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Research Article

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Mapping Soil Erosion Risk using Revised Universal Soil Loss Equation Model, Geographic Information System and Remote Sensing: A case study of Akure, Nigeria

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Abstract Gully and rill erosion features have been observed in Akure city. These features have devastating effects on human lives and properties in the region. This study estimates the amount of soil loss and generates a map of erosion risk areas in Akure with the aim of mitigation and risk management. The Revised Universal Soil Loss Equation model equation was integrated with Geographic Information System and Remote Sensing techniques to estimate the average rate of soil loss and to map the severity of the erosion. The Revised Universal Soil Loss Equation model takes into consideration the rainfall erosivity, soil erodibility, slope length and steepness, cover management and support practice factors. The erosion risk map was classified into low, moderate and high risk. Low risk zones cover an area of 964.64km^2 which is 96.3% of the total area, moderate risk zones cover an area of 32.81km^2 which is 3.3% of the total area and high risk zones cover an area of 4.29km^2 which is 0.4% of the total area. The soil loss estimated, ranged from 0 to 579.131 ton/ha/yr. The problem with erosion in Akure city was identified as lack of soil conservation practice implementation which has led to scattered patches soil loss in the region.

Keywords Soil loss, Erosion risk mapping, GIS, RULSE, Soil Conservation

1. Introduction

Soil erosion is a naturally occurring environmental process by which soil materials are displaced, transported, and deposited in downstream areas by wind, water, or gravitational forces [1-2]. In the context of water-caused soil erosion, removal of soil particles is the result of raindrops, while surface runoff carried out the transportation process [2-3]. The economic implications of soil erosion are more serious in developing countries because of lack of capacity to cope with it and also to replace lost nutrients [4]. Soil erosion models (such as Revised Universal Soil Loss Equation model) use mathematical expressions to represent the relationships among various factors and processes occurring in the landscape [4]. Nowadays, the Revised Universal Soil Loss Equation (RULSE), in combination with satellite remote sensing and Geographic Information Systems (GIS) mapping techniques, is found to be a convenient tool for soil loss assessment and successful conservation planning [2, 5-7]. In Akure city, the lack of soil conservation practice and decrease in vegetative cover has increased vulnerability of the city to erosion. This increase in erosion has led to loss of nutrient rich top soil and sedimentation of Alariver – the major river draining the city. The goal of this study is to estimate the rates of soil loss and to generate an erosion risk map of Akure city.

2. Methodology

2.1. Study Area

Akure city is the capital of Ondo State, Southwest Nigeria. It lies between longitude 5^o 0” to 5^o 30” and latitude 7^o 4” to 7^o 27”. Akurecity is made up of two local governments which are Akure North and Akure South. The city has a population of 484,798 (National Population Census, 2006).Akure is an agricultural trade centre for cassava, corn, rice, palm oil and kernels and banana. Akure city covers an area of 1,001.74 km^2. The city has a tropical climate and experiences more rainfall months with a short dry season. Akure is considered to be Am according to Koppen-Geiger climate classification. The average annual temperature is 26.7^{o}C and an average of 2378mm of rainfall annually. The city is composed of lowlands and rugged hills with granitic outcrops in several places. The natural vegetation is the high forest which is composed of varieties of hardwood timber. In the northern part, the vegetation consists of woody savanna featuring such tree species as Blighiasapida and Parkiabiglobosa.

