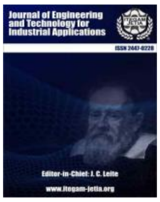
Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.9 n.42, p. 34-40. Jul/Aug, 2023.
DOI: https://doi.org/10.5935/jetia.v9i42.877



RESEARCH ARTICLE **OPEN ACCESS**

SOIL LOSS ESTIMATION USING RUSLE MODEL AND GEO-SPATIAL TECHNOLOGY IN THE BASEMENT COMPLEX OF AKURE, SOUTHWESTERN NIGERIA

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ARTICLE INFO

Article History
Received: July 29th, 2023
Revised: August 14th, 2023
Accepted: August 28th, 2023
Published: August 31th, 2023

Keywords:
Anthropogenic effect,
Erosion vulnerability,
GIS,
Remote sensing,
RUSLE.

ABSTRACT

Soil loss estimation has been carried out using the revised universal soil loss equation (RUSLE) model and geo-spatial technology in the basement complex of Akure, Southwestern Nigeria. The objectives are to predict average annual rate of soil erosion and address the menace of erosion in the area. Geologically, the area is underlain by the basement complex rocks of Southwestern Nigeria. Meteorological data, soil information, remote sensing data and digital elevation model (DEM) formed the data base. Three Landsat images of the study area covering 1987, 1997 and 2017, with 30 m spatial resolution were deployed using ArcGIS spatial analyst tool. The RUSLE parameters; Rainfall Erosivity Factor, Slope Length and Steepness Factor, Soil Erodibility Factor, Cover and Management Factor and Support Practice Factor were assessed in a GIS (Geographic Information System) environment. The soil loss was classified into low, moderate, high and very high level of severity. The results showed that soil erosion has moderately increased due to anthropogenic effects over the years.

I. INTRODUCTION

Soil erosion, the displacement or transportation of the upper layer of soil is an important phenomenon with several consequences. Soil erosion involves detachment and transport of soil particles from top soil layers. It is the systematic removal of soil, including plant nutrients from the land surface by various agents of denudation. The loss of the upper layer of soil due to the effects of forces such as water, wind and agricultural practices is profound. Soil erosion has been recognized as a major issue around the world [1 - 3].

Large amount of precipitation and associated runoff processes, wet and saturated soil including sand and silt, the characteristics of land cover and management such as removal of vegetation cover and deforestation, topography of land, poor drainage system account for erosion. Some human interventions can significantly increase erosion rates [1, 4, 5]. Its possible effects include devastating landscape alterations, river and reservoir siltation, water quality degradation, nutrient loss, and decreases in soil productivity [6, 7].

Advances in geospatial technology have assisted in the process of modeling soil loss with enhanced accuracy [2, 3, 8]. Soil erosion can be mapped using models such as USLE, RUSLE etc. The Universal Soil Loss Equation (USLE) is a widely used soil erosion prediction model, where rainfall-runoff erosivity is the prominent factor responsible for erosion. The Revised Universal Soil Loss Equation (RUSLE), a modification of the USLE model has been acknowledged to produce high-accuracy results. It is a product of an extensive review of the USLE and its data base, analysis of data not previously included in the USLE, and the theory describing fundamental hydrologic and erosion processes. The RUSLE Model provides a quantitative and consistent approach to estimate soil erosion under a wide range of conditions [9 - 11].

The study area is located between latitudes 7°7′30″N and 7°21′0″N; longitudes 5°1′30″E and 5°24′0″E. It falls within the central senatorial district of Ondo State, Nigeria (Fig. 1). The major rock types in the study area are charnockite and granite rocks. The three principal petrographic varieties are the fine-grained biotite granite, medium to coarse grained, non-porphyritic biotite – hornblende granite and coarse – porphyritic biotite- hornblende granite.

