MODELLING AND PREDICTION OF THE IMPACT OF CLIMATE CHANGE ON SOIL EROSION IN THE AGUATA AGRICULTURAL ZONE OF ANAMBRA STATE

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ABSTRACT
Climate change significantly influences soil erosion processes, particularly in agricultural zones where extreme weather conditions intensify environmental degradation. This study employs Geographic Information System (GIS) and remote sensing techniques to model and predict the impact of climate change on soil erosion in the Aguata Agricultural Zone of Anambra State, Nigeria. Utilizing the Revised Universal Soil Loss Equation (RUSLE) and Watershed Erosion Prediction Project (WEPP), soil erosion susceptibility maps were developed. Key factors influencing soil erosion, including rainfall erosivity (R-factor), soil erodibility (K-factor), slope length and steepness (LS-factor), vegetation cover (C-factor), and conservation practices (P-factor), were analyzed. The study revealed a mean soil erosion rate of 0.79 tons per hectare per year, with predictions indicating an increase to 0.82 tons per hectare per year over the next decade due to intensified rainfall patterns as a result of climate change. The findings underscore the urgent need for sustainable soil conservation strategies and climate adaptation policies to mitigate the adverse effects of climate change on agricultural productivity in the region.

Keywords: Climate Change, Soil Erosion, GIS, Aguata Agricultural Zone, Rainfall Erosivity

1. INTRODUCTION
Soil erosion, exacerbated by climate change, poses significant challenges to agricultural productivity and environmental sustainability (Pimentel and Kounang, 1998). Climate change, characterized by long-term shifts in temperature, precipitation, and atmospheric conditions, has intensified environmental challenges, particularly in agriculture (IPCC, 2014). Among the most critical disasters affecting farmlands is soil erosion, which threatens food security, land productivity, and local economies (Lal, 2001). Climate change exacerbates these issues by altering rainfall patterns, increasing storm intensity, and accelerating soil degradation (Nearing et al., 2005).

Soil erosion occurs when topsoil is removed by water, wind, or human activities, reducing soil fertility and making farming difficult (Montgomery, 2007). Increased rainfall intensity and prolonged dry periods, have accelerated soil degradation. Flooding that causes soil erosion often caused by heavy rainfall and rising water levels, destroys crops, displaces farmers, and further degrades soil (Borrelli *et al*., 2020). Both disasters form a vicious cycle, where erosion weakens soil retention, increasing runoff and flood risks. Unchecked, these issues will continue to endanger agricultural zones, making adaptive strategies essential for resilience (Kirkby *et al.,* 2004).

In Nigeria's Aguata Agricultural Zone (Anambra State), climate change has worsened soil erosion, severely affecting agriculture. Increased heavy rainfall has led to extensive topsoil loss and land degradation (Okpala-Okaka and Ogbu, 2019). However, despite recognition of climate change as a major driver of these disasters, the specific mechanisms linking climate change and erosion in this region remain poorly understood. This study aims to investigate these effects using Geographic Information System (GIS).

The study aims to model the impact of climate change on soil erosion in Aguata Agricultural Zone using GIS technology. This research is significant for: Providing data to guide policies on land use and climate resilience, helping farmers adapt to changing soil and water conditions (Wischmeier and Smith, 1978). Identifying conservation strategies to improve soil retention and prevent flooding, offering localized data to inform climate response measures, Highlighting key areas for further study and action, Contributing to Nigeria-specific climate research, respectively (Ogunbodede *et al.,* 2022).

The study will assess climate change's impact on soil erosion in Aguata Agricultural Zone over 30 years (1993-2023), using Python-based GIS models to predict trends for the next 10 years. This research will offer critical insights into mitigating climate-induced agricultural challenges in the region.

2. MATERIALS AND METHODS

2.1 Study Area

The Aguata Agricultural Zone, one of the four agricultural zones in Anambra State, Nigeria, is situated in a sub-humid climatic region (Ofomata, 1985). It covers an area of approximately 534 square kilometers and includes four local government areas: Nnewi North, Nnewi South, Orumba South, and Orumba North as shown in Figure 1.