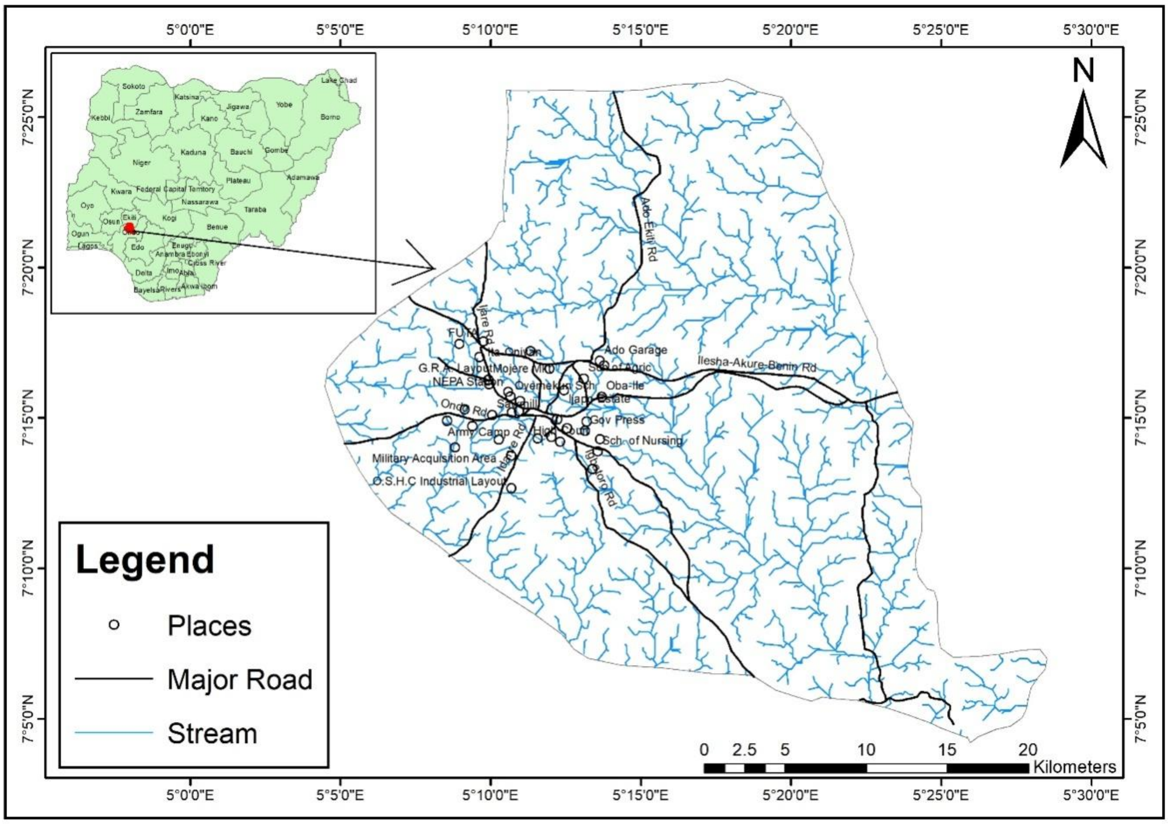

Figure 1: Study Area Map

2.2. Data

The data used for the study includes rainfall, soil types and properties, Landsat 8 Operational Land Imager(OLI) and Shuttle Radar Topography Mission (SRTM) Imagery.

Rainfall data for Akure was acquired from the Nigerian Meteorological Agency (NIMET) for the period of 30 years ranging from 1988 to 2017.This was used to generate the rainfall erosivity factor.

Soil types and properties were extracted from the Harmonised World Soil Database (HWSD) by Food Agriculture Organisation (FAO). This was used to generate the soil erodibility factor.

Landsat 8 Operational Land Imager (OLI) was acquired from the United States Geological Survey (USGS) imagery distribution platform. The imagery was used to produce the Normalized Difference Vegetation Index (NDVI) map to generate the cover management factor.

SRTM was used as Digital Elevation Model (DEM) data was acquired from the United States Geological Survey (USGS) imagery distribution platform. This data was used in production of the slope length and steepness factor.

2.3. Method

Revised Universal Soil Loss Equation was adopted for this study. RUSLE is widely used to predict long-term rates of erosion in a location subject to different management practices [8]. The assumption in RUSLE is that detached or deposited soils are controlled by sediment content of flow. The eroded material is not source limited but limited by the carrying capacity of flow [9]. The equation is a function of five input factors in raster data format; rainfall erosivity, soil erodibility, slope length and steepness, cover management and support practice [10]. The equation is:

$A = R \; x \; K \; x \; C \; x \; LS \; x \; P$

where;

A = Annual Average Soil Loss (t ha^{-1} yr^{-1})

