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Modeling and Mapping Soil Erosion in Onitsha North LGA, Anambra State Using a Rulse-Based Approach

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Abstract
Soil erosion remains a critical environmental problem in southeastern Nigeria, with Onitsha North Local Government Area (LGA) experiencing increasingly severe land degradation. This study applies the Revised Universal Soil Loss Equation (RUSLE) within a GIS environment to map, quantify, and analyze soil erosion risk. Key RUSLE factors (R, K, LS, C, and P) were derived from rainfall data, Landsat 8 imagery, soil maps, and Shuttle Radar Topography Mission (SRTM) data. The results show an average annual soil loss classified into low (80.89%), moderate (15.9%), and high (3.13%) erosion categories. Erosion susceptibility maps revealed that 3,326.54 hectares fall under low risk, 656.53 hectares under moderate risk, and 128.95 hectares under high erosion risk. This study highlights the importance of integrating GIS and rule-based models for sustainable erosion monitoring and land management. It recommends standardized input datasets, vegetation conservation, and erosion control practices to prevent further land degradation.

Keywords: RUSLE, GIS, Onitsha North, Erosion Risk, Land Degradation, Erosion Mapping, Nigeria, Remote Sensing, Rainfall Erosivity

1. Introduction

Soil erosion represents one of the most pervasive forms of land degradation globally, with significant implications for agricultural productivity, environmental sustainability, water quality, and socio-economic development (Pimentel & Burgess, 2013) [14]. It involves the detachment, transportation, and deposition of soil particles by agents such as water and wind, leading to the loss of fertile topsoil and disruption of natural ecosystems (Morgan, 2005) [7]. In developing countries, particularly within sub-Saharan Africa, the impacts of soil erosion are magnified by high population pressure, rapid urbanization, unsustainable land use practices, and inadequate infrastructure (Lal, 2001; Okoye *et al*., 2020) [6, 12].

In southeastern Nigeria, Onitsha North Local Government Area (LGA) has emerged as a critical erosion hotspot. The LGA is situated in a densely populated and economically active zone characterized by aggressive land use conversion, deforestation, and poor urban drainage systems. These anthropogenic stressors, combined with natural factors such as intense rainfall, undulating terrain, and weak soil structure, have created a highly vulnerable environment where gully erosion, sheet wash, and rill formation are common (Ezezika & Adetona, 2011; Ofomata, 1985) [4, 10]. The result has been the recurrent loss of infrastructure, displacement of residents, declining agricultural potential, and increased costs in disaster mitigation and response (Anyaegbunam, 2018; Nwankwoala & Owei, 2016) [2, 8].

Erosion hazards in Onitsha North have evolved from isolated gullies to widespread degradation patterns that now threaten entire communities. Despite the critical nature of the problem, planning and mitigation efforts have largely been reactive, owing to the lack of geospatial data, predictive tools, and coordinated land management strategies (Ogbukagu, 1976; Okon *et al*., 2021) [9, 11]. To shift towards a more proactive framework, it is essential to deploy spatially explicit models that can capture both the intensity and distribution of erosion risks. One such model that has gained international recognition is the Revised Universal Soil Loss Equation (RUSLE), developed by Renard *et al*. (1997) [16].

RUSLE incorporates five key variables: rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover-management (C), and support practices (P), to estimate potential long-term average annual soil loss under different environmental conditions. The flexibility and empirical foundation of RUSLE make it suitable for a wide range of geographic and climatic contexts (Wischmeier & Smith, 1978; Karydas *et al*., 2009) [17, 5].

With the advent of remote sensing and Geographic Information Systems (GIS), RUSLE can now be implemented within a spatial modeling framework that allows for pixel-based estimation and mapping of erosion risk across landscapes (Saha *et al*., 2005; Prasannakumar *et al*., 2012) [15]. GIS enhances RUSLE's functionality by facilitating the integration of large-scale spatial data, automating factor computations, and enabling real-time visualization and zonation of erosion-prone areas (Panagos *et al*., 2015; da Silva *et al*., 2019) [13, 3].

In Nigeria, several researchers have demonstrated the utility of GIS-based RUSLE models for erosion assessment in diverse ecological zones, including the savannah, rainforest, and coastal plains (Adegbite *et al*., 2021; Ezezika & Adetona, 2011; Nwankwoala & Owei, 2016) [1, 4, 8]. However, few studies have focused specifically on urban and peri-urban environments like Onitsha North, where anthropogenic pressures exacerbate erosion beyond the predictive capacity of traditional models.