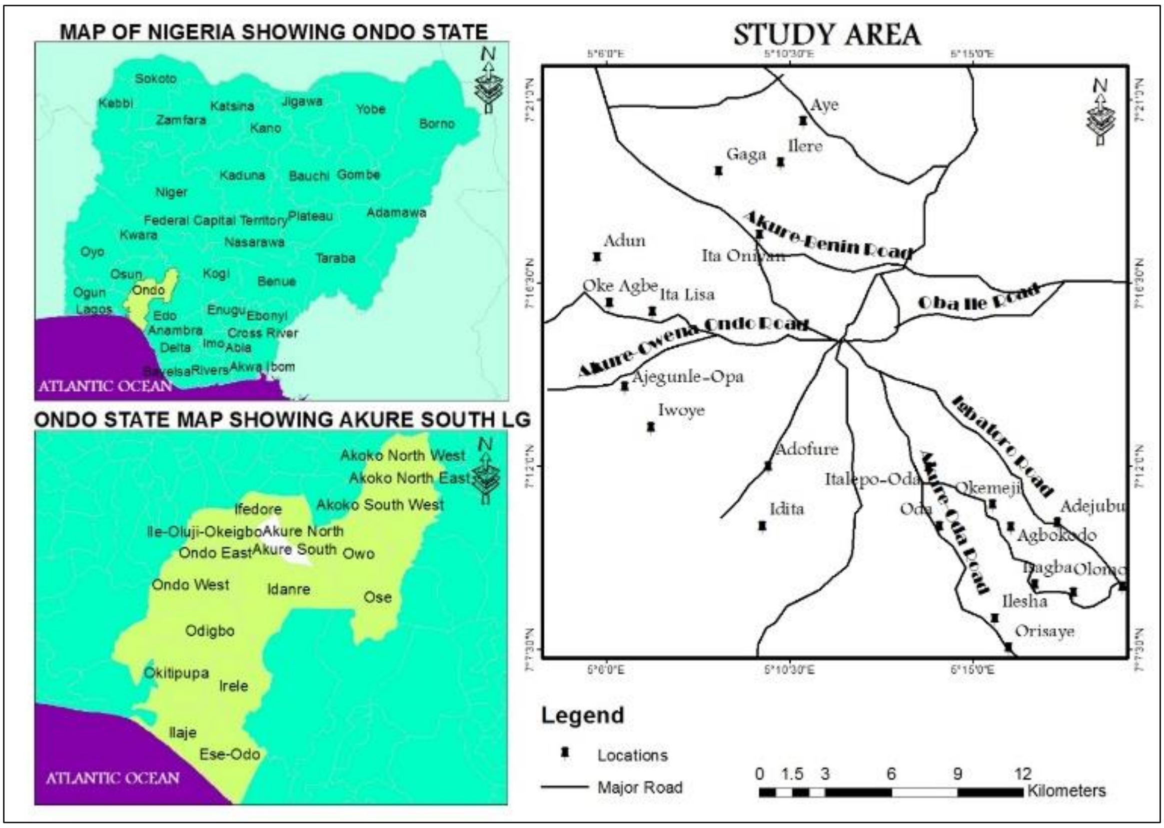

Figure 1: Map of the study area.
Source: Authors, (2023).

The study area is composed of lowlands and rugged hills with granitic outcrops in several places. Some of the more prominent hills rise above 250 m above sea level. The most outstanding characteristics of the drainage systems over the areas of Basement Complex rocks is the proliferation of many small river channels. The channels of the smaller streams are dry for many months, especially from November to May. The mean annual temperature is 27.3°C with the annual total rainfall of 1805.9 mm [12, 13].

The works of [6], [9], [10], [11] and similar authors demonstrated the importance of GIS and remote sensing, Multi-criteria Evaluation and RUSLE model in soil loss estimation. The combined use of the RUSLE model, remote sensing and GIS techniques in the assessment and quantification of the soil loss in the basement complex of Akure, Southwestern Nigeria is presented in this paper.

II. THEORETICAL REFERENCE

The RUSLE model and the input parameters have been presented in literature [3, 8, 11, 14, 15]. The predicted average annual soil loss, **A**, according to the Revised Universal Soil Loss Equation (RUSLE) is expressed as:

$$\boldsymbol{A = R * K * LS * C * P}$$

R is the Rainfall-Runoff Erosivity Factor. It is an index showing erosive force on surface soils. The rainfall intensity and erosive duration are requisite inputs in the computation of the R factor:

$$\mathbf{R = 38.5 + 0.35 * Pr}$$

where Pr = Annual average rainfall (mm/yr).

K, Soil Erodibility Factor indicates vulnerability of soil to rainfall and runoff detachment and transport based on soil texture, grain size, permeability and organic matter content.

LS, Slope Length and Steepness Factor, accounts for the effect of slope length (L) and the slope steepness (S) on erosion. The factor L and factor S are generally considered together.

C, Cover-Management Factor, is an index that indicates how crop management and land cover affect soil erodibility.

The P-factor, **Support Practice factor,** refers to the level of erosion control practices such as contour planting, terracing and strip cropping.