R = Rainfall Erosivity (MJ mm ha^{-1} h^{-1} yr^{-1})

K = Soil Erodibility (t ha h ha^{-1} MJ^{-1} mm^{-1})

C = Cover management (Dimensionless)

LS = Slope Length and Slope Steepness (Dimensionless)

P =Support Practices (Dimensionless)

Rainfall erosivity (R) factor takes into consideration the active force of rain which detaches and transport soil particles (Ahmed, 2012). The R factor equation adopted is;

R = 0.5 * P * 1.73 (in Metric unit) [11] **Equation 1**

Where, $P = Precipitation$

Soil erodobility (K) factor represents the susceptibility to soil erosion, the amount and rate of runoff measured under standard plot condition [12]. The K factor equation adopted in this study is;

$K = 27.66m1.14 \; x \; 10 - 8 \; x \; (12 - a) + 0.0043 \; x \; (b - 2) + 0.0033 \; x \; (c - 3)$ [13] **Equation 2**

$where;$

$K = Soil \; erodobility \; factor \; (ton/hr/haMJmm)$

$m = (Silt\% + Sand\%) \; x \; (100 - clay\%)$

$a = \% \; organic \; matter$

$b = structure \; code$: 1) $very \; structured \; or \; particulate$, 2) $fairly \; structured$, 3) $slightly \; structured$ and 4) $solid$.

$c = profile \; permeability \; code$: 1) $rapid$, 2) $moderated \; to \; rapid$, 3) $moderate$, 4) $moderated \; to \; slow$, 5) $slow$, 6) $very \; slow$

Cover management (C) factor is the ratio of soil loss from cropped land under specified conditions to the corresponding loss from clean-tilled, continuous fallow land [13]. The Normalised Difference Vegetation Index (NDVI) was used to determine the C factor using [14];

$C = exp\left[-\alpha \frac{NDVI}{\beta - NDVI}\right]$ **Equation 3**

whereα and β are unitless parameters that determine the shape of the curve relating to *NDVI* and the *C* factor. The slope length and steepness is a ratio of soil loss under given condition to that at a site with the standard slope steepness of 9% and slope length of 22.6m [8]. Flow accumulation and slop[10];

$LS = (Flow \; Accumulation \; x \; Cell \; size \; / \; 22.13)0.4 \; x \; (Sin \; Slope \; / \; 0.0896)1.3$ **Equation 4**

Support Practice (P) factor is the ratio of soil loss after a specific conservative practice to the corresponding soil loss after upslope and downslope cultivation. The factor considers application of practices by humans to reduce the degree of erosion and amount of soil loss as a result of erosion [10].

3. Results and Discussion

R Factor

The average rainfall was calculated and used to generate the spatial distribution map of rainfall over Akure city. Figure 2 shows the rainfall distribution over Akure city. The rainfall ranges from 122.2mm – 126.9mm. The rainfall values were inputted into equation 1 for R factor to produce the spatial distribution of rainfall erosivity over the city. Figure 3 shows the rainfall erosivity map for Akure. The rainfall erosivity ranges from 105.7 – 109.8.