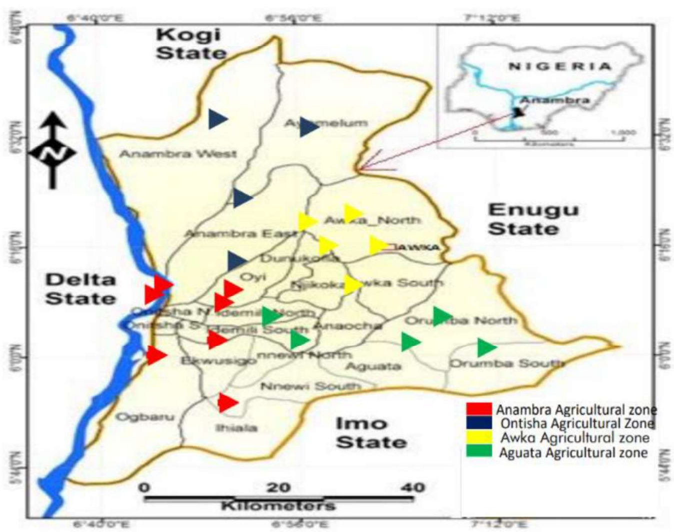

Figure 1. Map of Anambra State showing Aguata Agricultural Zone
Source: Ohaturuonye (2022)

The climate is tropical, with a raining season starting from April to October and a dry season starting from November to March. Annual rainfall ranges between 1,500 mm and 2,000 mm, supporting rainfed agriculture, though climate variability can cause water stress (Odekunle, 2004). The temperature averages between 25°C and 32°C, contributing to high evapotranspiration rates, which affect soil moisture retention and necessitate irrigation during the dry season (Martinez and Xu 2022).

The region is water-rich, with tributaries of the Niger River and the Anambra River, which support irrigation, fisheries, and domestic water use (Ezenwaji *et al.,* 2016). The topography includes a mix of lowland plains and undulating terrains, with fertile alluvial soils along riverbanks that support diverse crops such as rice, cassava, maize, and vegetables. However, soil erosion and leaching are concerns in the region, requiring soil management practices (Igbokwe *et al.,* 2008).

2.2 Data Collection and Processing

The study utilized two datasets which includes the Geographical Information System (GIS) and climate dataset. The Geographical Information System (GIS) comprises the

- *Digital Elevation Model (DEM);* this was sourced from the USGS, 30m resolution and was used for the terrain analysis, watershed delineation, and hydrological modeling. It was processed through conversion, projection (García and Pereira, 2023) resampling, and sink filling.

- *Satellite Imagery:* The satellite imagery used was obtained from the Landsat 8 with a 30m resolution.It was used for land cover and vegetation analysis, with preprocessing steps including conversion, radiometric correction, NDVI and EVI calculation, and alignment.

- *Land Cover:* the land cover was obtained from the USGS NLCD, with a 30m resolution: Processed for spatial alignment, resampling, and accuracy verification using satellite imagery and field observations.

- *Soil Type*: the soil type was sourced from the USDA SSURGO, with a 30 m resolution. The soil type was processed through conversion, projection, resampling, and validation against field data for soil erosion modeling.

Secondly, the climate Dataset which comprises the Rainfall Data was sourced from the Nigerian Meteorological Agency (NiMet). The rainfall data was processed into a raster format, re-projected, resampled, and validated against historical records for accuracy in hydrological modeling.

3. DEVELOPMENT OF SOIL EROSION MODEL

The soil erosion model was developed to predict soil erosion of Aguata Agricultural Zone. The comprehensive model was constructed following a systematic sequence of steps, including Modeling Framework, Algorithm Development, and implementation within a GIS environment as detailed below.

Modeling Framework: The modeling framework was based on established principles and equations from the Revised Universal Soil Loss Equation (RUSLE) (Equation 1) and the Watershed Erosion Prediction Project (WEPP). These models are widely used for predicting soil erosion rates and understanding runoff and sediment dynamics.

$$A = RKLSCP \quad (1)$$

Algorithm Development and Testing: Algorithms were developed to automate the computation of critical parameters in the RUSLE and WEPP models. Python programming language was employed for spatial analysis and the development of raster-based processing algorithms for each erosion and flood-related factor.

Erosion Modeling Parameters: The following parameters were calculated and integrated into the model: The R-Factor (Rainfall Erosivity Factor) was calculated using rainfall data representing the erosive power of rainfall, the K-Factor (Soil Erodibility Factor) was derived from soil type data indicating soil susceptibility to detachment and transport, the LS-Factor (Slope Length and Steepness Factor) was Computed from the DEM, quantifying the impact of terrain on runoff and soil erosion, the C-Factor (Vegetation Cover Factor) was Based on the vegetation indices such as NDVI and EVI which represents the protective effect of vegetation cover, and P-Factor (Support Practice Factor) was Calculated using land cover data, accounting for conservation practices like terracing and contour farming.

