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ORIGINAL RESEARCH ARTICLE

GIS-based assessment and modelling of soil erosion in part of Kaduna State, Nigeria

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ABSTRACT

Changes in land use due to urbanization, agricultural expansion and mono production have led to accelerated and spatial increase in soil erosion. This research concerns GIS Based Soil Erosion Modelling in Part of Kaduna State, Nigeria. The objectives of the research were to: estimate the amount of soil loss using SLEMSA and RUSLE model in the study area, determine the amount of soil loss using GIS in the study area. The result revealed that the most influential factor to soil loss in Kaduna South was cover management (C) index of (0.9). Conversely, the result indicated that the estimated amount of soil loss from the four LGAs was 11.39 (t $ha^{-1}yr^{-1}$) for SLEMSA model, furthermore, the result revealed that the most contributing factor on soil erosion in Igabi, Kaduna North and Kaduna South LGAs was cover management index (C) while in Chikun LGA soil erodibility (K) index was the contributing factor. The study revealed that the estimated amount of soil loss for the four LGAs was 13.35 t $ha^{-1}yr^{-1}$ according to RUSLE model, its concluded that integrating GIS, SLEMSA and RUSLE can provide solution to soil erosion problems in the study area.

Keywords: Assessment, GIS-Based Modelling, RUSLE, SLEMSA, Soil Erosion.

Introduction

Soil erosion is recognized as one of the most severe forms of land degradation and the greatest challenge to sustainable soil management globally (FAO, 2019; Lal, 2001). It is defined as the detachment, transportation and deposition of soil particles by erosive agents such as water, wind and gravity (Lal, 1990., Morgan, 2005). Globally, about 75 billion tons of soil are lost annually due to water erosion, with Africa accounting for about 30% of total soil degradation due to high rainfall intensity, fragile soils and anthropogenic pressures (FAO & ITPS, 2015; Stocking & Murnaghan, 2001). Modeling is a useful tool for assessing soil erosion scenario and supporting the appropriate selection of erosion control measures (Mahmood. 2024). Erosion and sediment yield can be predicted by using two main types of model empirical and physical based models. The first group is based on the identification of relationships between parameters when a robust data base exists. These relationships must be statistically significant. Physical based models consist of the description of processes involved with the help of mathematical equations dealing with the laws of conservation of energy and mass (Velten *et al.,* 2024).

In Nigeria, particularly in the Northern Guinea Savanna zone where Kaduna State is located, soil erosion by water has become a major environmental problem threatening agricultural productivity, water resources and infrastructure (Lal, 1990; Adegbola *et al.,* 2021). Kaduna State, covering about 46,053 km^2, experiences high seasonal rainfall of 900-1200 mm characterized by intense convective storms with high erosivity (NiMet, 2020; Ibrahim *et al.,* 2020). Coupled with fragile sandy loam soils with low organic matter, undulating topography, deforestation, bush burning and inappropriate agricultural practices, soil erosion has accelerated beyond natural rates (Elwell, 1977; (Morgan, 2005; Bala *et al.,* 2021). Traditionally, soil erosion assessment was carried out using conventional field methods such as erosion plots, pins, and runoff plots which are time-consuming, labor-intensive, expensive and limited to small areas (Morgan, 2005; Stocking & Murnaghan, 2001). These methods cannot provide spatially distributed information over large areas such as an entire LGA. With advancement in geospatial technology, integration of Geographic Information System (GIS) and Remote Sensing (RS) has emerged as a powerful, cost-effective and time-efficient approach for assessing soil erosion at catchment, LGA and regional scales (Renard *et al.,* 1997; Mitasova *et al.,* 1996; FAO, 2019).

