



Assessment of Erosion Vulnerability for Ala River Watershed in Akure South, Akure North, Idanre and Owo Local Government Areas of Ondo State, Nigeria

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ABSTRACT: Understanding and reducing erosion vulnerability in the Ala River watershed is paramount for sustainable land use management and environmental conservation. Hence, the objective of this research is to develop erosion vulnerability map for Ala River watershed in Akure South, Akure North, Idanre and Owo Local Government Areas of Ondo State using the Revised Universal Soil Loss Equation (RUSLE) and Geographic Information System (GIS). Data obtained show that Rainfall and Runoff Factor values range from 827 to 897 mm/year. The watershed has a uniform erodibility factor of 0.05. The slope gradient (%) map of Ala River watershed indicates that most of the watershed is covered with a slope gradient (%) value of (0 - 2.31). The entire watershed has slope length factor (L) value of (0 - 18.3). Results indicate that areas with scarce vegetation, steep slopes, and high rainfall intensity exhibit higher erosion risks, while regions with dense vegetation and flat slopes are less vulnerable. Erosion rates were extremely high in the upper parts of the watershed with the built-up areas in Akure Metropolis, and in the lower tip of the watershed with high areas of bare land and water bodies. The mid areas of the watershed with mostly dense vegetation had low erosion rates. These findings indicate the need for improved land management and conservation practices in high-risk areas to mitigate soil loss and environmental degradation.

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Erosion is a widespread natural process, increased by human activities. It has become a critical issue due to worldwide environmental damage and social-economic challenges (Smith, 2018). The common type of soil erosion is the water erosion and it happens when rainfall or irrigation water detaches and transport soil particles. Soil erosion processes include loosening, dissolving and detachment of rock materials from the earth surface setting off a complex interactive process of natural and anthropogenic factors. Soil water erosion has caused land degradation worldwide, resulting in the loss of 75

billion tons of fertile soil yearly (Sarapatka *et al.*, 2018; Phinzi *et al.*, 2020, Barboza *et al.*, 2024). Runoff induced soil erosion has caused major ecological problems to 56 % of the earth (Gelagay and Minale, 2016). Soil, a non-renewable resource that takes centuries to develop has been depleted in just decades by human activities. Human activities, such as land use changes, have adversely affected the physical, chemical and microbiological of soil and water quality, especially in developing countries (Depountis *et al.*, 2018; Girmay *et al.*, 2020; Kebede *et al.*, 2021). Since soil is critical for 97% of food

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production (Pimentel, 1993, Pai, 2016) preventing its depletion is essential for sustainable development. Land use and land cover (LULC) changes are intricate processes responsible for erosion and sedimentation rates (Abdelwahab *et al.*, 2014). Land use change can be unsustainable if change degrades land and makes it unsuitable for crop production (Zare, 2017). In Sub-Saharan African sub-region, LULC change is the key driver of soil loss (Seutloali and Beckedahl, 2015). Susceptibility of land to erosion processes is described as erosion vulnerability and caused by parameters such as soil erodibility, rainfall, slope, and land cover (White and Johnson, 2021). There has been a great need for accurate selection of erosion risk assessment method in investigating spatial variability of erosion (Green and Smith, 2016). The RUSLE model has been used widely to estimate soil loss (Li *et al.*, 2023) using parameters such as rainfall erosivity, soil erodibility, slope length and steepness, cover management, and conservation practices (Ghosal and Bhattacharya, 2020).

The RUSLE model is robust tool in assessment of erosion risk and it integrates definite spatial data in determination of soil loss potentials across varied landscapes. Previous applications of RUSLE have demonstrated its efficacy in predicting erosion risks and guiding land management decisions. The study area is Ala River watershed and it has been threatened by increasing risks of soil erosion thereby putting agriculture, water quality and biodiversity in danger. Erosion vulnerability mapping using RUSLE is vital for guided and targeted conservative efforts that optimize land use practices and water resources. This study focuses on quantifying soil erosion rates, mapping vulnerable area to identify high-risk areas, and analyses of contributory factors such as soil type, land use and land cover, and topography. Hence, the objective of this paper is to assess the erosion vulnerability for Ala River watershed in Akure South, Akure North, Idanre and Owo Local Government Areas of Ondo State, Nigeria