III. MATERIALS AND METHODS

Temporal changes of soil erosion risk were assessed from 1987 to 2017. The parameters of RUSLE model were estimated using remote sensing data in a GIS environment. The study utilized 30 m Landsat imagery (Landsat 5, 7 and 8), 30 m SRTM Digital Elevation Data, Tropical Rainfall Measuring Mission (TRMM) Rainfall Data, Soil Map of the area and base map. Three (3) study periods were considered. Table 1(a & b) shows the attribute of the remotely sensed data.

The major input parameters used in the study included Rainfall Erosivity Factor (R), Slope Length and Steepness Factor (LS), Soil Erodibility Factor (K), Cover and Management Factor (C) and Support Practice Factor (P) as documented in [2 - 4, 8, 10].

ArcGIS 10.2 was used to run the model. The Flowchart of the methodology is presented in Fig. 2.

Table 1(a): Remotely sensed data attribute - Landsat Data.

Landsat Data			
Path	Row	Sensor	Resolution
190	55	Landsat5 TM	30m
190	55	Landsat7 ETM	30m
190	55	Landsat8 OLI_TIRS	30m

Source: Authors, (2023).

Table 1(b): Remotely sensed data attribute - DEM Data.

DEM Data		
Date	Sensor	Resolution
2017	Aster	30m
2007	Aster	30m
1997	SRTM	90m

Source: Authors, (2023).

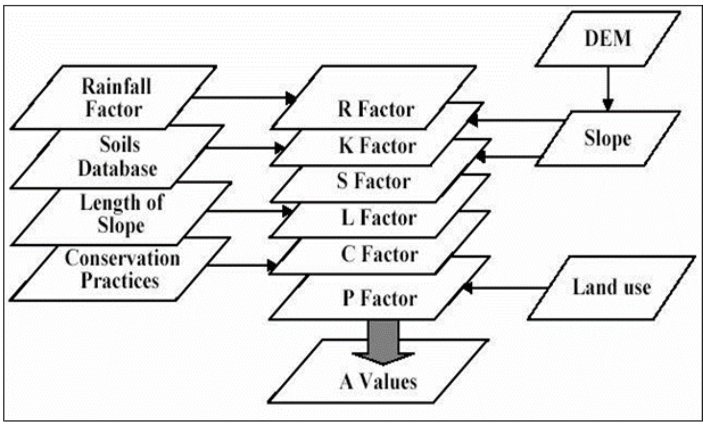

Figure 2: Procedures of RUSLE implementation in GIS.
Source: Authors, (2023).

IV. RESULTS AND DISCUSSIONS

The components of RUSLE model are presented as maps.

IV.1 RAINFALL AND RUNOFF EROSIVITY FACTOR (R)

(Figs. 3 - 5) show the variation of the runoff erosivity factor over the study cycle.

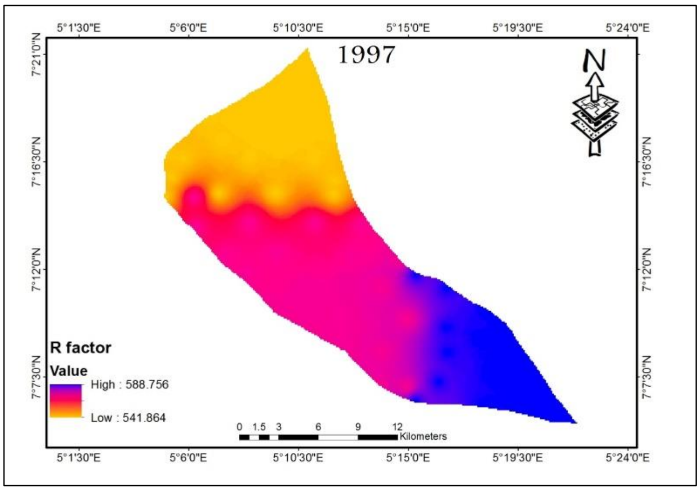

Figure 3: R factor map of 1997.
Source: Authors, (2023).

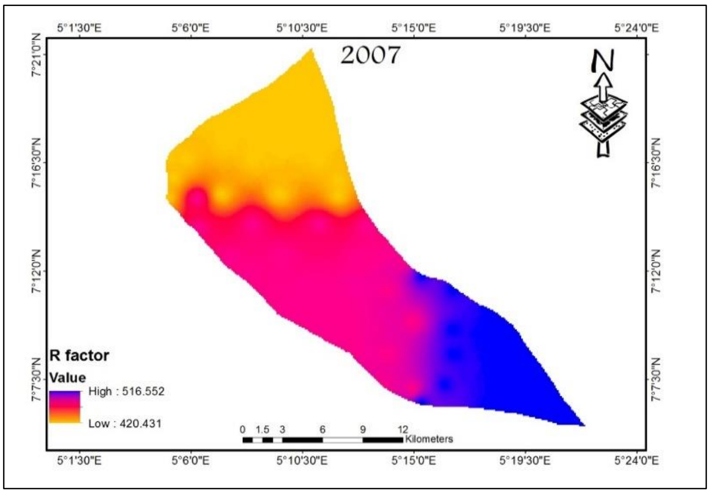

Figure 4: R factor map of 2007.
Source: Authors, (2023).

