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ASSESSMENT OF SOIL EROSION VULNERABILITY AT THE RIVER LAMURDE CATCHMENT USING REVISED UNIVERSAL SOIL LOSS EQUATION AND GEOSPATIAL TECHNIQUES

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ABSTRACT

This study evaluated the susceptibility of the River Lamurde catchment to soil erosion by applying the Revise Universal Soil Loss Equation (RUSLE) alongside geospatial techniques, in response to increased human activities and variable rainfall patterns. Factors like soil erodibility, vegetation cover, slope length, support practices, and rain erosivity were quantified and integrated into the RUSLE model using ArcGIS. IBM SPSS was used for change detection statistics to analyze land use/land cover changes over time. The findings of the study indicate that factors such as soil erodibility index, vegetation, bare surface, and water bodies significantly influence the occurrence of soil erosion in the area. The study reveals that 17.4% of the land in the area exhibit low susceptibility to soil erosion, while 53.9 % have moderate vulnerability and 28.7% have high vulnerability. To address the issue of erosion, the study suggests employing erosion prevention techniques and sustainable land management methods, incorporating erosion prevention and mitigation measures into planning and development, establishing a monitoring program, raising public awareness, supporting research initiatives, and integrating erosion control and land management strategies into local policies.

Keywords: Soil Erosion; River Lamurde; Universal Soil Loss Equation; Geospatial Techniques, Soil Erosion Vulnerability, River catchment.

1. Introduction

Soil, one of the most essential resources of humankind, is under threat of erosion (Alewell *et al*., 2019; Ahmadi, *et al, 2016*). It depends on a combination of factors such as the steepness of the slope, climate, land use & land cover, and ecological disasters like forest fires (Kanth, *et al*, 2019; Pinho, *et al*, 2015). Soil erosion causes harmful effects both at the site where it occurs and beyond, making it one of the most serious environmental threats due to its negative impact on both the environment and the economy. Factors such as erosivity, erodibility, and land management practices are crucial in determining soil condition. Topography controls soil movement in a watershed and areas mostly covered by a high fraction of vegetation are at a lower risk of soil erosion (Song *et al*., 2015). Reduction of the protective effect of land cover leads to demotion of vulnerability categories (Chadli, 2016).

The eroded materials carried down to the lower reaches of the rivers make rivers incompatible to carry excess amounts of water and sediment load, especially during heavy downpours thus making water quality a strong indicator of soil erosion (Yesuph and Dagnew, 2019). Assessing a watersheds vulnerability to soil erosion plays a key role in identifying its level of fragility and developing effective conservation strategies. To understand soil conservation and ecosystem management in a watershed, it is important to evaluate soil erosion and map the susceptible area to soil loss (Gelagay & Minale, 2016; Hategekimana, *et al*, 2020). Assessment of the annual soil erosion rate and developing of a soil erosion map provide spatial patterns of classified soil erosion risk zones indicating the areas with high, severe, and low erosion risk areas (Zhou *et al*., 2014). Soil erosion processes and modeling approaches have socioeconomic importance and help in understanding ecosystem dynamics and stability (Alewell *et al*., 2019; Hategekimana *et al, 2020*).

Multiple approaches are available to evaluate how prone a region is to soil loss, taking into account factors such as land use, soil quality, and topography. Modelling and prediction of soil erosion have a long history of several decades (Alewell *et al*., 2019; Yusuf, & Jauro, 2024). Advancements in climatic datasets, remote sensing technologies, earth observations data, and increased big datasets are promising factors for modeling approaches in the present and future (Hacisalihoghlu *et al, 2010;* Govers *et al*, 2017; Alewell *et al*. 2019). Over the past decade, soil erosion research has expanded globally, employing a diverse array of modeling approaches—including physical, empirical, statistical, and process-based methods—to anticipate erosion across various landscapes (Yusuf et al., 2019; Montanarella et al., 2015).

Estimating soil erosion involves considering numerous variables, including land use and cover, climatic and environmental changes, topography, vegetation management, and conservation practices.

Modeling soil erosion offers a deeper understanding of these dynamics and is typically more efficient and less costly than conducting extensive field studies (Bati et al., 2019; Marzen et al., 2016). Models like the Revised Universal Soil Loss Equation (RUSLE), particularly when implemented within GIS and paired with remote sensing, serve as powerful spatial decision-support tools for managing and accessing erosion risks (Alexakis, 2009; Yusuf et al., 2019).

A cursory look at the river Lamurde catchment reveals that the area has witnessed massive vegetation degradations as a result of heightened human activities propelled by population explosion. The increase in population and human activities, particularly constructions, farming, grazing, etc. are an outflow of Jalingo attaining the status of the capital of Taraba State, whereby it attracts people to itself daily. Rainfall records, obtained from the Taraba State University, show an increasing pattern over the years. It is in light of this that this study was formulated to estimate soil loss due to soil erosion within the research area.