MATERIALS AND METHODS

Description of Study Area: Ala River watershed drains more than 80% of Akure metropolis. The upper reach of the river drains parts of Akure South, Akure North, Idanre and Owo Local Government Areas. Ala river is a tributary of Ogbese river which ultimately drains in of Osse River in Nigeria. The river has a watershed area of about 430 square kilometers. Ala river is a second order stream and drains into Ogbese river which is tributary of Osse River. Ala watershed is wholly located in the rainforest region of Nigeria. The watershed lies between latitude 7° 19' North and 6° 58' North above

the equator and longitude 5° 9' East and 5° 27' East. The overburden in study area is predominantly clay with an extensive basement rock formation (Ibitoye *et al.*, 2020). The rock outcrops are mostly quartz, granite and migmatites (Ibitoye *et al.*, 2020). The morphometry of the watershed described a catchment that is elongated (Ibitoye *et al.*, 2020). Ala watershed has two seasons namely; dry and rainy season. The rainy season commences in November and ends in March while the rainy season starts in April and ends in October. The main occupations within the rural areas of the watershed are farming and lumbering, while the occupations of the inhabitants in urban areas are civil service and trading.

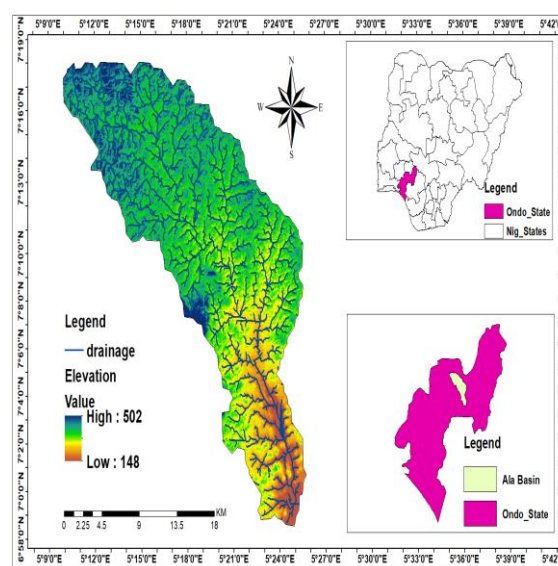


Fig.1: Study Area Map

Data Collection: Thirty years historical rainfall data was sourced from Nigerian Meteorological Agency (NIMET). The average annual rainfall over the area was for the thirty years period was used for the generation of rainfall and runoff factor. The geo-spatial data for soil types over the watershed were sourced from the Harmonised World Soil Database (HWSD) of the Food and Agriculture Organization (FAO). The soil data was pre-processed to a usable format for Arc-GIS analysis. Land cover of 10-meter spatial resolution for Ala Watershed was obtained from ESRI Sentinel-2 Land Cover Explorer. The satellite imagery acquired in 2023 has 9 classes of water, forested lands, wetlands, built-up areas, agricultural lands, low vegetation and bare ground. The Shuttle Radar Topography Mission (SRTM) acquired elevation data on a for generation high resolution digital elevation data was processed for modeling of slope length and slope steepness factor.

Revised Universal Soil Loss Equation for Soil Erosion Modeling: Equation 1 is the RUSLE equation. An empirical equation that was developed by Wischmeier and Smith in 1978

$$A = R * K * L * S * C * (1)$$

The equation describes the average annual loss of soil (A) with units of Mg/ha/yr. Other parameters of the equation include rainfall and runoff erosivity (R), soil erodibility (K), slope length and steepness (S), the cover and management practice (C) and the support practice (P).

Rainfall and Runoff Factor (R-factor): The Rainfall and Runoff Erosivity factor, known as the R-factor, quantifies the impact of rainfall's energy and intensity (Kunta and Carosio, 2007). It is determined as the long-term annual average of the product of event rainfall kinetic energy (measured in MJ ha⁻¹) and the maximum rainfall intensity over 30 minutes (expressed in mm per hour) (Weischmeier and Smith 1978; Renard and Freidmund 1994). The erosivity of rainfall, based on its kinetic energy, is calculated using the following equation:

$$R = 0.5 * P * 1.73 \quad (2) \text{ (in Metric units).}$$

The R-factor value was calculated for each grid cell of mean annual rainfall using ArcGIS software. The mean annual precipitation surface was employed to compute the R-factor through the spatial analyst module of ArcGIS (Obiora-Okeke, 2019).