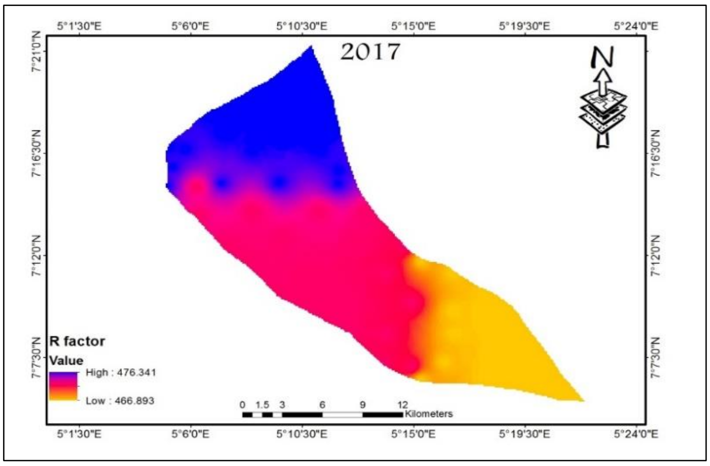

Figure 5: R factor map in 2017.
Source: Authors, (2023).

IV.2 ERODIBILITY FACTOR (K)

Fig. 6 shows the soil types in the area. The soil erodibility is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff [1, 15]. A high K value implies more vulnerability to soil erosion whereas, low k values indicate less vulnerability to soil erosion. Presence of organic matter in soil decreases erodibility since it reduces soil vulnerability to loosening. Soil erodibility factor proposed by [16] cited in [1] was adopted [2, 3, 10].

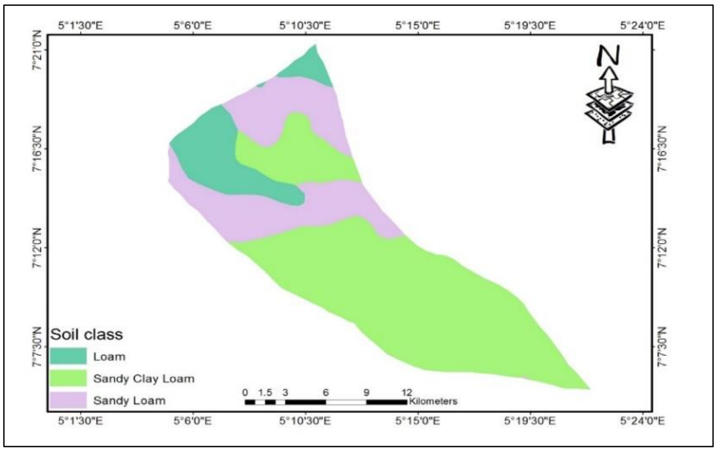

Figure 6: Soil map of the área.
Source: Authors, (2023).

IV.3 SLOPE LENGTH FACTOR (L) AND SLOPE STEEPNESS FACTOR (S)

The slope length factor, indicates the effect of the slope length on erosion (Figs. 7 - 9). S is the steepness of the slope signifies the effect of the slope on erosion. The relationship between the loss of soil and the gradient is influenced by the density of the vegetation cover and the size of the soil particles [1, 3, 6].

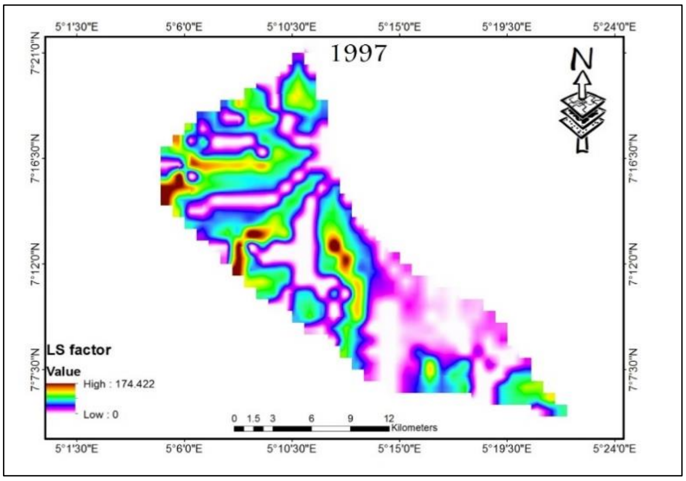

Figure 7: LS factor map of 1997.
Source: Authors, (2023).

