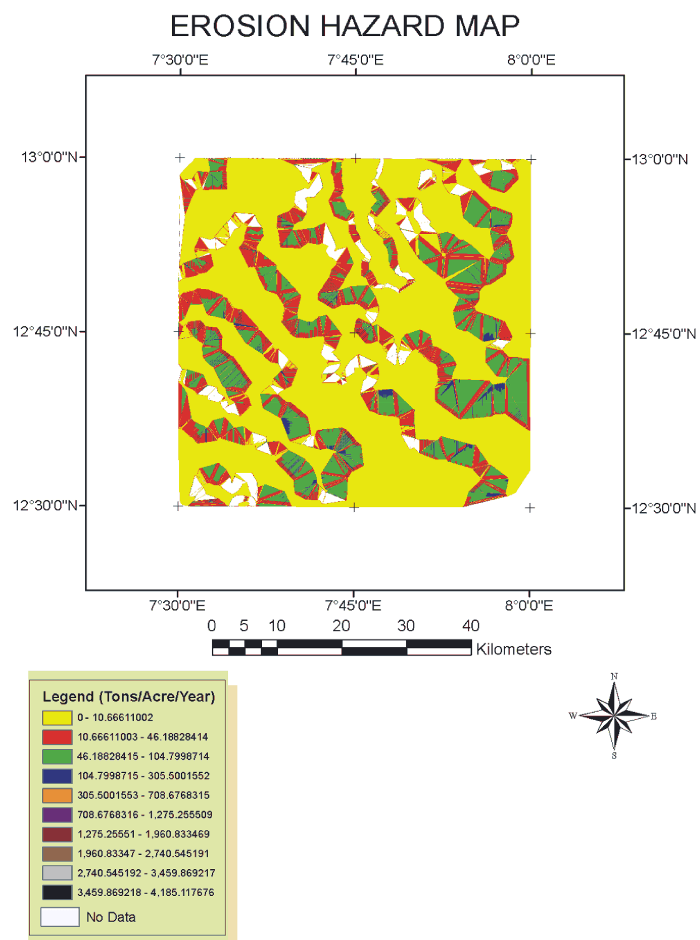

Fig. 10: Erosion Hazard Map

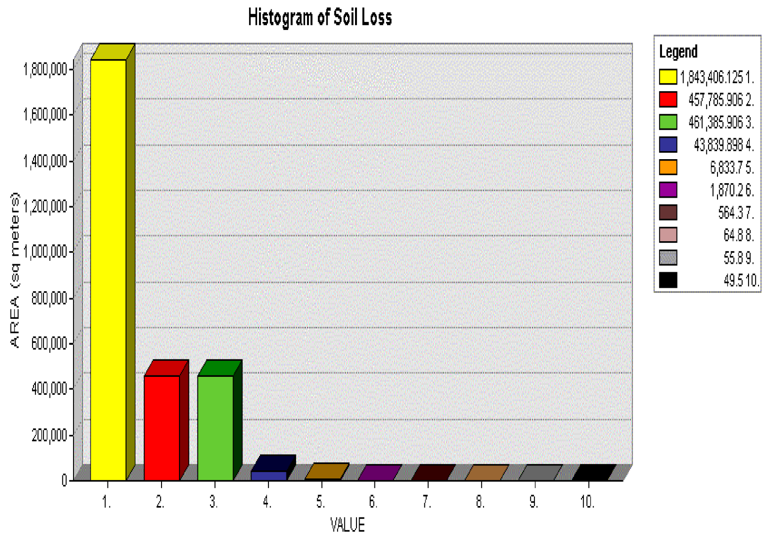

Fig. 11: Histogram of soil loss

Soil Erodibility Factor (k): Soil erodibility (k) represents both susceptibility of soil to erosion and the rate of runoff as measured under the standard and plot condition. The erodibility index map derived from FAO's Soil map of the study area is shown in Fig.5. The k-values obtained for the study area ranged from 0.04 to 0.13.

The Slope/Topographical Factor (SL): The slope/ topographical factor (SL) depends on both the length and gradient of slope. It has been observed that soil loss increases more rapidly with slope steepness than it does with slope length. This study employed the modified SL equation developed by [11] instead of Wischmeier and Smith's SL to determine the upslope 104.80-305.50 ton/ac/yr, respectively. The two classes combined cover 32.65% of the area shown in Fig. 11.

It is evident from in depth analysis of all factors that SL factor seems to have a significant effect on the estimated total soil loss in the area. This is because the areas mostly affected by erosion within the study area coincided with the areas where SL factor is the highest contributing area. The DEM and SL factor map generated for the study area are shown in Fig. 6 and 7.

Crop Cover (L) and Management Practice (P) factor: As evident from Table 4 and Fig. 8 (histogram) of land use/cover distribution, the greater proportion of the study area is under farmland (including grazing) and savanna. Also, towns /built-up account for small proportion of the area (Fig. 8). The C factor for land use /cover classified in the area ranges from 0.02 (degraded forest) to 0.16 for agricultural land. This implies that erosion is lower under the degraded vegetated area than the agricultural/grazing land. The C-factor map for the study area is shown in Fig. 8. The result on management / support practice (P) is shown in Fig 9. The support practice factor affects erosion by modifying the flow pattern or direction of surface runoff as well as reducing the amount and rate of runoff.

RUSLE Model: The mean annual soil loss estimated for the study area using RUSLE was put at 17.75 ton/ac/yr. Based on the model, the study area was classified into ten erosion classes ranging from 0.0 to 4185.12 ton/ac/yr (Fig. 10). However, 65.47% of the Kastina area is within the first class with erosion rates ranged from 0.0 to 10 ton/ ac/yr. This is considered to be within the moderate range. The most severe eroded areas with erosion rates of between 104.80 and 4,185.12 ton/ac/yr accounts for 1.86% of the study area. The areas within the third and fourth class have severe erosion rates of between 46.19 and 104.80 and 104.80 and 305.50ton/ac/yr, respectively. The two classes combined cover 32.65% of the area shown in Fig. 11.

It is evident from in depth analysis of all factors that SL factor seems to have significant effect on the estimated total soil loss in the area. This is because the areas mostly affected by erosion within the study area coincided with the areas where SL factor is highest.

CONCLUSION

A detail evaluation of RUSLE parameters in Katsina area of Katsina State, Nigeria was carried out in this study using Remote Sensing (RS) and GIS platforms. Ten erosion classes were classified from the Landsat ETM +

image of the area. The landuse/cover classes identified are builtup/towns degraded forests, farmlands, grassland, bare land,and water bodies. Farmlands (36.7%) followed by -grasslands (32.6%) covered the largest extent of the study area overall. The potential rates of soil loss from the ten classes ranged from 0.0 to 418.10 ton/ac/yr. However, the mean soil loss estimated for the study area was put at 17.75 ton/ac/yr. The most severely eroded part of the study area account for about 1.86% of the total area extent. On the whole, this study has demonstrated conclusively that Remote Sensing and GIS are useful tools for modeling soil erosion, evaluating various disturbance alternative and spatial optimization of conservation measures.

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