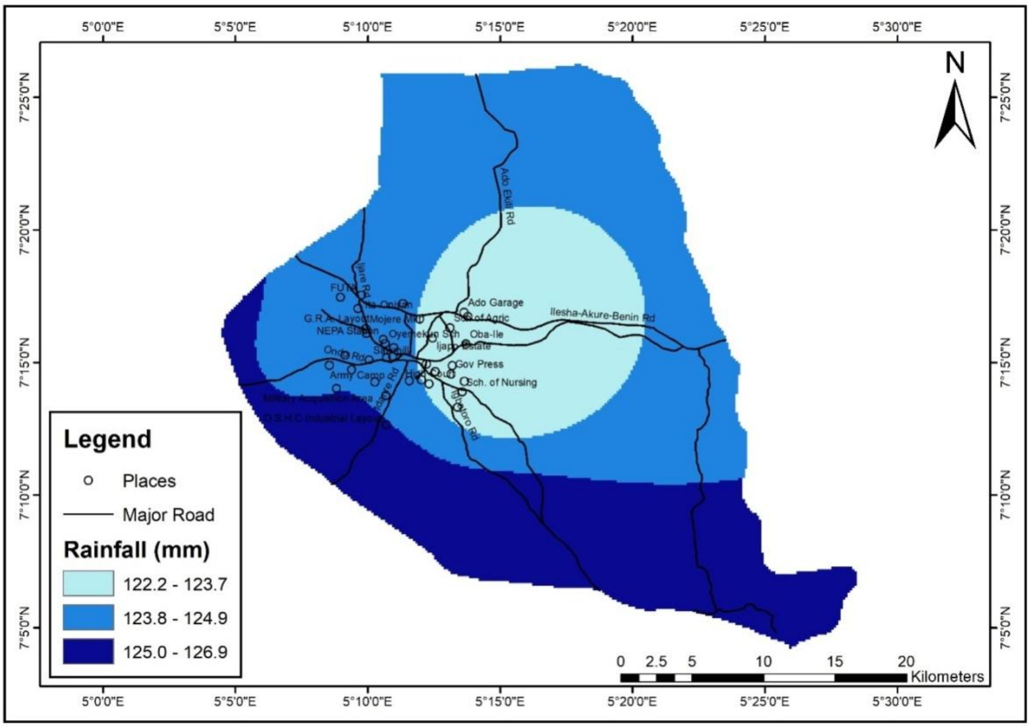

Figure 2: Rainfall Map

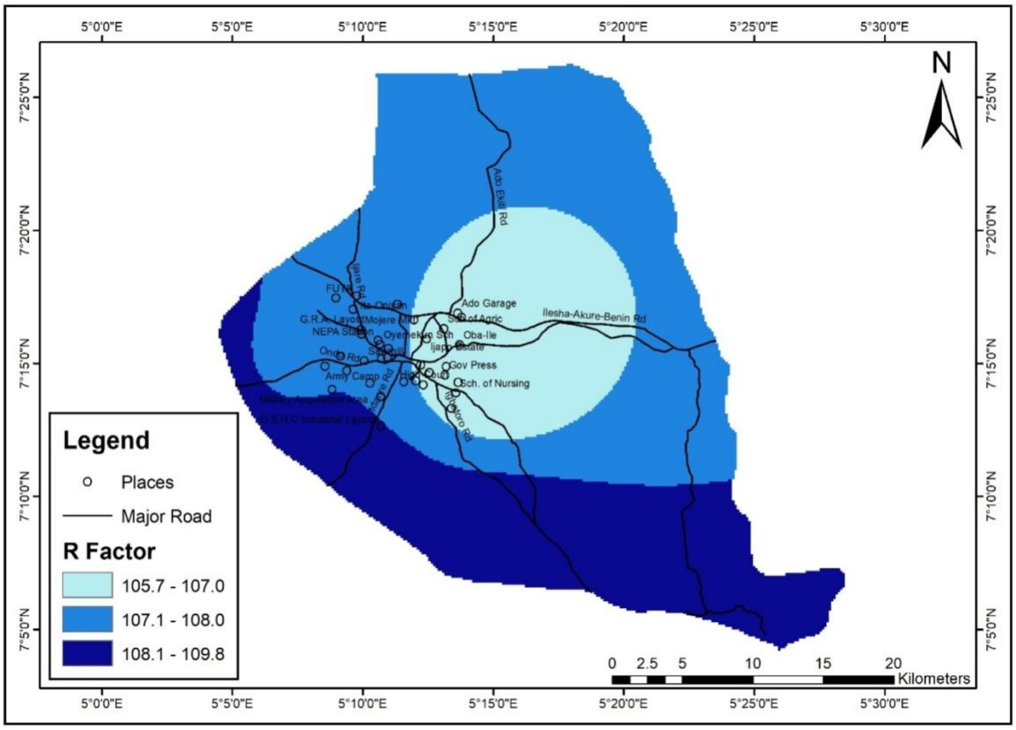

Figure 3: R Factor Map

K Factor

The soil erodibility factor is dependent on the type and characteristics of soil in the study area. Two types of soil were identified in the Akure city; Ferric Luvisols and EutricNitosols. Properties such as soil drainage, soil texture and content are used to determine the soil erodibility. K Factor was calculated using equation 2. Table 1 shows the K Factor of soil types in Akure city. Figure 4 shows the K factor map for Akure. The soil properties were input into equation 2 to produce the K Factor map. The K factor for Ferric Luvisols is 0.06 and EutricNitosols is 0.07.