This study seeks to address that gap by applying a GIS-integrated RUSLE model to map erosion susceptibility, estimate average annual soil loss, and provide a basis for targeted conservation planning in Onitsha North LGA. The primary objectives of the study are: (i) to derive spatially distributed RUSLE factors using high-resolution environmental datasets; (ii) to quantify and classify soil erosion risk across the LGA; and (iii) to recommend practical and policy-level strategies for soil conservation, land stabilization, and sustainable land use management.

2. Materials and Methods

2.1 Description of the Study Area

The study was conducted in Onitsha North Local Government Area (LGA) of Anambra State, Nigeria, a region known for its dense urban population, undulating terrain, and vulnerability to land degradation. Geographically, the area lies between latitudes 6°10′N and 6°15′N and longitudes 6°45′E and 6°50′E. Onitsha North experiences a tropical wet and dry climate with high annual rainfall ranging between 1,800 mm and 2,000 mm, which significantly contributes to soil detachment and runoff. The topography of the region is marked by slopes that range from gentle to steep, which, combined with intensive urbanization, accelerates erosion processes. The geology consists predominantly of sandy-loam soils derived from coastal plain sands, which are moderately erodible when exposed to heavy rainfall and poor land cover.

2.2 Data Acquisition and Sources

A range of spatial and non-spatial datasets were acquired to compute the RUSLE factors. Rainfall data covering a multi-year period was collected from the Nigerian Meteorological Agency (NiMet) to derive the rainfall erosivity factor (R). A Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with 30-meter spatial resolution was obtained from the USGS Earth Explorer to compute slope-related factors such as LS and P. Soil maps and textural data were sourced from the Nigerian Ministry of Agriculture and Natural Resources and used to determine the soil erodibility factor (K). Landsat 8 Operational Land Imager (OLI) satellite imagery for the year 2023 was also downloaded from the USGS Earth Explorer portal and used to estimate vegetation cover and land use for computing the cover management factor (C).

2.3 Preprocessing of Spatial Data

All spatial datasets were georeferenced to the Universal Transverse Mercator (UTM) projection, Zone 32N, using the WGS 84 datum. The Landsat 8 imagery underwent radiometric and atmospheric correction using the Semi-Automatic Classification Plugin (SCP) in QGIS to improve spectral accuracy. Cloud cover was minimized by selecting dry-season imagery, and the Normalized Difference Vegetation Index (NDVI) was generated to derive C-factor values. The SRTM DEM was resampled and filtered to remove sinks and ensure accurate slope and flow direction computation, which are critical for LS-factor derivation.

2.4 Derivation of RUSLE Factors

The Revised Universal Soil Loss Equation (RUSLE) integrates five factors to estimate soil loss: R (rainfall erosivity), K (soil erodibility), LS (slope length and steepness), C (cover management), and P (support practice). The R-factor was computed using empirical equations adapted for tropical climates, which relate annual rainfall totals to rainfall kinetic energy. This factor reflects the aggressiveness of rainfall in detaching soil particles and generating surface runoff. The K-factor was calculated using the soil texture, organic matter content, and permeability as provided in the soil maps. These parameters were entered into the standard RUSLE equation developed by Wischmeier and Smith (1978) [17] to derive values representing the soil's susceptibility to erosion. The LS-factor was derived from the SRTM DEM using the formula proposed by Moore and Burch (1986), which incorporates both slope gradient and slope length. The factor reflects how topography influences the velocity and erosive power of surface runoff. The C-factor was estimated from the NDVI derived from the Landsat 8 image. NDVI values were reclassified into land cover types and assigned corresponding C-values based on standard RUSLE classification tables, with values ranging from 0.01 (dense vegetation) to 1.0 (bare soil or built-up surfaces). The P-factor was mapped based on land use patterns and slope, with values assigned according to the presence or absence of erosion control measures such as contour plowing or terracing. Areas with no conservation practice were assigned a value of 1.134, indicating maximum susceptibility.

2.5 GIS Integration and RUSLE Model Implementation

Each of the five RUSLE factors was converted into raster format with a common spatial resolution of 30 meters. The raster layers were then multiplied using the raster calculator in QGIS to generate a final soil loss raster using the RUSLE equation:

$$A = R \times K \times LS \times C \times P$$

Where A represents the estimated annual soil loss (tons/ha/year).