According to vulnerability assessment, Igabi LGA has 3,358.38 sq km highly vulnerable and 358.44 sq km moderately vulnerable to land degradation. Its ranked as the third most vulnerable LGA in Kaduna State, with specific gully sites in Rigasa Community, Daura Road / Bayan Wuya area, Layin Cinema, Unguwar Yan Kilishi, Makera, Tarotaro and Madaki Habu Street, Hayin Danmani, as first-phase priority high-risk area. Hayin Toro-Toro Cemetery and Layin Bilya Cemetery both within Rigasa community in Igabi LGA has equally been eaten up by erosion. (Ishaq., 2022). Chikun one among southern (LGA) of Kaduna State, experiencing soil erosion in the areas (Musa *et al.,* 2022; Bala *et al.,* 2021). The LGA is facing rapid population growth, urban expansion from Kaduna Metropolis, and conversion of forest and farmland to built-up areas, leading to increased surface runoff and gully formation (Lawal *et al.,* 2019; Musa *et al.,* 2022). Its reports from Kaduna State Environmental Protection Authority (KEPA, 2018) indicate that over 60 active gully sites exist in Chikun LGA, which divested effect on roads, farmlands and settlements,

Its against this background that this study seek to address the following research question were answered:

i. What is the amount of soil loss in SLEMSA and RUSLE model in the study area?
ii. What is the amount of soil loss using GIS after overlay all input parameters in the study area?

This was achieved through the following specific objectives which are to:

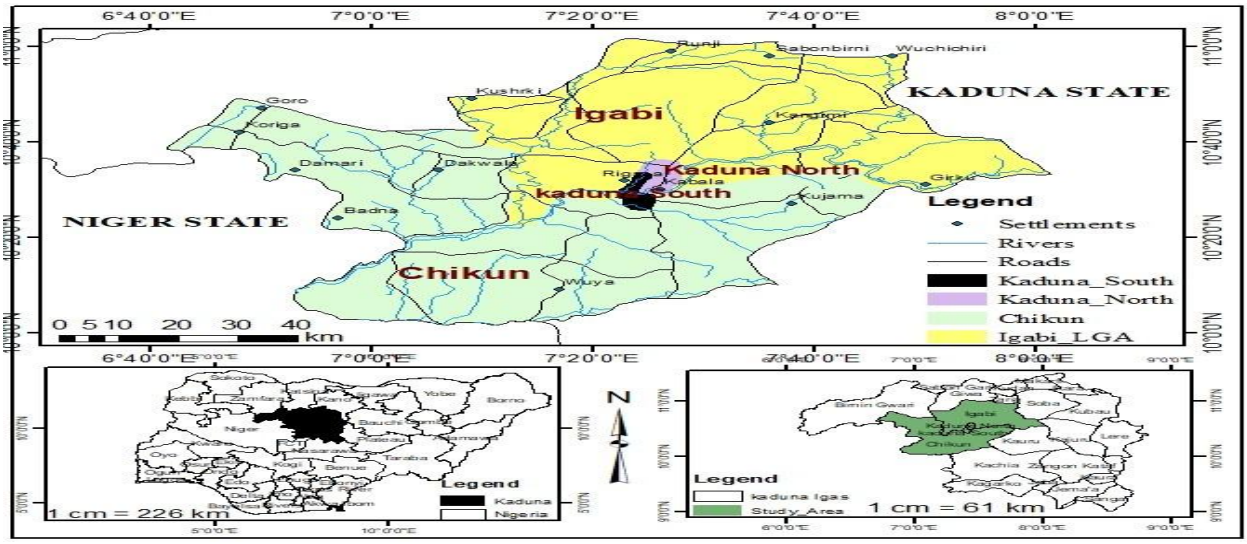
1. estimate the amount of soil loss using SLEMSA and RUSLE model in the study area
2. determine the amount of soil loss using GIS in the study area.