2. MATERIAL AND METHODS

2.1 STUDY AREA

The River Lamurde catchment lies between latitudes 8°46′ and 9°08′N, and longitudes 11°09′ and 9°33′E (Fig.1:1). For this study, the catchment was mapped using a Digital Elevation Model (DEM) within an ArcGIS environment. Covering and area of about 613, 43km2, it spans four (4) Local Government Areas in Taraba State: all of Jalingo LGA, and part of Ardo-kola, Bali, Lau, and Yorro. It is bordered by Lau LGA to the north, Yorro LGA to the east, and Ardo-Kola LGA to the south and west, with Jalingo LGA situated within it. River Lamurde, which grains Jalingo town, is a ninth-order stream originating from the Yorro Mountain near Gangoro. It flows downhill through Yorro, Tazarang, Alkali Gwa, Bassa, and Jalingo, covering over 96km westward before discharging into the Benue River system near Tau community (Zemba & Yusuf, 2012)

The region experiences a tropical climate characterized by distinct wet and dry seasons. Rainfall occurs from April to October, while the dry season lasts from November to March.The rainy season reaches its peak in August and declines from late September when its impact on soil erosion is high. The mean annual rainfall is between 1,016mm-1,270mm with a mean annual temperature of between 290 C to 320 C and an annual range of 30 C. Though the temperature varies with months, the highest temperature is in March and the least is in August when the rainfall is at its peak and with high relative humidity (Yusuf, *et al*, 2017; Zemba, 2012).

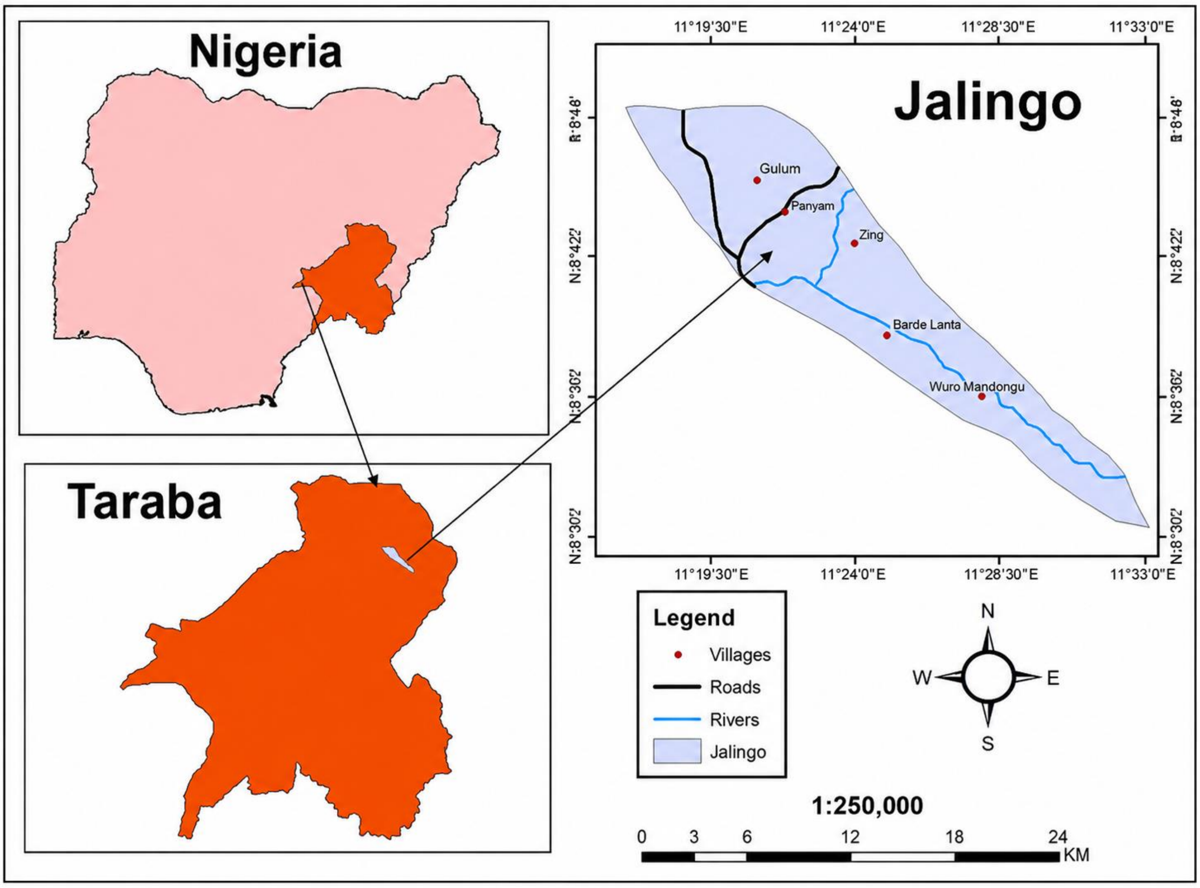

Fig. 1.1: River Lamurde Catchment, the Study Area

Geologically, the study area is composed mainly of sandstones from the Yolde formations, representing the transition from marine to continental sedimentation. In certain parts, alternating layers of shales and mudstones with minor sandstone deposits are present. The area lies within an undifferentiated complex rock system. Its relief features an undulating plain interspersed with mountain ranges, increasing its vulnerability to erosion. The basin is drained by River Lamurde and its numerous tributaries, including Mayo-gwoi, kpantinappu, Bovo, Zampa, Mikira, Sozina, Gana, Zuwa, Voti, and Hweiya. The river is seasonal, often overflowing its banks during August and September, when rainfall reaches its peak in the catchment, resulting in severe flooding and erosion.