2.6 Erosion Risk Classification

The computed annual soil loss values were classified into three categories: low erosion risk (less than 10 tons/ha/year), moderate erosion risk (10–50 tons/ha/year), and high erosion risk (greater than 50 tons/ha/year). These classes were defined based on thresholds from FAO and literature specific to the West African subregion.

3. Results

3.1 Physical and anthropogenic factors that contribute to soil erosion in the study area

A number of factors have been suggested to contribute to soil erosion in the study area, Onitsha North. These factors comprise of rainfall, soil type, slope, elevation and land use. They in one way or the other play a vital role in soil runoff. It is known that high rainfall causes significant soil loss making rainfall a significant factor in eroding soil. For soil type and slope, soil with low retaining property produced high runoff while the steeper the slope, the more the chance of soil erosion. High and relatively moderate elevation areas are usually results to soil displacement and the key to minimizing soil erosion is to avoid leaving the soil surface devoid of vegetation since area with smaller land cover obviously has the higher risk of soil erosion.

Since these factors are considered to play an important role in soil erosion, they constitute the bases for RUSLE computation and the following thematic maps (Figures 1 - 5) were produced to depict their extent of significance in contributing to erosion. Figure 4.1, the R-factor displays the measure of the erosive force and intensity of rain in a normal year. R values is computed from rainfall records. From figure 4.1, it can be ascertained that the south eastern part of the study area had the highest erosive force in the study area.
The K-factor (figure 2), is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. The higher the value of K, the more susceptible the soil is to erosion. From figure 2, it can be ascertained that the western part of the study area is more susceptible to erosion. L factor (figure 3), which is the function of 'slope length' along with the S factor (slope steepness), represents the topographical factor commonly expressed as LS factor, this implies that as the slope steepness (S) increases, the velocity and erosivity of runoff increase. Hence from interpretation, figure 3 and 4 shows the areas with increased velocity and erosivity in the study area. The P-factor (figure 5) refers to the level of erosion control practices, put in place in a watershed and from interpretation, figure 5 shows areas in need of erosion control practices in the study area.

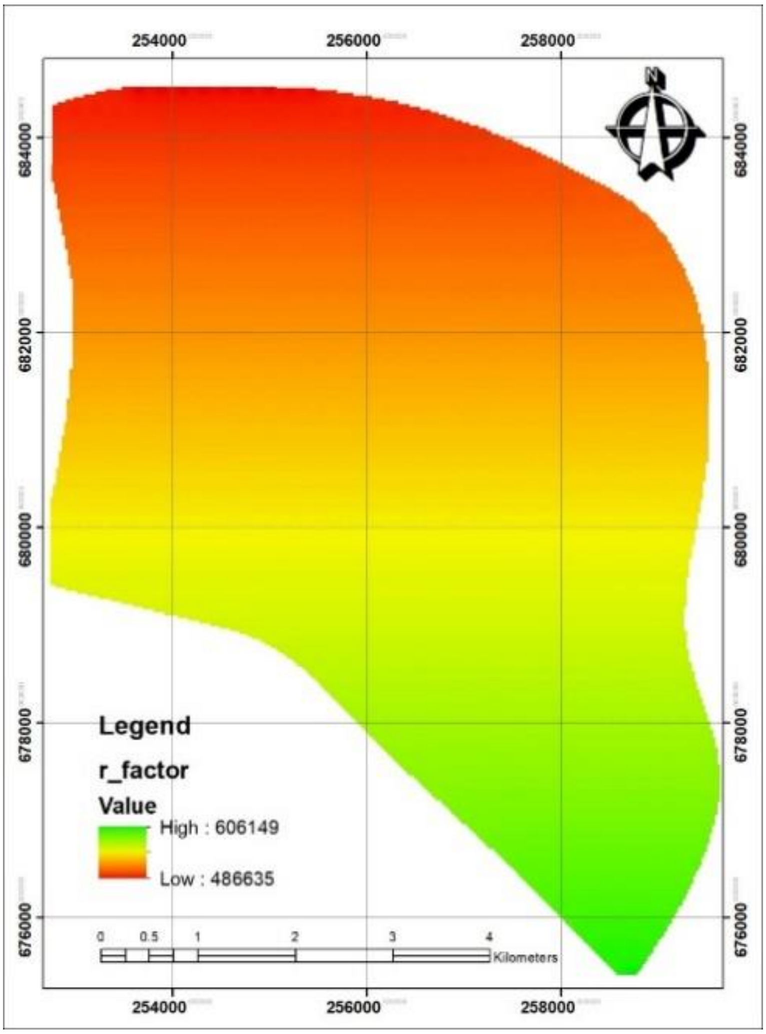


Fig 1: Shows the R-Factor Map of Onitsha North.