Soil Erodibility Factor (K-factor): The K-factor, a key parameter in the Revised Universal Soil Loss Equation (RUSLE), represents the soil erodibility and indicates the soil's susceptibility to erosion by water based on its physical and chemical properties (Pham et al., 2018). Soil erodibility is influenced by factors such as particle size distribution, organic matter content, soil structure, and permeability (Renard et al., 1997). The K-factor of soil is estimated based on its texture, including the percentage of silt and very fine sand, sand content, organic matter, structure, and permeability (Wischmeier and Smith, 1978; Barboza, 2024). The erodibility value for each soil class can be calculated using the equation 3 proposed by (Wischmeier and Smith, 1978):

$$100k = 2.1 (\% \text{ silt} * (100 - \% \text{ clay})^{1.142} (10^{-4}) (12 - \% \text{ organic matter})) + 3.23 (b - 2) + 2.5 (c - 3) \quad (3)$$

In this equation 3, b refers to the soil structure code used in classification where 1 is very fine granular, 2

is fine granular, 3 is medium or coarse granular, 4 is slow to moderate, 5 is slow, and 6 is very low (Meraj, 2022). The raster map of the K factor was generated using a digital soil map and the erodibility value of each soil type (Wischmeier and Smith, 1978).

Slope Gradient Factor (LS-factor): The slope gradient and the slope length factor together describe the topographic factor (LS-factor). The LS-factor represents the distance from the start of surface flow to the point where the slope begins to decrease due to material deposition or the capture of surface runoff into drainage channels (Barboza, 2024). Soil erosion vulnerability increases with the extension of the slope (Kayet et al., 2018). The slope length and slope gradient factors were calculated using the filled Digital Elevation Model (DEM) and incorporated into equation 4 to produce the topographic factor grid, as follows:

$$4LS = \left(\frac{L}{22.13}\right)^{0.5} r (0.065 + 0.045S + 0.0065S^2) \quad (4)$$

$L \frac{L}{22.13} m$, in which m is length of slope (in m), m is 0.5 if the slope is > 5%, 0.4 if between 3% and 5%, 0.3 if between 1% and 3% and 0.2 if below 1% and L is the slope length factor; S is the slope gradient factor, $S = (0.43 + 0.30s + 0.043s^2)/6.613$ and s is the gradient (%).

Cover Management Factor (C-factor): The C-factor measures the impact of different vegetation covers, land management practices, and land use types on soil erosion rates. A low C-factor value indicates effective protection against erosion, while a high C-factor value suggests minimal protection, making the area more susceptible to erosion. The C-factor is defined as the ratio of soil loss under a specific crop to that of the base soil (Morgan, 2005). The C-factor is assigned to land use and land cover types based on factors such as canopy cover, fall height, and ground coverage. A cover management factor (C) is determined for each land use and land cover type using values from similar land cover types provided by Wischmeier and Smith (1978).

Support Practice Factor (P-factor): The support practice factor (P-factor) is defined as the ratio of soil loss under a specific soil conservation practice (such as contouring or terracing) to the soil loss from a field with upslope and downslope tillage (Renard et al., 1997). The C-factor accounts for management practices that affect soil erosion by altering the flow pattern, including techniques like contouring, strip-cropping, or terracing (Renard et al., 1997). P-factor values range from 0 to 1, where 0 indicates a very

effective manmade erosion control practice and 1 signifies no manmade erosion control (Obiora-Okeke, 2019). In-situ field observation data were collected to determine the P factor values.

RESULTS AND DISCUSSION

Rainfall and Runoff Factor (R-factor): Figure 2 shows R-factor values ranging from 827 to 897 mm/year. The map shows variations in rainfall erosivity across the Ala River watershed. Each range represents different levels of rainfall intensity and erosion potential. Regions with R-factor values ranging from 827 to 845 mm/year experience low-intensity rainfall. These rainfalls intensity have insufficient energy to significantly dislodge or transport soil particles thereby resulting in minimal soil erosion. Areas with R-factor values between 846 and 857 mm/year are characterized by slightly intense rainfall events compared to regions with lower erosivity. These conditions increase the likelihood of soil erosion, especially in areas with steep slopes, bare soils, or poor land management practices. Moderate rainfall erosivity was observed in areas with R-factor values of 858 to 866 mm/year, where rainfall events are frequent and moderately intense. These areas are more vulnerable to soil erosion especially on bare soils, sparsely vegetated lands, or steep slopes. In areas with R-factor values ranging from 867 to 877 mm/year, rainfall events are frequent and intense. This will provide sufficient energy to detach and transport large amounts of soil. Such conditions make these regions highly prone to erosion, particularly in landscapes with steep slopes and inadequate vegetation cover. Regions with R-factor values between 878 and 897 mm/year experience the highest levels of rainfall erosivity in the Ala River watershed.