Table 1: K factor for each soil type

Soil Type	K Factor
Ferric Luvisols	0.06
EutricNitisols	0.07

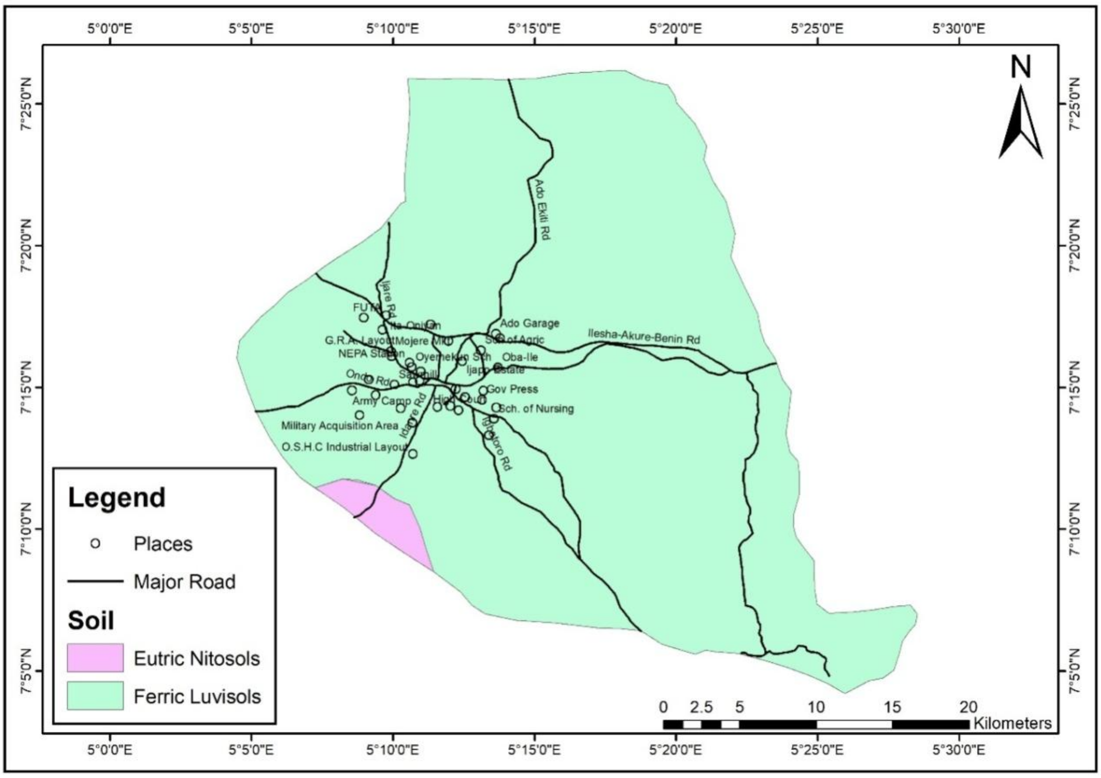

Figure 4: Soil Map

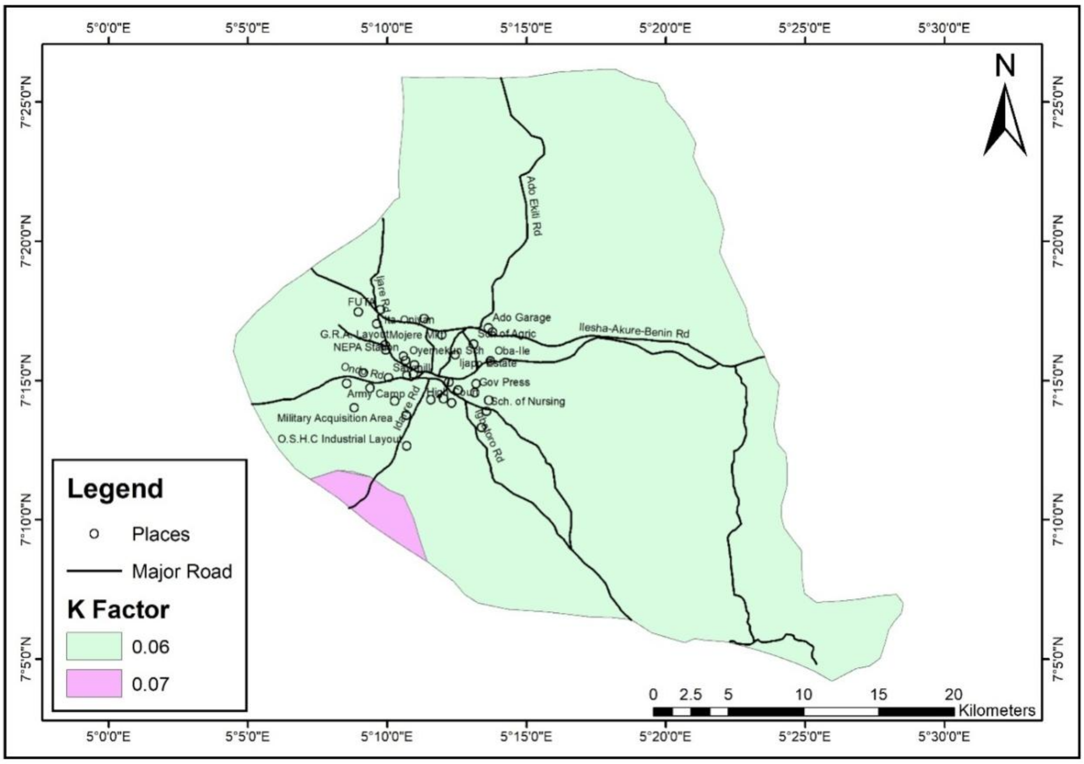

Figure 5: K Factor Map

LS Factor

The slope length and steepness was delineated from Digital Elevation Model (DEM) data. The flow accumulation and slope were taken into considering when calculating the LS factor. These factors were used as input in equation 3. The LS Factor ranges from 0 to 132.675. Figure 6 shows the slope length and steepness map.