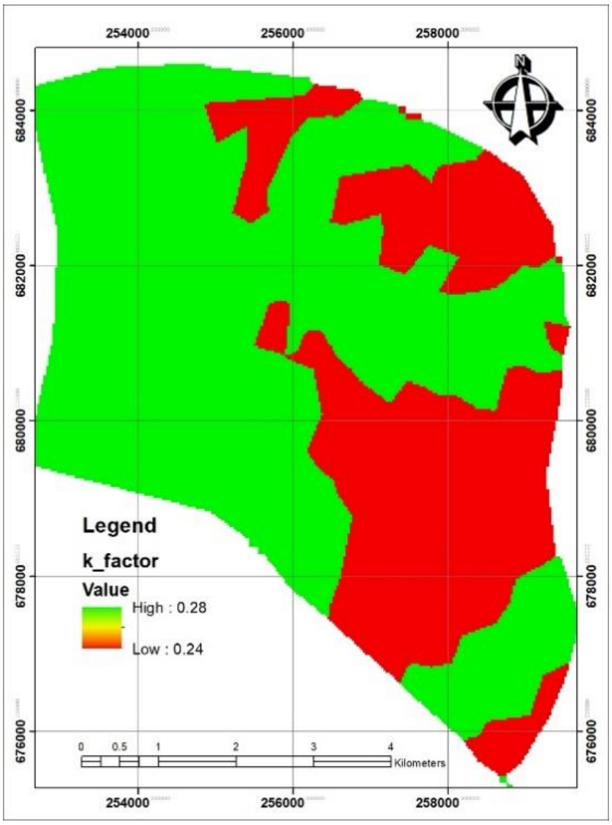


Fig 2: Shows the K-Factor Map of Onitsha North.

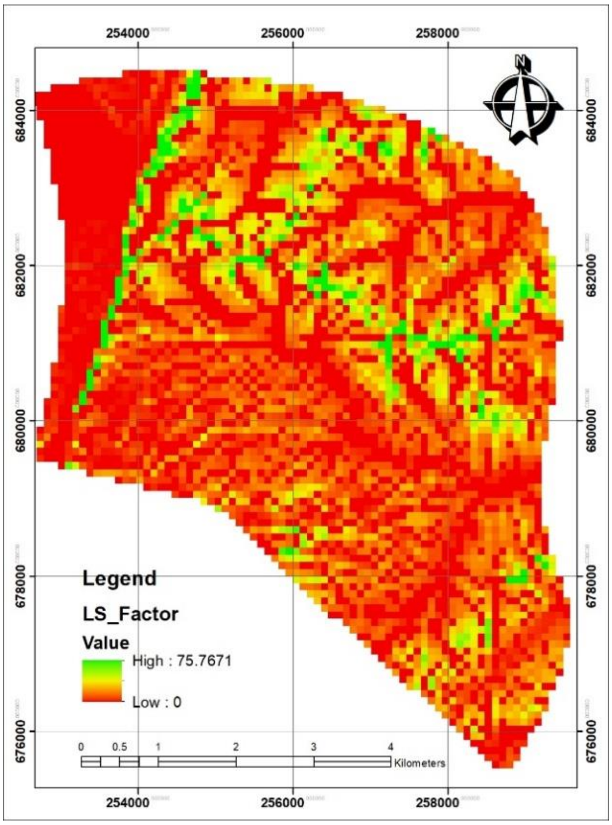
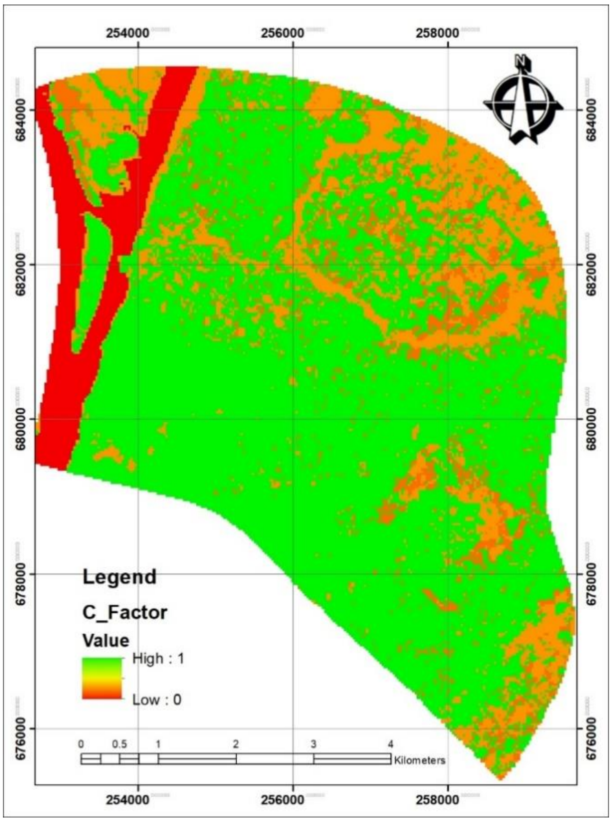