The study area falls within the southern Guinea savanna zone (Yusuf, *et al*. 2017; Zemba, 2012). The vegetation of the area, represented by shrubs, scattered trees, and grasses, is denser and more vibrant in the rainy season compared to the dry season. The vegetation is characterized predominantly by savanna vegetation. Agriculture serves as the primary economic activity for most residents in the area, particularly those living along the River Lamurde. The river plain support annual dry season farming, while the wet season is dedicated to cultivating food crops like maize, rice, and guinea corn. This continuous and intensive use of the catchment throughout the year contributes to its susceptibility to erosion.

2.2 Methods

The categories of data required for this study were acquired and processed at different levels before the final analysis to arrive at the results. These include Digital Elevation Model (DEM), rainfall data, data on land use and land cover, terrain slope, and soil characteristics. Landsat images of 2002, 2012, and 2022 and SRTM were acquired from Earth Explorer (www.earthplorer.gov) and they included DEM, as well as data on land use, slope and land cover. Rainfall data was obtained from the archive of Taraba State University weather records while the map of the soil types was digitized to generate soil information of the study area.

The Landsat images were subjected to classification and change detection in ArcGIS10.8 to generate the land use and land cover while soil data was sourced from the digitization of the soil map in a GIS environment. Rainfall data were first compiled in Microsoft Excel and then imported into a GIS-based platform for spatial analysis. In ArcGIS 10.2, data were integrated to conduct a soil erosion vulnerability assessment applying the Revised Universal Soil Loss Equation (RUSLE). This model calculates the mean yearly soil loss by combining five key factors, rainfall erosivity (R), soil erodibility (K), topography (LS), cover management (C), and support practice (P), as expressed in the equation $A = R \times K \times LS \times C \times P$, where each factor is represented as a raster layer within the GIS environment.

3. RESULTS AND DISCUSSION

This section outlines the results of the soil erosion assessment using RUSLE for the Lamurde River catchment. It details the spatial distribution and statistical characteristics of each RUSLE factor, rainfall erosivity (R), soil erodibility (K), topographic factor (LS), and cover management (C), and support practices (P). The study further illustrates the composite soil loss estimates and vulnerability mapping. Discussion interprets the spatial patterns and their implications for erosion risk within the research area.

Soil Erodibility Factor (K)

The soil erodibility factor (K), reflects how prone a soil is to erosion, assessed based on its inherent properties, including texture, organic matter content, structure, and permeability. It measures how easily soil particles can be detached and transported by water and wind. In this study, three soil erodibility (K) values were used: 0.1**,** 0.2**,** and 0.3 (Figure 2). Soils with a K-factor of 0.1 are categorized as having low erodibility**.** These soils are comparatively resistant to erosion, displaying properties that make it challenging for particles to detach and be transported. As a result, they are less vulnerable to erosion, and erosional controls may be less urgently needed in regions dominated by this soil type. Notably, these soils are prevalent within the central part of the catchment, where human presence is high—characterized by impervious surfaces and visible rock outcrops.

Soils with a K-factor of 0.2 fall into a moderate erodibility category. These soils exhibit intermediate vulnerability to erosion: they're less resistant than soilss having a K-factor of 0.1, yet not as easily eroded as those with higher K values. In contrast, soils having a K-factor of 0.3 are placed in the highly erodible category. Their structure and composition make them especially prone to detachment and erosion by wind or water. These high-K soils have a higher tendency for their particles to dislodge and be transported, putting regions with such soils at elevated risk. Therefore, it's crucial to apply effective erosion control and sound land management strategies in these areas to reduce erosion potential. In this study, the lower portion of the catchment corresponds to soils with this higher erodibility (K = 0.3).

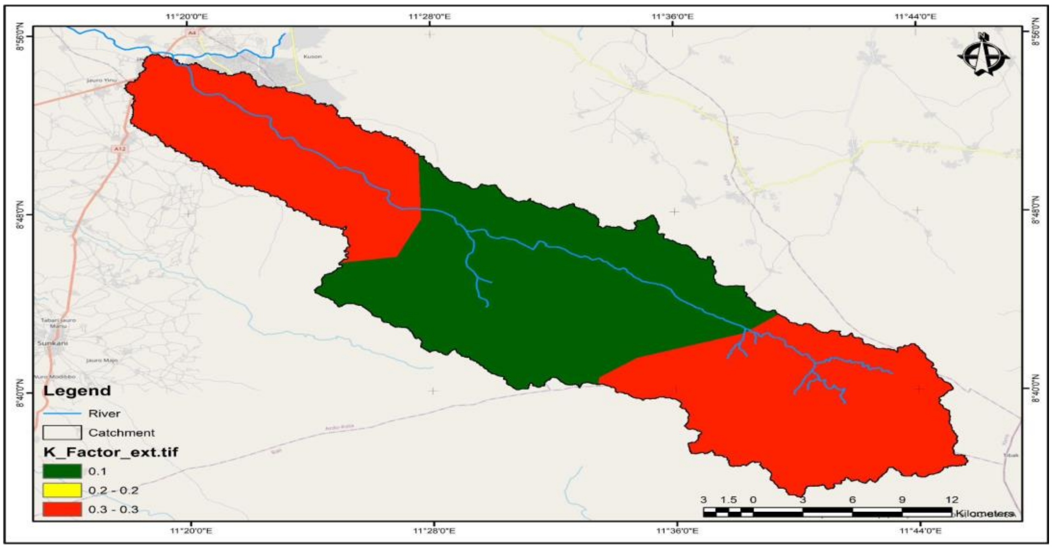

Fig. 2: Soil Erodibility Factor (K) of River Lamurde Catchment

Cover Factor (C)

The cover management (C) represent the effectiveness of land use and vegetation in minimizing soil erosion, considering aspects like vegetation type and density. In this research, we derived the C factor by examining the composition of various land use categories. These categories were then reclassified to generate a land cover classification map (Fig. 3)

The cover management (C) is a key component of RUSLE that measures the impact of land use and vegetation cover on soil erosion vulnerability. It represents the extent to which different land covers modify the soil's response to rainfall by reducing its erosive impact. Areas with minimal vegetation like exposed soil or barren land typically exhibit high C values, reflecting their elevated erosion vulnerability.