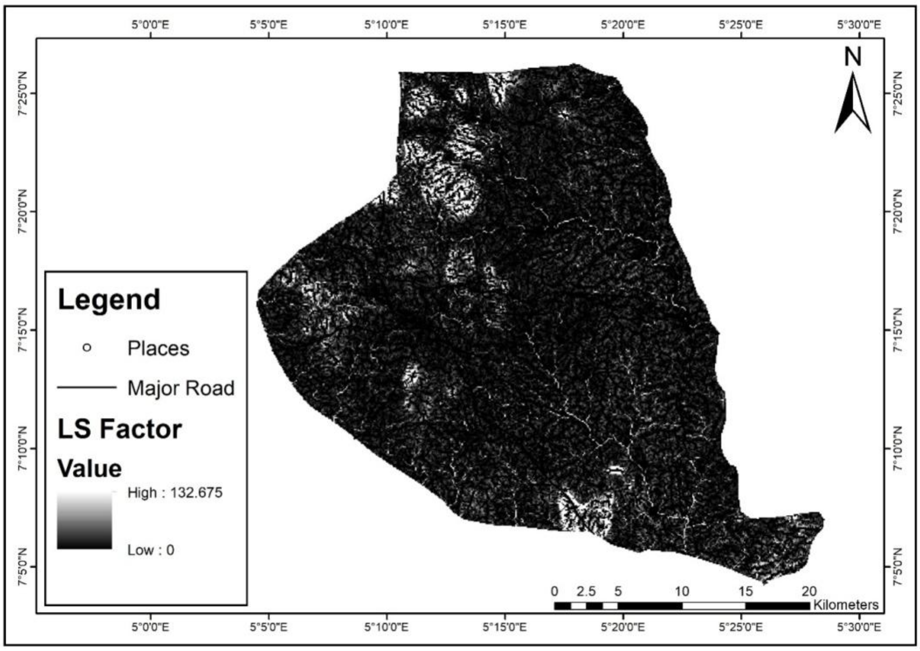

Figure 6: LS Factor Map

C Factor

Cover management factor was estimated using the Normalised Difference Vegetation Index (NDVI). The NDVI was fitted into equation 4 to generate the C Factor map. The C Factor ranges from 0.272398 to 0.92054. Figure 7 shows the cover management factor map for Akure city.

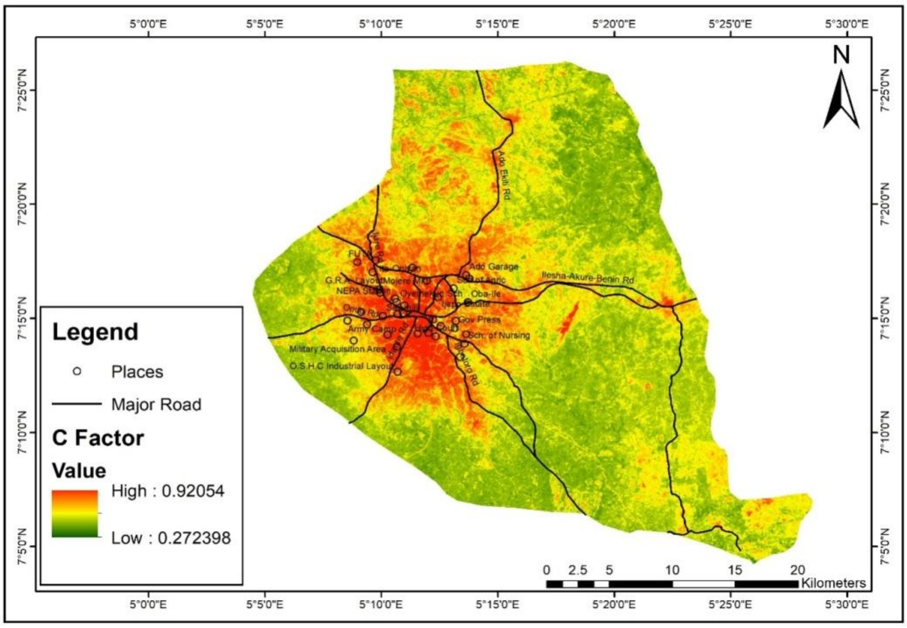

Figure 7: C Factor Map

P Factor

There are no records of conservation management practices for soil loss in Akure. The P value therefore was set to 1.

Soil Loss

Soil loss is measured in tonnes per hectare per year. The soil losswas determined by multiply all the factors. Figure 8 shows the soil loss map for Akure. The soil loss ranges from 0 to 579.131 t/ha/yr. Places with high soil loss are in scattered patches in the study area. Figure 9 shows the erosion risk map. The erosion risk was classified into three classes; low, moderate and high. Table 2 shows the area covered by each erosion risk class. Low risk zones cover an area of 964.64km^2 which is 96.3% of the total area, moderate risk zones cover an area of 32.81km^{2}which is 3.3% of the total area and high risk zones cover an area of 4.29km^2 which is 0.4% of the total area.