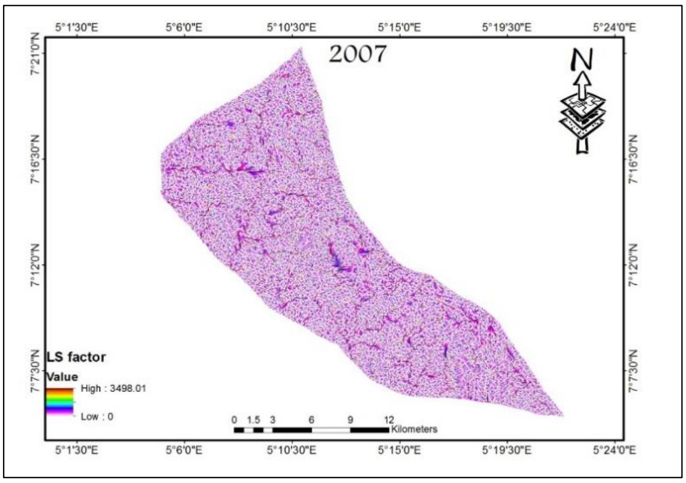

Figure 8: LS factor map of 2007.
Source: Authors, (2023).

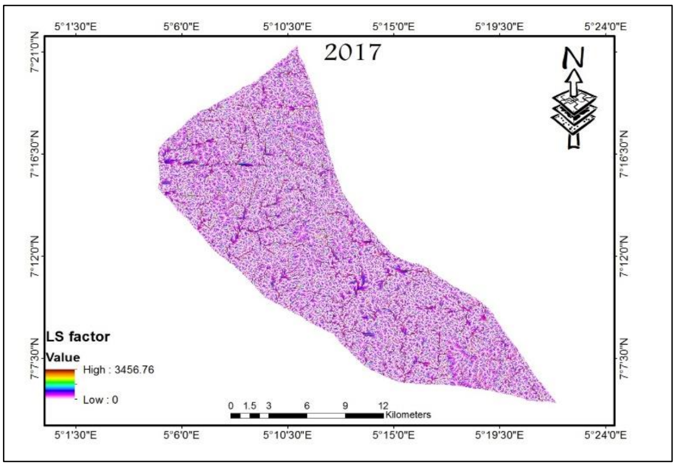

Figure 9: LS factor map of 2017.
Source: Authors, (2023).

IV.4 COVER MANAGEMENT FACTOR (C)

The C factor map (Figs. 10 - 12) reveal the effect of crops and management practices on erosion rates. It indicates how the conservation plan will affect the average annual land loss and how this potential loss of soil will be distributed in time during construction activities, crop rotations or other management schemes. Four landcover classes namely Forest, Vegetation, Bare land, and Built environment were mapped out [4, 5, 15].

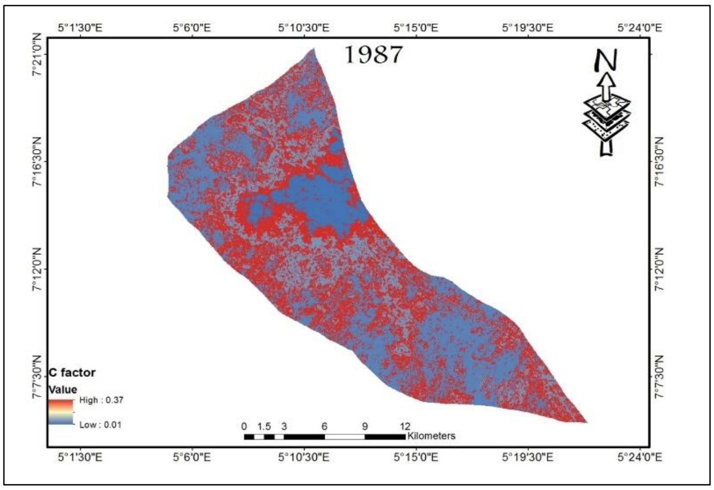

Figure 10: C factor map of 1987.
Source: Authors, (2023).