Built-up areas, including roads and infrastructure, can increase surface runoff due to reduced infiltration and can channel water into drainage systems, potentially increasing erosion downstream. Depending on the density and design of built-up areas, RUSLE may indicate varying levels of soil erosion potential. Impervious surfaces and altered drainage patterns can lead to increased erosivity. Vegetation acts as a natural barrier against soil erosion.

Plant roots stabilize soil particles, minimizing erosion from water and wind. According to RUSLE, regions with dense vegetation exhibit a lower potential for soil erosion. Bodies of water, including rivers and lakes, can help control erosion by dissipating energy from flowing water. They act as sediment traps, reducing downstream erosion.

The reclassification of land use categories (Fig.3) to produce the Land cover classification map aids in spatially characterizing erosion-prone areas, which is crucial for implementing effective erosion control and land management strategies. For the Lamurde River catchment, it was classified into four classes: 0-0.1, 0.1-0.2, 0.2-0.3, and 0.3-1.

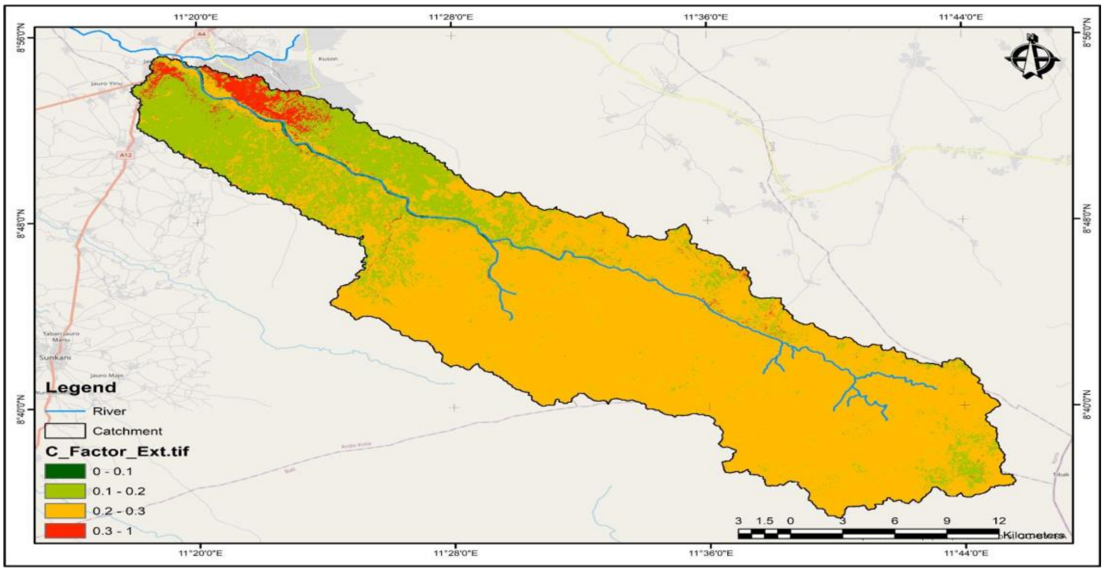

Fig. 3: Land Classification (C Factor) of River Lamurde Catchment, 2022

Class 0-0.1 represents areas with very minimal likelihood of soil erosion due to land cover and land use management. Land in this class is typically covered by dense vegetation, such as forests or grasslands, which provide effective protection against erosion. Soil disturbance is minimal, and practices like contour farming or terracing may be employed to further reduce erosion. In general, these areas exhibit a low susceptibility to soil erosion, and erosion rates are expected to be minimal. They include areas at the upper course of the catchment.

Land areas with C-factor values ranging from 0.1 to 0.2 exhibit only slightly greater erosion risk than those falling within the 0.0 to 0.1 range. While vegetation may be present in these zones, its cover is typically less dense or effective at reducing erosion. Soil disturbances or current land management practices in these areas can further elevate erosion susceptibility. To curb soil loss, implementing conservation measures, including reduced tillage or crop rotation, may be advisable.

Moderate Susceptibility (C = 0.2–0.3), areas with C-factor values ranging from 0.2 to 0.3 have a moderate risk of soil erosion. Vegetation here is typically less effective in protection compared to areas with lower C values, and land-use activities—such as intensive farming or tilled fields may exacerbate erosion risk. As a result, these zones usually require active erosion mitigation strategies, including conservation tillage, crop rotation, mulching, or other soil-preserving practices.