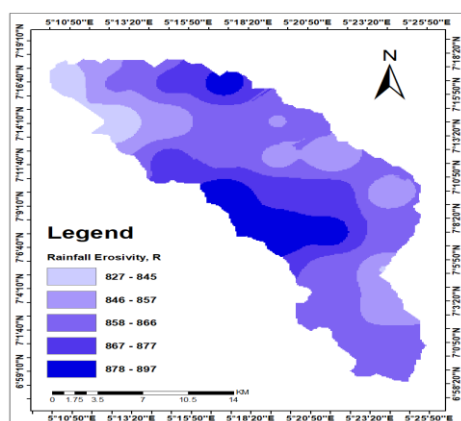


Fig. 2: Rainfall Erosivity Map

Soil Type: The Soil Type map (Figure 3) in the Ala River Basin, which identifies the dominant soil type

as Ferric Luvisols, plays an important role in understanding erosion vulnerability using the Revised Universal Soil Loss Equation (RUSLE). Soil type affects several factors in the RUSLE model, particularly the Soil Erodibility Factor (K), which reflects the soil's inherent vulnerability to erosion. However, clay soils can still be prone to erosion if they are poorly managed, especially on steep slopes or in areas with heavy rainfall.

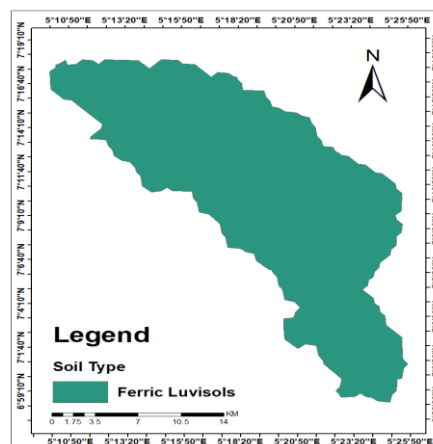


Fig. 3: Soil Map

Soil Erodibility Factor (K): The Soil Erodibility Factor (K) map is shown in Figure 4. The map shows that the watershed has a uniform erodibility factor of 0.05 due to uniform soil type. K value of 0.05 is a relatively low erodibility rating. Soils with a K-factor of 0.05 could be well-aggregated, with high levels of clay or organic material that help bind soil particles together, making them more resistant to detachment and transport by water.

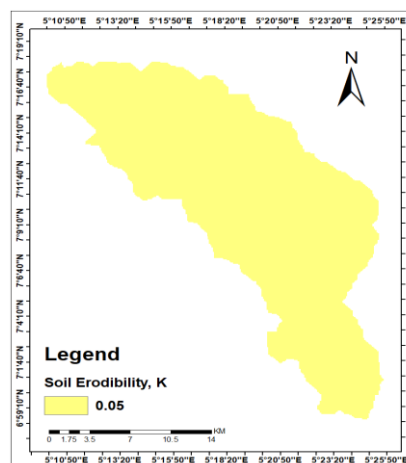


Fig. 4: Soil Erodibility Map

Slope Gradient Factor (LS-factor): Figure 5 shows that majority of LS-factor in Ala River watershed lie between 0 - 1.08. This represents areas with very low slope gradients, from flat terrain to slightly inclined

surfaces. Flat or gently sloping areas are less prone to erosion because water flows more slowly, reducing its capacity to detach and transport soil particles. Soil erosion in these areas tends to be minimal, unless other factors, like land use practices (e.g., deforestation or overgrazing), lead to degradation.

across the Ala River watershed based on the length of the slopes. Areas with short slopes (0 - 18.3) are less prone to erosion, while regions with longer slopes (252 - 780) face much higher erosion risks due to the increased potential for runoff to accumulate and gain velocity.