Fig 3: Shows the LS-Factor Map of Onitsha North



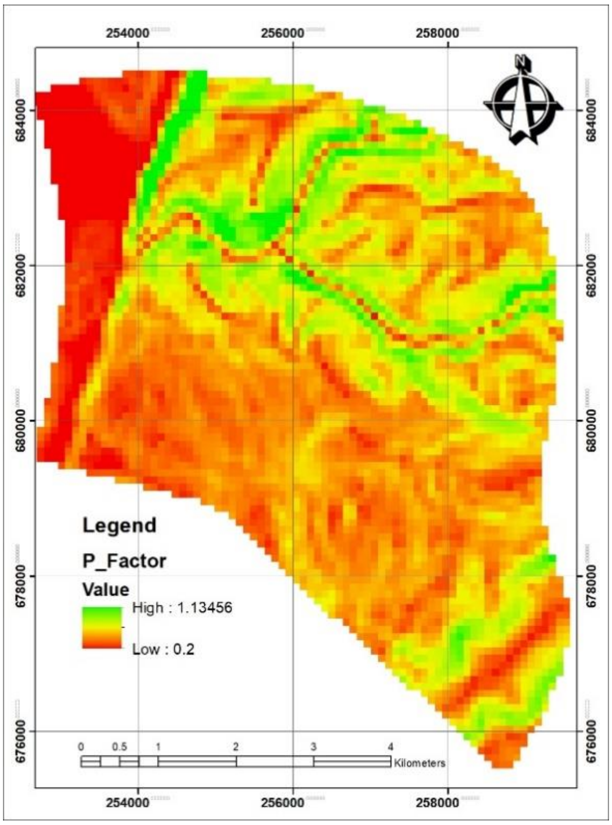


Fig 4: Shows the C-Factor Map of Onitsha North. **Fig 5:** Shows the P-Factor Map of Onitsha North

3.2 The Average Soil Loss (A) in the Region

The average annual soil erosion (A) is estimated by implementing the RUSLE equation ($A = R * K * LS * C * P$) which involves multiplying the factors developed as raster data. The map of average annual soil loss and the histogram of classes of average annual soil loss and corresponding area are shown in Figure 4.6a and 4.6b respectively.