High Erosion Potential (C = 0.3–1.0), regions with C-factor values between 0.3 and 1.0 are highly susceptible to erosion risk. These areas generally possess sparse vegetation, and inadequate land use practices, including overgrazing or unsustainable farming, can substantially heighten erosion risk. Soil degradation is a significant issue in this area, underscoring the immediate need for targeted erosion control strategies to protect environmental integrity. In this study, such conditions are particularly evident within the middle and downstream sections of the Lamurde River.

Length Slope (LS) Factor

The LS factor, which integrates slope length (L) and slope steepness (S), is a key indicator for pinpointing region susceptible to intense soil erosion risk and for guiding effective control measures. In the River Lamurde catchment, the Digital Elevation Model (DEM) (Fig. 4) reveals a dramatic elevation range from 173 meters, representing lowland areas in the middle to lower courses, to 1,533 meters, marking highlands in the upper reaches that form the watershed's head. This pronounced topographic variation plays a pivotal role in RUSLE-based erosion assessments in the catchment, as it directly influences the calculation of the LS factor. Steeper slopes common in high-elevation zones are especially vulnerable to erosion. That's because water flows more swiftly downhill on such gradients, increasing its capacity to dislodge and transport soil. Elevation differences generate gradients that dictate the speed and direction of runoff, ultimately shaping erosion patterns across the landscape.

The terrain of the Lamurde River catchment, as obtained from the Digital Elevation Model (DEM), encompasses a wide spectrum of slope angles. These slope gradients—computed from elevation data—reveal key insights into the region's topography. Within the study area, slope angles range from 0°, representing nearly flat terrain, to 67°, indicating very steep inclines. The wide variation in slope angles highlights the complex and diverse topography of the catchment, which exerts a strong influence on soil erosion dynamics by shaping runoff behavior and controlling patterns of soil displacement. Areas with minimal slope angles near 0 degrees typically represent flat or gently sloping terrain, while the presence of steeper slopes, reaching up to 67 degrees, signifies rugged and mountainous regions within the catchment.