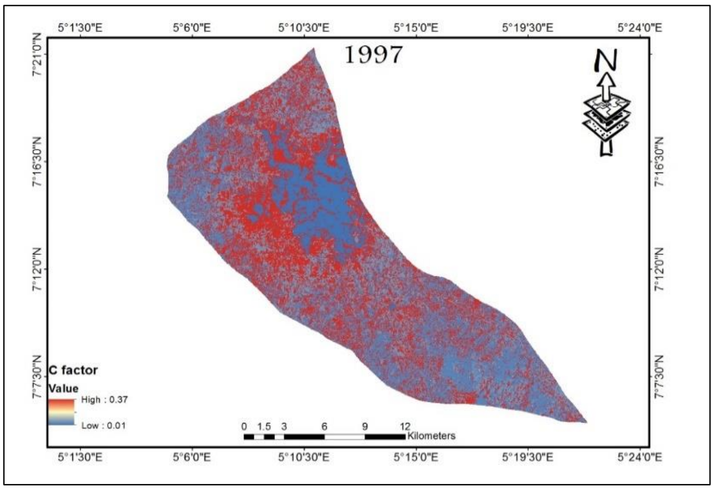

Figure 11: C factor map of 1997.
Source: Authors, (2023).

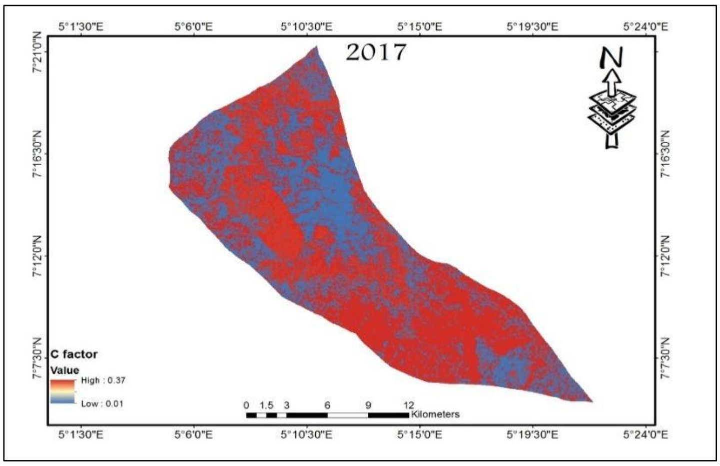

Figure 12: C factor map of 2017.
Source: Authors, (2023).

IV.5 CONSERVATION PRACTICE FACTOR (P)

The P factor reveals the impact of support practices on the rate of erosion (Fig. 13 - 15). It reflects practices that reduce the rate. P factor map was developed in ArcGIS using landuse/landcover map of the study area [1, 4, 5].

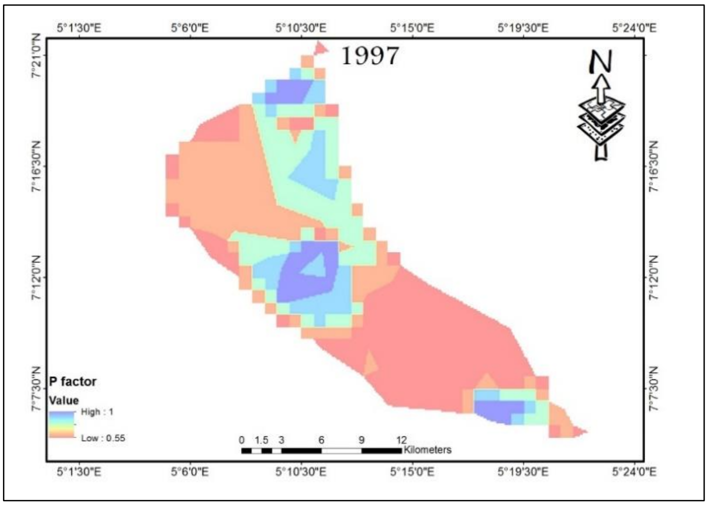

Figure 13: P factor map of 1997.
Source: Authors, (2023).