Materials and Methods

The study area

The research was carried out in Igabi LGA Kaduna State in Northern part of Nigeria the area is seriously affected by soil erosion. the it lies between Latitudes 9^0 58' 32" - $11^0$18' 0059" North

of the Equator and Longitudes 5^{0}57' 53" - 8^0 16' 43"East of Greenwich Meridian. The study area has an area of about 16,929 square kilometers. (See Figure 1.1) the climate according to Ayoade (1996), Kaduna state has a tropical continental climate characterized by wet and dry seasons. These seasons reflect the influences of tropical continental and equatorial maritime air masses which sweep over the entire country,



Source: Modified from Administrative Map of Kaduna State

Figure 1.1: The Study Area

The area was covered by tropical ferruginous soils which are heavily weathered and markedly laterized. Generally, the soils are red brown to red yellow soils. (Abaje, 2007). The vegetation of the area is made of trees, shrubs and grass with the density of trees and other plants decreasing as one move northwards (Abaje, 2007). The structure of the vegetation consists of scattered trees, tall grasses and shrubs. Seven Local Government Areas made of the Central Senatorial District are affected by soil erosion, one LGA was selected as the most Local Government Area with evidence of soil erosion, however were purposive selected for the study. Two (2) wards were purposive selected among twelve (12) wards areas. Due to evidence of soil erosion prone area; Audi, Rigasa and Yan kilishi.. Based on the reconnaissance survey conducted, three (3) gully sites were identified and mapped within the L G A.

(i) Image Acquisition

LANDSAT ETM+ multispectral satellite imagery of 30m spatial resolution (2021) was used for the study. The portion of interest was subset from each of the larger scenes using Arc GIS 10.1 software since the images covers a large area its require extraction of area of interest by which the study is taking place.

(iii) Image Classification

In image classification various classes were identified (table 1.1) supervised classification technique was performed, using maximum likelihood classification (MLC) algorithm because of the familiarity of the training ground by the researcher. This technique enables analysts to generate training classes based on the actual land-use/land-cover themes present within the study area and helps in curtailing ambiguity that is associated with the unsupervised image classification. According to Oosten *et al.* (2002). The MLC is the most

widely and commonly used with remotely sensed data, and is proven to yield the best classification result (Jensen, 1996). The feature classes and algorithm from the classification result were generated and used for post-classification comparison between the years of the imageries.

Based on the prior knowledge of the area from reconnaissance survey, a classification scheme after Anderson *et al.,* 1976; Ibrahim *et al.,* 2020; Adegbola *et al.,* 2021. The classification scheme utilized six (6) classes thus Urban/Built-up, vegetation, cropland, bare surface, water body and Natural grasses, shrubs, savanna. The study however, the classification scheme was modified to present, built-up land, vegetation land, agriculture land, water and barren ground as shown in Table 1.1

(viii) Advanced Very High Resolution Radiometer (AVHRR)

The most widely used remote-sensing derived indicator for differentiation of growth is the Normalized

Advanced Very High Resolution Radiometer (AVHRR)

Advanced Very High Resolution Radiometer (AVHRR) is a broad-band, multi-spectral sensor carried on board the National Oceanic and Atmospheric Administration (NOAA) Polar Orbiting Environmental Satellites (POES) and the European MetOp satellites (Kidwell, 1998; NOAA, 2023; Cracknell, 1997).

AVHRR is regarded as one of the longest-operating satellite sensors in history, providing continuous global observations from 1978 to present, making it invaluable for long-term environmental change studies such as soil erosion, land use change, and climate variability (Kidwell, 1998; Tucker *et al.,* 2005; ESA, 2021).

Although AVHRR provides long-term NDVI data since 1978, its coarse resolution (1.1km) is unsuitable for detailed LGA or regional level soil erosion assessment. Therefore, this study utilized Landsat 8 OLI (30m) which provides higher spatial detail for LULC classification based on modified Anderson scheme (Anderson et al., 1976; Musa et al., 2022).

$$C = \exp\{ - a \frac{NDVI}{B-NDVI} \quad (1)$$

Exp:- exponential

Renard *et al.,* (1997).