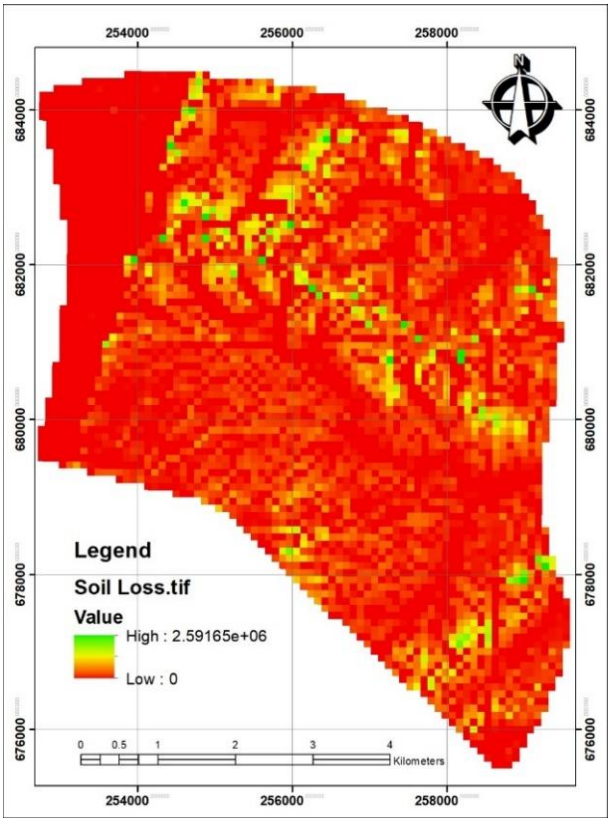


Fig 6a: Shows the Average Annual Soil Loss Map of Onitsha North

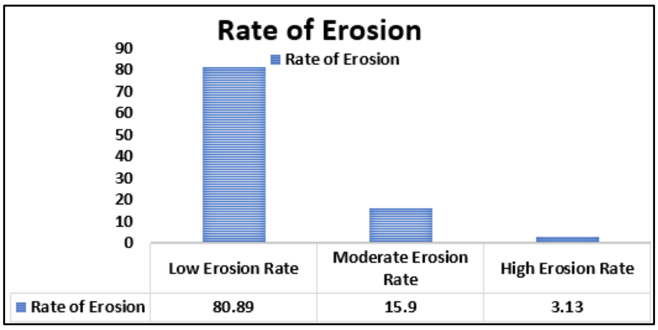


Fig 4.6b: Erosion Rate Distribution

The average annual soil erosion (A) represents a crucial metric derived from the Revised Universal Soil Loss Equation (RUSLE), encompassing factors such as rainfall intensity, soil type, slope length and steepness, as well as cover management and support practices, all of which are meticulously developed as raster data layers. This comprehensive calculation provides insights into the overall soil loss potential across the study area.

Upon computation, the average soil loss (A) was stratified into three distinct erosion rate levels, offering valuable insights into the magnitude and severity of erosion susceptibility within the study area. The subsequent classification revealed compelling findings:

1. Low erosion rate: Approximately 80.89% of the study area exhibited a low erosion rate, indicating minimal soil loss potential. These regions are characterized by favorable conditions, such as gentle slopes, robust vegetative cover, and effective support practices, which collectively mitigate erosive processes and preserve soil integrity.
2. Moderate erosion rate: Approximately 15.9% of the study area demonstrated a moderate erosion rate, signifying a moderate degree of soil loss potential. These areas may exhibit slightly steeper slopes or less robust vegetative cover, resulting in a higher susceptibility to erosive forces compared to regions with low erosion rates.
3. High erosion rate: Approximately 3.13% of the study area experienced a high erosion rate, highlighting significant soil loss potential and heightened vulnerability to erosive processes. These regions may be characterized by steep slopes, sparse vegetative cover, or inadequate support practices, exacerbating erosion rates and posing significant challenges to soil conservation efforts.

These findings provide insights for targeted interventions and prioritizing erosion control measures to mitigate soil loss and preserve the ecological integrity of the study area. Additionally, understanding the spatial distribution of erosion rates facilitates informed decision-making regarding land use planning, resource allocation, and sustainable development initiatives, ultimately contributing to the long-term resilience and sustainability of the region's landscapes and ecosystems.

3.4 The Erosion Susceptibility of Onitsha North LGA

The erosion susceptibility map delineated three distinct levels of erosion risk within Onitsha North, offering a comprehensive overview of the varying degrees of susceptibility to soil erosion across the region. Through analysis and classification, the study identified areas categorized under low, moderate, and high erosion risk, shedding light on the severity and extent of erosion vulnerability within the study area, see figure 7.