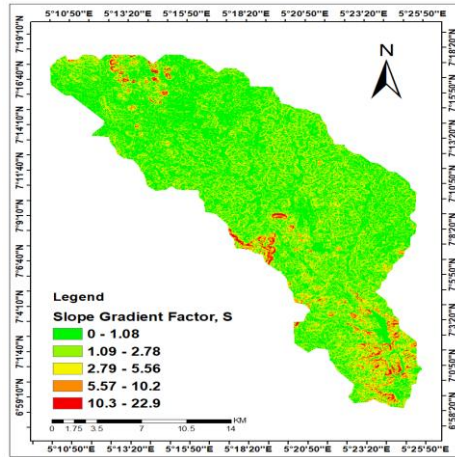


Fig. 5: Slope Gradient Factor Map

The slope gradient (%) map of Ala River watershed as shown in Figure 6 indicate that most of the watershed is covered with a slope gradient (%) value of (0 - 2.31). This represents areas with very gentle slopes or almost flat terrain. Flat or gently sloping areas are less vulnerable to erosion because water moves slowly over the surface, reducing its ability to detach and transport soil particles.

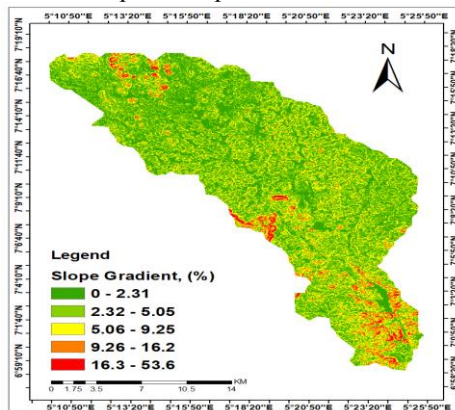


Fig. 6: Slope Gradient Map

Figure 7 shows the Slope Length Factor of the Ala River watershed. The entire watershed has slope length factor (L) value of (0 - 18.3) which represents areas with very short slope lengths, typically near flat terrain or areas with minimal elevation change. In areas with short slope lengths, water does not travel far before being dispersed, which limits its ability to cause significant erosion. The Slope Length (L) map highlights the variation in erosion vulnerability

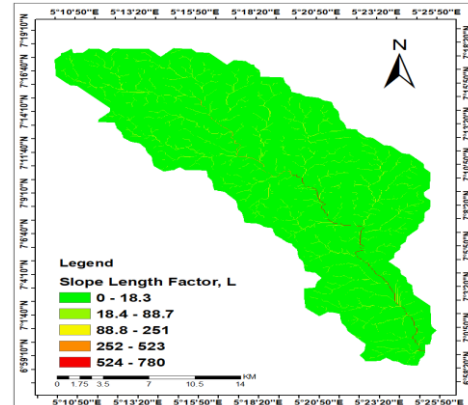


Fig. 7: Slope Length Factor Map

Land Use and Land Cover: Figure 8 shows that northern part of Ala River Watershed is predominantly built-up area. Soil erosion may not occur directly in heavily built-up zones due to the presence of impermeable surfaces but urbanization can significantly alter natural hydrological patterns. Increased surface runoff from impervious surfaces can lead to erosion in surrounding areas, particularly in areas without adequate drainage systems. The central part of Ala River watershed (Figure 8) is predominantly covered with vegetation which has the lowest erosion vulnerability because the plant cover intercepts rainfall, reduces raindrop impact, and stabilizes the soil through root systems. Vegetation also promotes water infiltration and reduces surface runoff, thereby minimizing soil loss. Forested areas are particularly effective in controlling erosion, while grasslands and agricultural fields may offer moderate protection, depending on the type of crops or land management practices used.