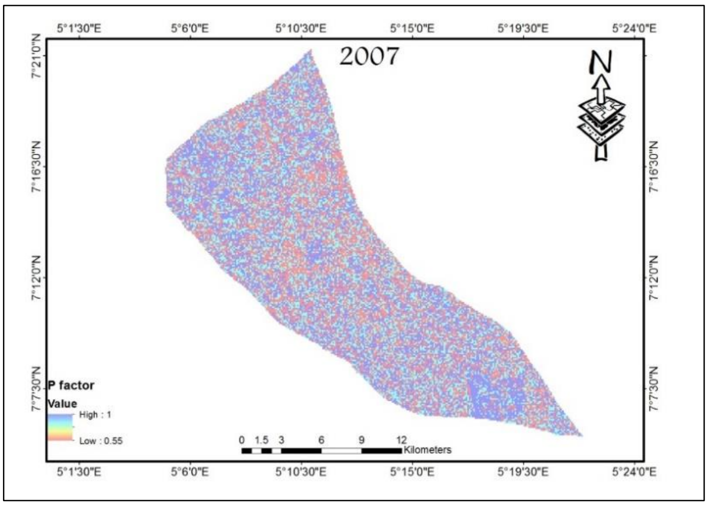

Figure 14: P factor map of 2007.
Source: Authors, (2023).

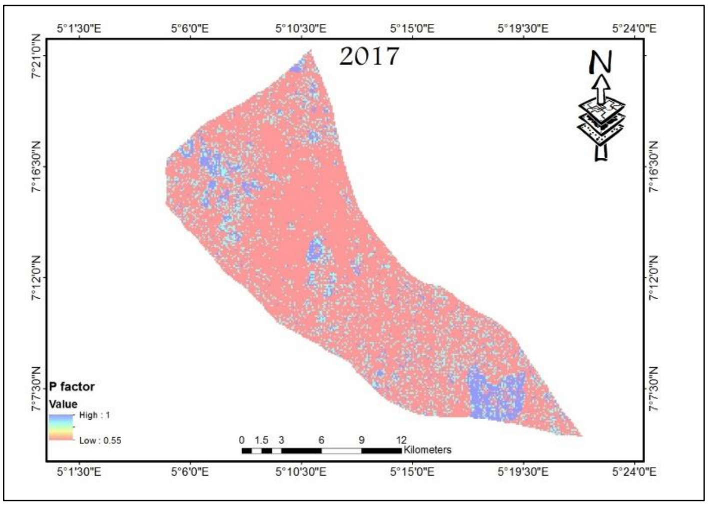

Figure 15: P factor map of 2017.
Source: Authors, (2023).

IV.6 LAND USE /LAND COVER CLASSIFICATIONS

Mapping of the study area in 1997, 2007 and 2017 showed four basic land use/land cover classes namely forest, vegetation, built environment and bare land as shown in (Figs. 16 - 18), respectively. Table 2 shows the area extent of each class.

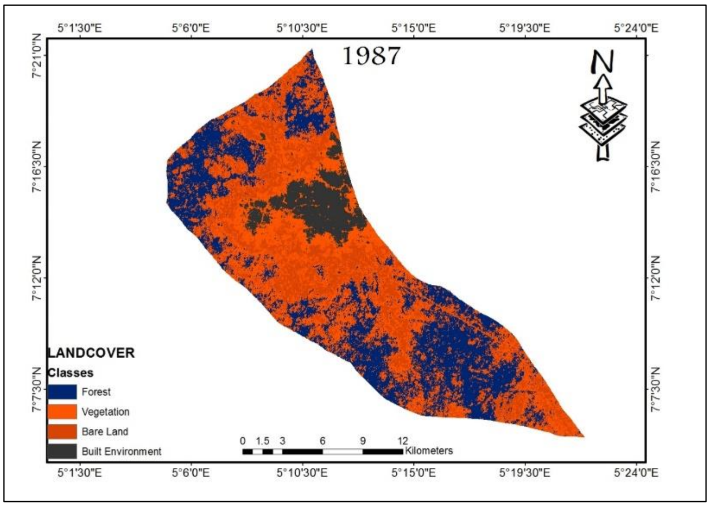

Figure 16: Landcover map of 1987.
Source: Authors, (2023).

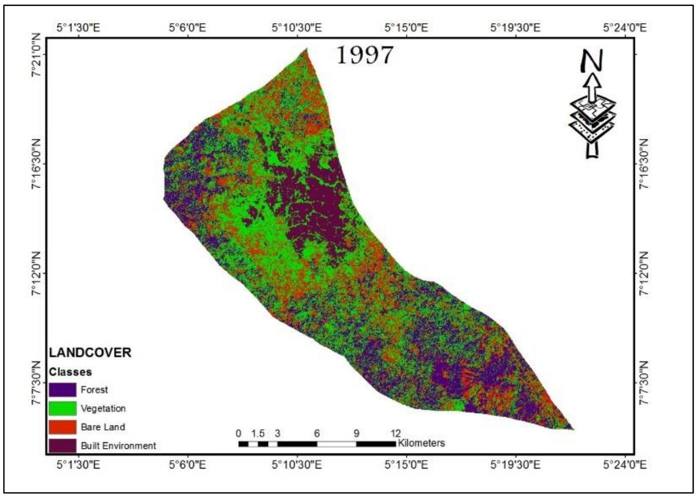

Figure 17: Landcover map of 1997.
Source: Authors, (2023).