The land cover classification was estimated as indicated in Table 1.1

Table 1.1 Land use Cover Classification Scheme

Code	Land use/land cover classes	Description
1	Built-up land	Residential, commercial, industrial, roads, urban infrastructures such as schools, roads, etc.
2	Vegetated land	Dense forest, sparse forest, gallery forest Dark red / Dark green
3	Cropland	Land used as cropland, agricultural farmland etc.
4	Water body	Rivers, streams, ponds and dams.
5	Bare Surface	Land devoid of vegetation cover and exposed soils.
6	Forested/shrub	Natural grasses, shrubs, savanna

Source: Adapted from Anderson *et al.,* 1976; Ibrahim *et al.,* 2020; Adegbola *et al.,* 2021

Result and Discussion

Estimating Annual Soil Loss for the Study Area Using SLEMSA Modal

Soil loss estimation model (SLEMSA) model, require four (4) input parameters to determined soil erodibility (k). The result revealed that soil erodibility (k) index, Rainfall (R) index, Cover management (C) index and Topographic (X) index, the result is presented in Table 1.2.

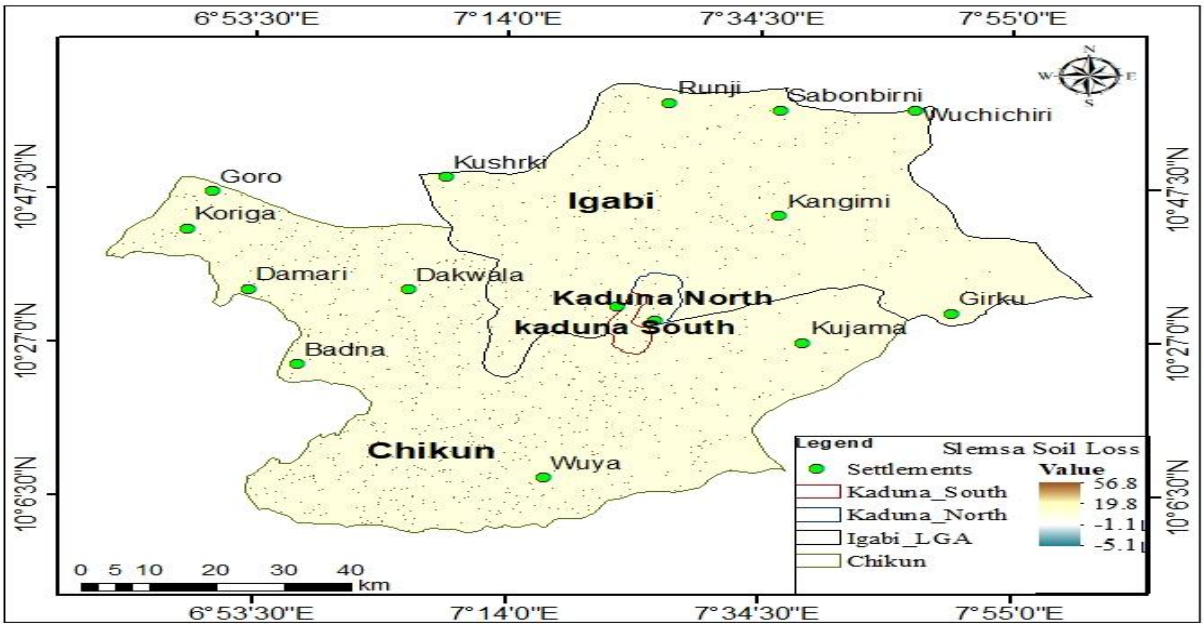
Table 1.2 Estimated Amount of Soil Loss in the Study Area (SLEMSA Model)

Study LGAs	K index	Rainfall/K,E index	C index	X index	Soil loss ($t/ha^{-1}yr^{-1}$)
Igabi	0.3	0.37	1.0	0.33	2.0
Chikun	2.1	0.12	01	0.33	3.55
Kaduna North	0.7	0.68	0.8	0.67	2.85
Kaduna South	0.1	0.99	0.9	01	2.99
Total					**11.39 ($t/ha^{-1}yr^{-1}$)**