Table 2: Areas covered by erosion risk classes

Erosion Risk	Area (Km^2)
Low	964.64
Moderate	32.81
High	4.29

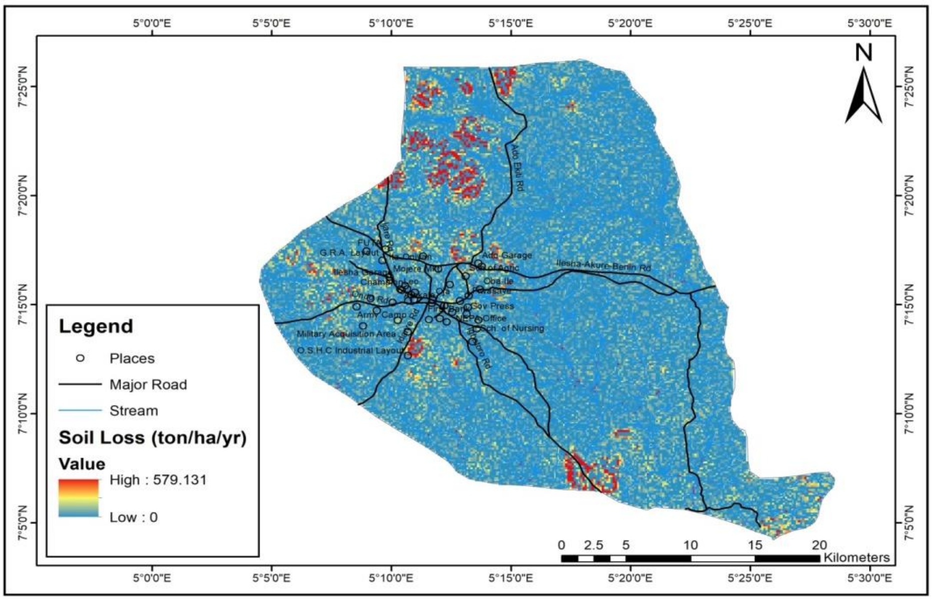

Figure 8: Soil Loss Map

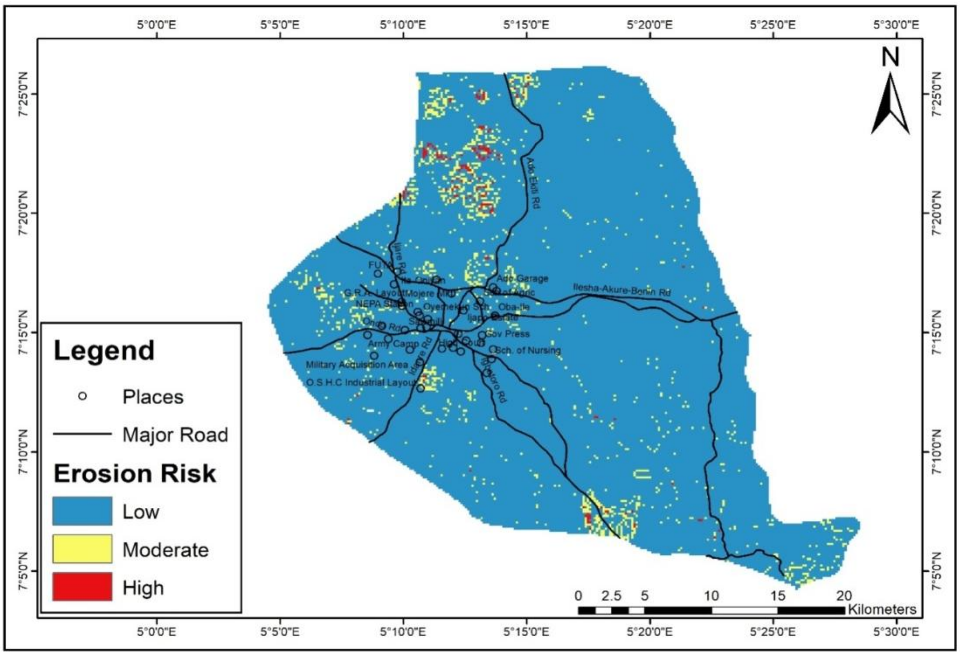

Figure 9: Erosion Risk Map

4. Conclusion

Remote sensing and GIS coupled with RUSLE model are useful tools in determining the spatial extent and amount of soil loss. Soil erosion in Akure are scattered over the land mass area in patches. The study shows that there are no support and soil conservation practices employed in Akure currently which has led to a widespread of soil loss in the area. The erosion map generated is useful for effective planning and management to mitigate soil erosion menace in Akure city. It is highly recommended that decision makers should encourage and implement soil conservation practices to forestall future soil erosion disaster in Akure.

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