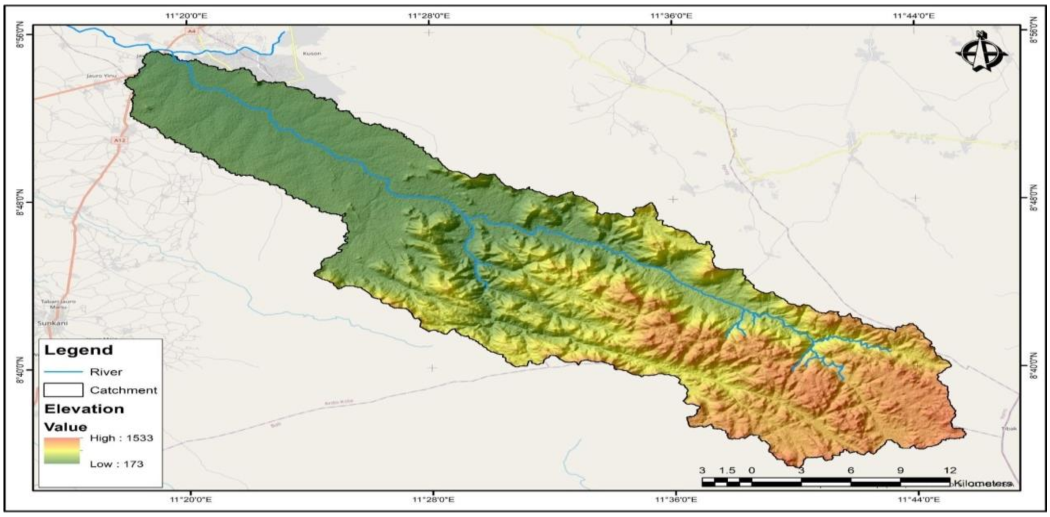

Fig. 4: Digital Elevation of River Lamurde Catchment

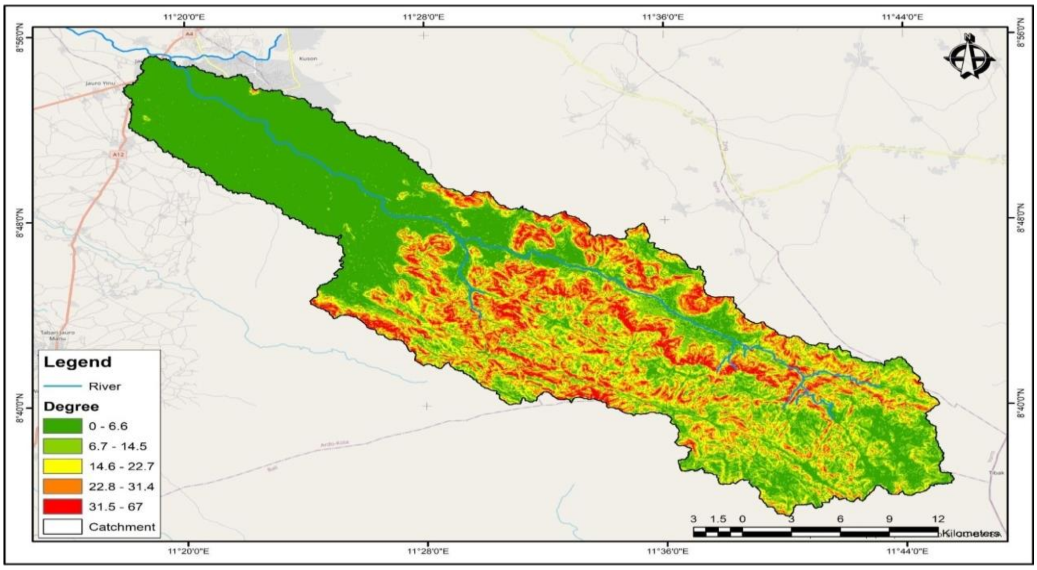

Fig. 5: Slope of River Lamurde Catchment

The LS factor, within the study area, is typically classified into five, and each class represents a range of LS values (Fig.6). The LS Class 0.0 – 7.3 represents relatively short slopes with gentle gradients. Soils on these slopes are less prone to erosion compared to steeper and longer slopes. Erosion risk in this category is relatively low. Slope angles corresponding to LS factor values between approximately 7.4 and 36.7 generally indicate gentle to moderate slopes, which are less susceptible to severe soil loss. Moderate Erosion Risk (LS = 36.8–117.4), this category encompasses longer and steeper slopes, making soils more vulnerable to erosion.

While erosion risk is elevated, it remains manageable with appropriate stabilization measures. High Erosion Risk (LS = 117.5–330.3), these slopes combine both significant length and steepness, posing a pronounced erosion hazard. It is essential to apply robust soil conservation measures like terracing, contour farming, and preserving vegetation to curb erosion. Very High Erosion Risk (LS = 330.4–1871.6), corresponding to the most prolonged and steepest slopes in the catchment, these areas are highly prone to erosion. Mitigation may demand intensive interventions, including engineered structures like check dams or sediment basins, to effectively reduce soil loss.

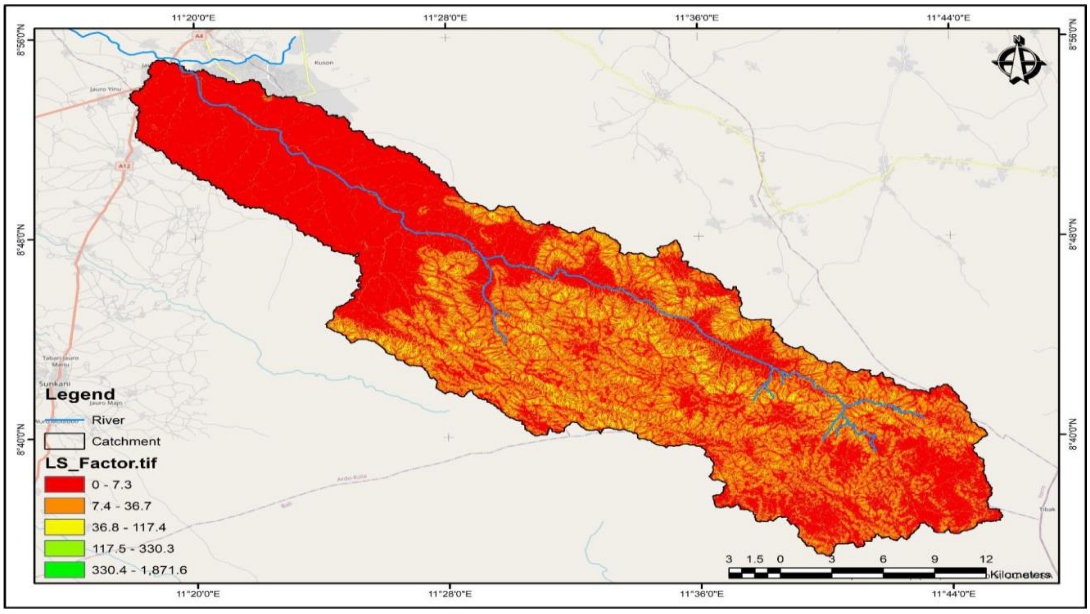

Fig.6 Length Slope (LS) Factor of River Lamurde Catchment

Support Practice (P)

The support practice factor (P) evaluates how effective land management techniques are at mitigating soil erosion. It accounts for methods like terracing, contour farming, and other conservation measures. In the River Lamurde catchment, P-factor values vary between 0.2 and 2.2 (see Fig. 7), reflecting diverse management effectiveness across the area.

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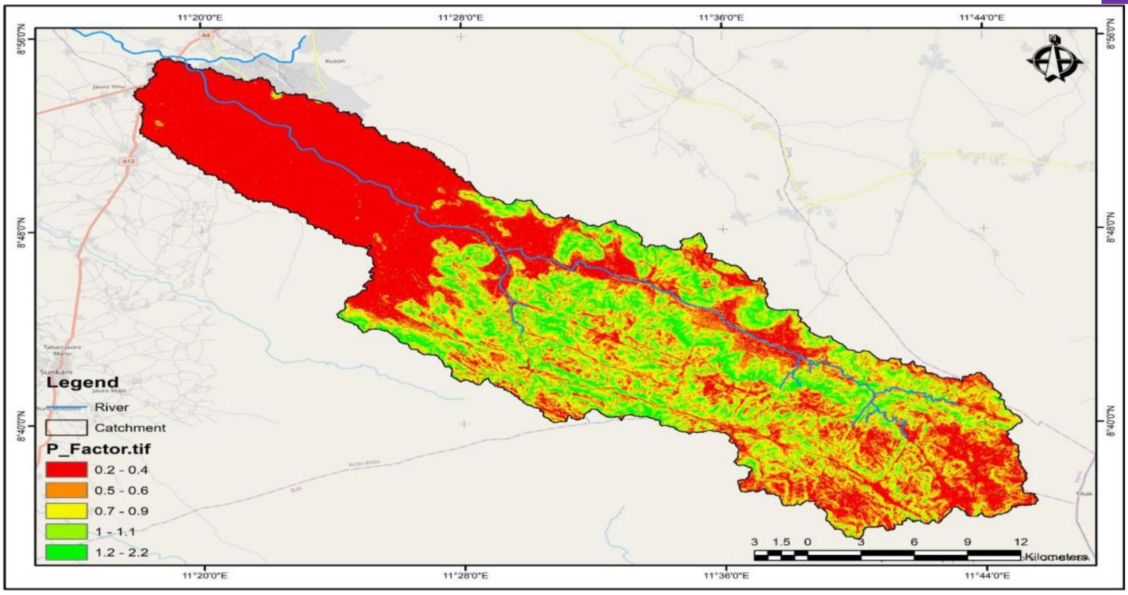