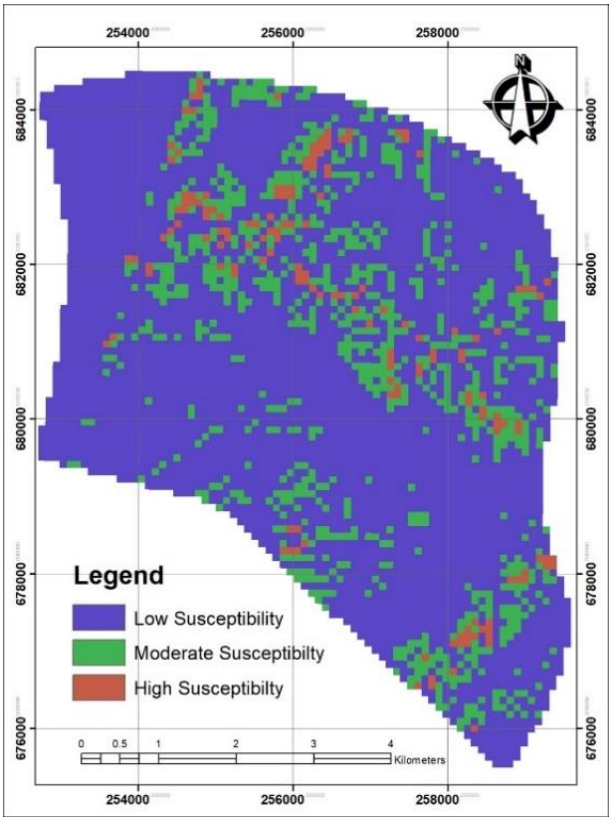


Fig 7: Erosion Susceptibility Map

In detail, the classification revealed that regions characterized by low erosion risk spanned a substantial total area of 3,326.54 hectares. These areas exhibit relatively minimal susceptibility to soil erosion, suggesting a lower likelihood of erosive processes impacting the landscape significantly. Conversely, regions categorized under moderate erosion risk covered a total area of 656.53 hectares, indicating a moderate degree of susceptibility to soil erosion. While erosion processes may occur in these areas, the extent and severity are not as pronounced as those observed in regions classified under high erosion risk.

Notably, areas designated as high erosion risk covered a total area of 128.95 hectares, highlighting significant susceptibility to soil erosion and indicating a heightened risk of erosive processes adversely impacting the landscape. These regions warrant immediate attention and targeted conservation efforts to mitigate erosion and preserve the ecological integrity of the affected areas.

The erosion susceptibility map, with its detailed classification of erosion risk levels, serves as a valuable tool for land managers, policymakers, and conservationists, providing essential insights for prioritizing erosion control measures and implementing targeted interventions to safeguard vulnerable landscapes within Onitsha North. Additionally, the map facilitates informed decision-making processes regarding land use planning, resource allocation, and sustainable development initiatives, ultimately contributing to the preservation of the region's natural resources and environmental sustainability.

4. Conclusion

This study has effectively demonstrated the potential and applicability of Geographic Information System (GIS)-based rule-driven modeling for the mapping and analysis of soil erosion within Onitsha North Local Government Area (LGA), Anambra State, Nigeria. By integrating the Revised Universal Soil Loss Equation (RUSLE) within a spatial analytical framework, the study was able to generate quantitative and spatially explicit estimates of average annual soil loss across the landscape. The approach proved both reliable and reproducible, offering a practical method for identifying erosion-prone areas and prioritizing them for conservation interventions.

The results of the RUSLE model revealed a heterogeneous distribution of erosion risk across the LGA. A significant proportion of the land area, approximately 80.89%, falls under the low erosion risk category, indicating relatively stable landscapes with minimal loss of topsoil. However, the model also identified zones of moderate to high erosion risk, which collectively account for over 18% of the land area. These high-risk zones are primarily located in areas characterized by steep slopes, minimal vegetation cover, unprotected bare surfaces, and poor land use practices. Such areas are particularly vulnerable to surface runoff and sediment detachment, which if left unmanaged, could evolve into severe gully erosion.

The presence of these high-risk erosion hotspots underscores the urgent need for targeted land management and mitigation measures. Recommendations include implementing slope stabilization techniques, promoting reforestation and afforestation efforts, adopting conservation tillage, contour farming, and other erosion control practices. Public awareness campaigns and community-based participation in erosion control initiatives can further strengthen these efforts.

Moreover, this study highlights a key limitation in the accuracy and resolution of available datasets. While the current analysis provides a valuable approximation, it is recommended that future studies incorporate more precise and up-to-date local datasets, such as high-resolution DEMs, rainfall intensity records, and detailed soil profiles, to improve the reliability of erosion predictions. Additionally, the development of a standardized national erosion modeling framework would enhance consistency across regional studies, support national land degradation monitoring programs, and inform policy formulation on soil and watershed management.

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