Data Analysis, 2026

Based on the results from Table 1.2, its revealed that the most influential parameter in the four LGA areas under study was cover management (C) index. The result indicated that the amount of soil loss in Chikun LGA was 3.55 ($t/ha^{-1}yr^{-1}$). Soil erodibility (K) index 2.1 has been seen as the most influential factor in the area's moderate soil loss estimated, the amount of soil loss was estimated 2.85 ($t/ha^{-1}yr^{-1}$) in Kaduna North. This considered under the category of significant soil loss in the research area, based on the (C) value of (0.8) is seen as a very significant factor of soil erosion factor. The result revealed that the soil loss estimated in Kaduna South was 2.99 ($t/ha^{-1}yr^{-1}$), indicating a high level of soil erosion. The most influential factor for the loss in Kaduna South was cover management (C) index of (0.9). The estimated soil loss from the four LGAs was 11.39 ($t/ha^{-1}yr^{-1}$). This result is consistent with that of Ajon *et al*. (2018), in Makodi, Benue State revealed that under bare fallow plots, ranging from 13.9 to 31.8 ($t/ha^{-1}yr^{-1}$) that exceed the acceptable limit of 12.5 ($t/ha^{-1}yr^{-1}$) the result further revealed that the maximum values estimated soil loss in the study area ranged from 0-11.39 ($t/ha^{-1}yr^{-1}$), which shows a high value of soil erodibility index for SLEMSA model.

The spatial extent of soil loss by SLEMSA model is presented in Fig 1.2



Data Analysis, 2026

Figure 1.2 Amount of Soil Loss (SLEMSA) Model

Estimating the Annual Soil Loss for the Study Area Using RUSLE Model

For the RUSLE model, six (6) parameters were determined soil erodibility (k) the result revealed that Rainfall (K/E), Soil erobibility (k), Topographic factor (L/S), Cover management (c) and Practices management factor was presented in Table 1.3.

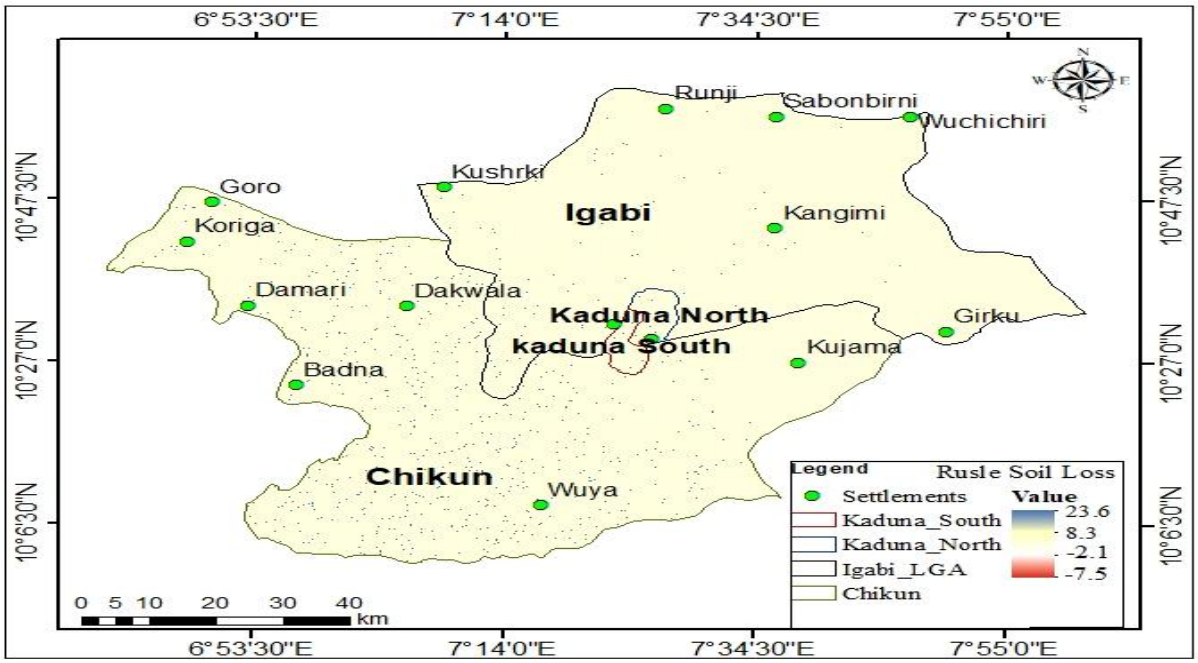
Table 1.3 Estimated Amount of Soil Loss in the Study Areas Based on (RUSLE Model)