Fig.7 Support Practice (P Factor) of River Lamurde Catchment

Low P-Factor (0.2–0.4), indicates highly effective conservation practices with excellent support measures. Soil erosion is minimal in these areas. Moderate P-Factor (0.5–0.6), reflects fair management efforts. While some erosion control exists, soil loss may still occur at moderate levels. Moderately High P-Factor (0.7–0.9), suggests that support practices are inadequate and need improvement, as soil erosion becomes more pronounced. Poor P-Factor (1.0–1.1), signifies weak or ineffective conservation strategies. Erosion becomes a major concern in these areas. Very High P-Factor (1.2–2.2), indicates severely inadequate support practices, leading to a significant high

Rain Erosivity Factor (R)

The rainfall erosivity factor (R) is a fundamental component of soil erosion modeling, This factor captures the soil-eroding potential of rainfall—higher R values indicate more erosive rainfall conditions. To determine an accurate R factor for the Lamurde River catchment, historical precipitation data were meticulously analyzed. This data (shown in Fig. 8) provided essential insights into the strength, frequency, and the duration of rain events, enabling precise estimation of rainfall erosivity in the region.

The marked variability in mean annual rainfall across the River Lamurde catchment carries important implications for the local environment and the dynamics of soil erosion. Regions with a mean annual rainfall at the lower end of this range (0.04) are typically categorized as arid or semi-arid, characterized by limited water availability and often experiencing prolonged dry periods. In contrast, areas with a mean annual rainfall at the upper end of this range (0.06) tend to have a more humid climate, with a greater supply of moisture.

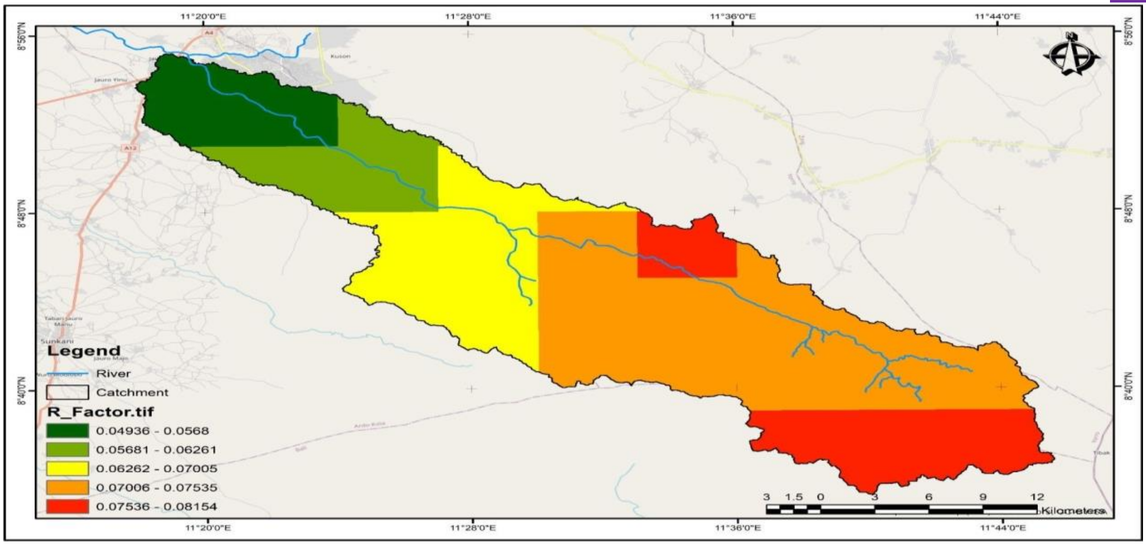

Fig.8: Rain Erosivity factor (R Factor) of River Lamurde Catchment

RUSLE Outcome and Soil Erodibility at Lamurde Catchment

Fig. 9 reveals the soil erosion probability zones while Table 1 contains extractions on land use types, soil erodibility, and their respective areas in hectares after conducting a RUSLE. Soil Erodibility reveals that of the total land area of 61,342.75 hectares, 10,521.90 hectares of bare surface, 18.11 hectares of vegetation, 136.73 hectares of built-up area, and 0.42 hectares of waterbody have high erodibility vulnerability. 792.17 hectares of bare surface, 2, 8449.70 hectares of vegetation, 3,820.02 hectares of built-up area, and 23.82 hectares of waterbody have moderate soil erodibility while 286.10 hectares of bare surface, 79,150.03 hectares of vegetation, 694.85 hectares of built-up area, and 7,466.90 hectares of waterbody have low soil erodibility. In summary, 17.4% 53.9%, and 28.7% of the land areas of the River Lamurde catchment have low, moderate, and high vulnerability to soil erosion.