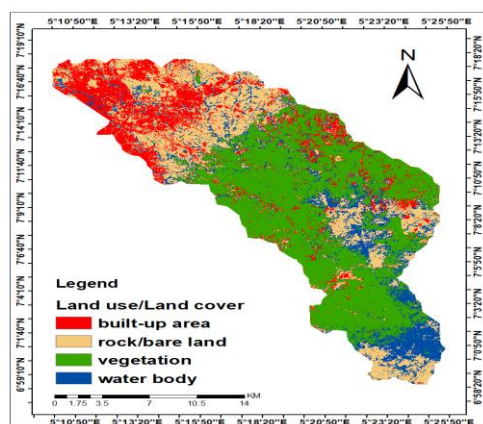


Fig. 8: Land Use and Land Cover Map

Cover Management Factor (C-factor): Figure 9 shows that the northern part and southernmost tip of Ala River Watershed has a C-factor value of 0.8 – 1. This indicates areas with minimal vegetation cover, such as urban areas, open lands, or unpaved roads. These areas are highly vulnerable to erosion as there are almost no protection against the erosive forces of rainfall and runoff. Areas like this with high C-factor values are the most vulnerable to erosion. The central part of Ala River Basin however has a C-factor values of 0 - 0.2 which indicate very high levels of ground cover, typically consisting of dense natural vegetation, well-managed forests, or permanent crops like orchards. These areas have minimal soil exposure to raindrop impact and surface runoff, leading to low erosion vulnerability.

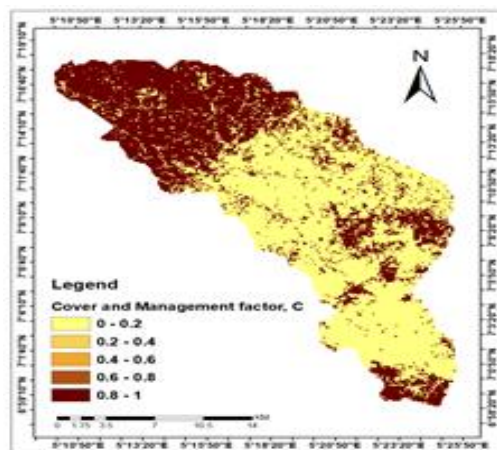


Fig. 9: Cover Management Factor Map

Soil Erosion Rates: Figure 10 shows the Soil Erosion Rate map Ala River Watershed generated using the RUSLE equation. The estimated amount of soil loss ranges from 0 to 486.5 tons/ha/yr. The map identified areas with different levels of erosion vulnerability, providing insights into the spatial variation of soil loss across the basin. These values represent annual soil erosion rates under current conditions,

considering factors such as rainfall, slope, land use, soil properties, and conservation practices. Figure 10 show that the majority of Ala River Watershed has a soil erosion rate value of 0 - 81.09 tons/ha/yr which represents areas with the lowest soil erosion rates, meaning minimal soil loss per year. Low erosion rates typically occur in areas with gentle slopes, good vegetative cover, and soils that are resistant to erosion (low erodibility). These regions may include flatter areas, well-managed agricultural lands, or forests where erosion control measures are effective. These areas are less vulnerable to erosion, often due to favorable conditions such as low slope gradients, dense vegetation cover, or stable land management practices. However, maintaining these conditions is important to prevent future erosion

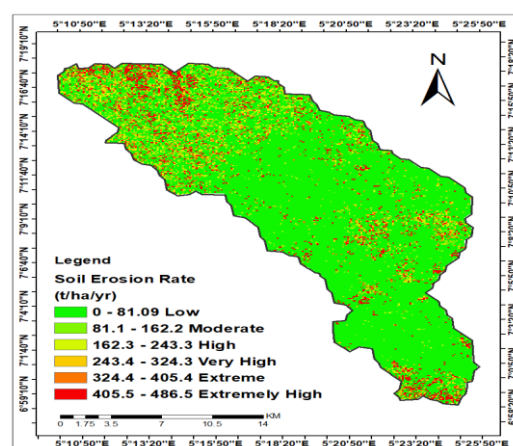


Fig. 10: Soil Erosion Rate Map

Conclusion: The findings of this research highlight the interplay between natural factors and human activities in shaping erosion dynamics within the basin. The results demonstrate that regions with dense vegetation and gentle slopes, primarily in the central and southern parts of the basin, exhibit low erosion vulnerability. Conversely, areas in the northern part of the basin, characterized by urbanization, deforestation, and steep slopes, are at higher risk. The study underscores the significant role of land cover in mitigating erosion, with forests and well-managed agricultural lands providing critical protection against soil loss. The analysis also reveals that rainfall intensity and poor land management practices exacerbate erosion risks, particularly in steep and unprotected terrains. This research emphasizes the importance of adopting targeted conservation strategies.

Declaration of Conflict of Interest: The authors declare that no known conflict of interest or personal relationships that could have influence the work reported in this paper.

OBIORA-OKEKE, O. A; OJO, O. M; ADEWUMI, J. R

Declaration of Data Availability: Data are available upon request from the corresponding author.

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