Study Site	Rain/K,E	K index	LS index	C index	P index	Soil loss (t/ha^{-1}yr^{-1})
Igabi	0.37	0.3	0.33	1.0	0.35	2.35
Chikun	0.12	2.1	0.33	1.0	0.13	3.68
Kaduna North	0.68	0.7	0.67	0.8	0.58	3.75
Kaduna South	0.99	0.1	01	0.9	0.58	3.57
Total						**13.35 (t/ha^{-1}yr^{-1})**

Data Analysis, 2026.

The result revealed that, the RUSLE model indicated that soil loss has showed that Igabi LGA had lowest soil loss, of 2.35 (t/ha^{-1}yr^{-1}) In contrast, Chikun LGA had the second highest soil loss of 3.68 (t/ha^{-1}yr^{-1}) This finding is disagree with the results of Sinisa et al. (2021) in Kaduna North, where the estimated quantity of soil loss was 5.43 (t/ha^{-1}yr^{-1}). The result further revealed that the estimated amount of soil loss in Kaduna South was 3.57 (t/ha^{-1}yr^{-1}). This was the moderate result obtained from the four (4) LGAs. The result revealed that the most influencing parameter in Igabi, Chikun LGAs was cover management index (C). The study revealed that the estimated soil loss for the four LGAs was 13.35 (t/ha^{-1}yr^{-1}) the result tend to disagree with that of Saira et al. (2021) who reported an average yearly soil removal of 18 (t/ha^{-1}yr^{-1}) in Pakistan.

The Spatial extent of soil loss by RUSLE model is presented in Fig 1.3



Data Analysis 2026

Figure 1.3: Amount of Soil Loss (RUSLE) Model.

The RUSLE model parameters were overlaid in order to produce the annual soil loss map the soil loss map, the RUSLE model is presented in Fig 1.3.the result revealed that the highest soil erosion loss was in Kaduna South with and Kaduna North was 8.3-23.6 ($t/ha^{-1}yr^{-1}$), which was found scattered throughout the study area. However, the result indicated that the lowest soil erosion loss was found in Igabi and Chikun had 2.1-7.5 ($t/ha^{-1}yr^{-1}$).

Conclusion

This study integrated GIS with SLEMSA and RUSLE to estimate soil loss in Igabi, Chikun, Kaduna North and Kaduna South LGAs. The mean annual soil loss was 11.35 t/ha/yr for SLEMSA and 13.35 t/ha/yr for RUSLE. Mean annual soil loss was 11.39 t/ha/yr (SLEMSA) and 13.35 t/ha/yr (RUSLE). The 1.96 t/ha/yr difference is due to model formulation, with RUSLE overestimating compared to SLEMSA which is adapted for African savanna (Elwell, 1978). Both values exceed the FAO tolerable limit of 2-5 t/ha/yr, indicating high and unsustainable erosion, especially on bare and degraded lands. The models showed high spatial agreement, proving GIS integration effective for erosion assessment and conservation planning. According to GIS result its concludes that most of the area was covered by moderate to moderately high soil erosion risk.

Recommendations

1. Farmers should be encouraged to promote soil conservation practices that mitigate accelerated erosion such as contour ridging and terracing, to reduce gully erosion.
2. State Government should educate local communities on the causes and effects of soil erosion and involve them in environmental conservation efforts.

3. Government, communities and individuals should improve on the implementation of cover management index, though farming, afforestation, control over grazing, bush fires.
4. The study recommends that there is the need for monitoring and control land use art so to avoid sand mining within the study area.

Declarations

Author contributions (CRediT): *Not applicable*

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Ethics approval and consent (where applicable): *Not applicable*

Data availability: *Not applicable*

Use of AI tools (where applicable): *Not applicable*

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