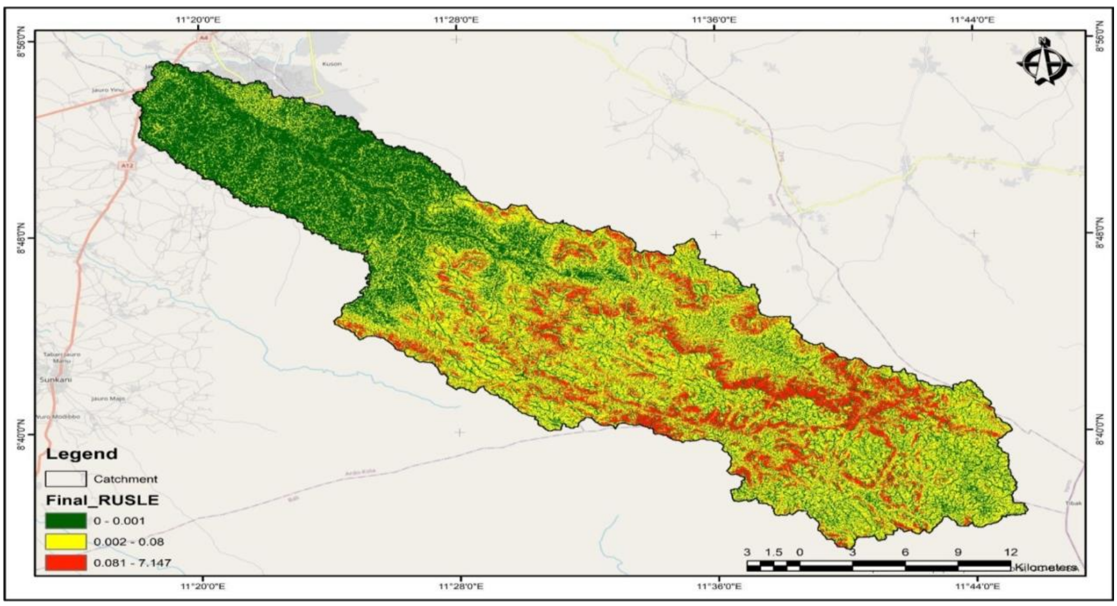

Fig. 9: Final Soil Erodibility map (RUSLE) of River Lamurde

CONCLUSION

The study identified that the river Lamurde catchment faces increased soil erosion risk due to factors such as significant increases on bare ground and built-up areas, along with a gradual reduction in vegetation cover over time. Changes in land use and land cover (LULC) significantly increase susceptibility of erosion across the study area.

Recommendations

Drawing from the outcomes of this study, the following recommendations are suggested:

1. **Erosion Control Measures**: Initiate afforestation and reforestation efforts to restore and preserve vegetation cover throughout the catchment. This approach will aid in stabilizing the soil, minimizing erosion, and improving landscape resilience
2. **Sustainable Land Management**: Advance sustainable land-use techniques including terracing, contour farming, and agroforestry. These practices safeguard soil structure, reduce runoff, and support long-term agricultural productivity.
3. **Urban Planning Integration**: Embed erosion prevention strategies into urban planning protocols. Incorporate green infrastructure like permeable pavements, bioswales, and proper stormwater systems to mitigate impacts from urbanization.
4. **Monitoring and Adaptive Management:** Establish a continuous monitoring framework to track changes in land use, erosion patterns, and the effectiveness of implemented control measures. This data-driven approach will support responsive and adaptive land management.
5. **Erosion Control Measures:** Implement erosion control measures, including afforestation and reforestation programs, to restore and maintain vegetation cover within the catchment. This will help reduce soil erosion and stabilize the landscape.
6. **Sustainable Land Management:** Encourage sustainable land management practices, including terracing, contour farming, and agroforestry, to minimize soil erosion and improve soil health.
7. **Urban Planning:** Incorporate erosion prevention and mitigation measures into urban planning and development to mitigate the impact of built-up areas on erosion dynamics. This includes proper stormwater management and green infrastructure planning.
8. **Monitoring and Assessment:** Implement a monitoring and assessment program to continuously track soil erosion patterns, land use changes, and the effectiveness of erosion control measures. This will generate critical data to support adaptive management.

9. **Public Awareness:** increase awareness among local communities and stakeholders about the importance of soil conservation and erosion control. Encourage community involvement in conservation efforts.
10. **Research and Further Studies:** Support research initiatives and further studies to gain a deeper comprehension of soil erosion processes, climate change impacts, as well as the long term effects of erosion control interventions within the catchment.
11. **Policy Integration:** Integrate erosion control and land management strategies into local and regional policies, ensuring that they align with sustainable development goals and environmental conservation objectives.

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Data availability

No datasets were generated or analyzed during the current study.

Declarations

Ethics approval and consent to participate

The author(s) declare that it is not applicable.

Consent for publication

The author(s) declare that this is not applicable.

Competing interests

The author(s) declare that they have no competing interests.

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