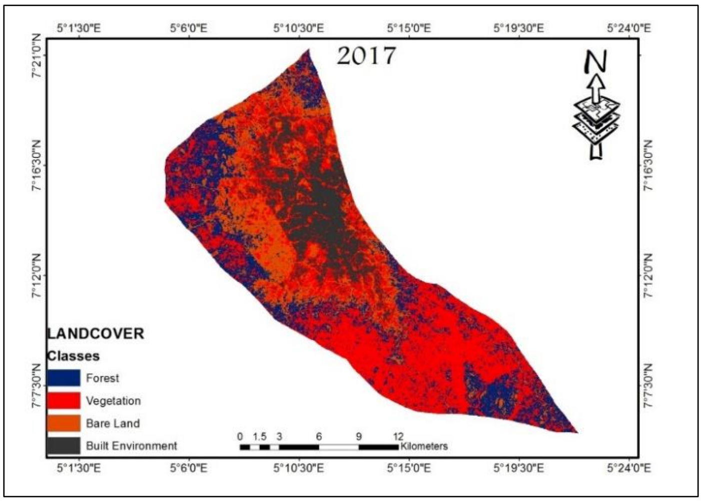

Figure 18: Landcover map of 2017.
Source: Authors, (2023).

Table 2: Area extent of Landcover classes.

Classes	1987 Area (in sq km)	1997 Area (in sq km)	2017 Area (in sq km)
Bare Land	57.25	70.31	58.79
Built Environment	26.01	37.87	49.54
Forest	109.69	89.57	75.82
Vegetation	137.79	133.00	146.59

Source: Authors, (2023).

Vegetation dominated the landcover all through the study cycle. The second major landuse/land cover type was forest. Built environment increased across the years while the forest cover indicated decline. Land use/land cover information is essential for the selection, planning and implementations of land use schemes to meet the increasing demands of basic human needs and welfare [6, 7, 17].

IV.7 ESTIMATION OF SOIL LOSS

The annual soil loss rate was obtained by integrating the respective RUSLE factors; erosivity (R), erodibility (K), topographic (LS), cover management factor (C), and conservation support practice (P) layer values using ArcGIS 10.2 [3, 11, 14]. The study showed four classes (Table 3). The high and very high erosion prone areas constitute the erosion hotspots. These areas require urgent remediation measures. Low soil erosion risk dominates the area in the moderate forest class. However, it increases by approximately 17% across the years. Areas with steeper slopes have been identified as highly vulnerable to erosion. Generally, it can be seen that the average rate of soil loss and the contribution to the total soil loss from steeper slope is higher compared with that of gentle slope. [3, 11, 14].

Table 3: Area under various soil loss zones of the study area (Soil loss trend).

Classes	1997 Area (in sq km)	Area (in %)	2007 Area (in sq km)	Area (in %)	2017 Area (in sq km)	Area (in %)
LOW	247.36	75.92	313.90	90.00	300.1	92.00
MODERATE	30.98	9.510	12.50	4.50	25.10	7.00
HIGH	21.13	6.50	1.40	0.40	2.60	0.80
VERY HIGH	26.34	8.10	0.30	0.10	0.70	0.20

Source: Authors, (2023).

V. CONCLUSIONS

The RUSLE model combined with GIS has proven to be effective for evaluating erosion vulnerability. Implementation of suitable measures in the erosion hotspot is important. Effective management practices would protect key infrastructures such as roads and properties. Enhanced spatial resolutions and accuracies of the digital elevation models are desirable to check possible limitations of the study.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Oyedele and Omosekeji.
Methodology: Oyedele and Omosekeji.
Investigation: Oyedele, Omosekeji and Olaseeni.
Discussion of results: Oyedele, Omosekeji and Olaseeni.
Writing – Original Draft: Oyedele.
Writing– Review and Editing: Omosekeji and Olaseeni.
Resources: Oyedele, Omosekeji and Olaseeni.
Supervision: Oyedele and Olaseeni.
Approval of the final text: Oyedele, Omosekeji and Olaseeni.

VII. ACKNOWLEDGMENTS

All sources of data for this work are acknowledged with thanks. The useful suggestions of the Editor-in-Chief and the anonymous reviewers are appreciated.

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