The model implementation in the GIS environment involves the using ArcGIS software, a robust platform for spatial analysis, raster processing, and hydrological modeling. The Python programming language was used for scripting, automating model workflows, and performing advanced computations. The raster layers representing each erosion factor (R, K, LS, C, P) were computed and combined to generate erosion susceptibility maps. Also, the vector layers, such as watershed boundaries and stream networks, were integrated to enhance spatial analysis and visualization. Also, the factor maps were overlaid using GIS tools to compute the overall erosion and flood susceptibility map. This overlay approach allowed for a spatially explicit representation of risk areas. Hence, the GIS-based hydrological tools were employed to analyze flow direction and flow accumulation, identifying areas with concentrated runoff and potential flooding hotspots.

4. RESULTS AND DISCUSSION

The soil erosion model developed as well as the next ten years' prediction model was based on the effect of climate change on environmental disasters such as erosion and flood in aguata agricultural zones of Anambra State. Four (4) different results stages is presented and discussed, namely; the terrain analysis, the morphometric parameters, the hypsometric analysis, and the erosion modeling and prediction.

4.1 Terrain Analysis

4.1.1 The digital elevation model (DEM)

The terrain analysis of the Aguata Agricultural Zone was conducted using a Digital Elevation Model (DEM), which provided insights into elevation range, slope variations, and overall terrain patterns. The study revealed that the minimum elevation in the area is 50 m representing low-lying features such as valleys, plains, or gully erosion sites, while the maximum elevation reaches 236 meters, indicating the presence of hills, ridges, or elevated plateaus (Figure 2). The mean elevation was found to be 100.91 meters, suggesting a moderately elevated landscape, though it is slightly skewed by extreme values. The median elevation was recorded at 94 meters, slightly lower than the mean, indicating a terrain distribution with more land closer to lower elevations.

The elevation variation within the study area was calculated as 186 meters, suggesting moderate topographic relief characterized by rolling hills or foothills. The difference between the mean and median elevations reflects a positively skewed distribution, meaning that while much of the terrain is closer to the lower elevation levels, a few high points elevate the overall average, this agrees with the findings of Zhang et al., (2020). This terrain analysis is crucial for understanding factors such as erosion risks, water flow patterns, and agricultural suitability in the region.

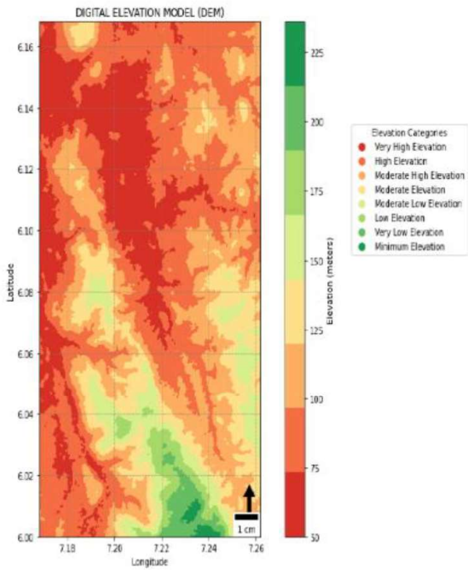

Figure 2. The Digital Elevation Model of the Study Area

4.1.2 Slope analysis

The slope analysis of the Aguata Agricultural Zone quantifies the steepness of the terrain, providing essential insights for hydrology, geomorphology, land use planning, and hazard assessment. The study revealed that the mean slope is 58.36 degrees, indicating a generally steep landscape typical of hilly or mountainous regions. However, the averaging process may obscure significant variations in slope across different areas. The median slope, recorded at 63.43 degrees, suggests that half of the terrain is steeper than this value, while the other half is less steep as shown in Figure 3. Since the median is slightly higher than the mean, the slope distribution may be negatively skewed, with fewer gentle slopes affecting the average value. The standard deviation of 16.55 degrees reflects a moderate level of variability, indicating a mix of steep and gentle slopes within the study area. The high mean and median slope values suggest that the region is predominantly steep, which can influence factors such as accessibility, vegetation patterns, and water flow dynamics. The presence of steep slopes may also contribute to erosion and potential geomorphological changes, while gentler slopes are more likely to be found in valley floors or plateau-like areas.

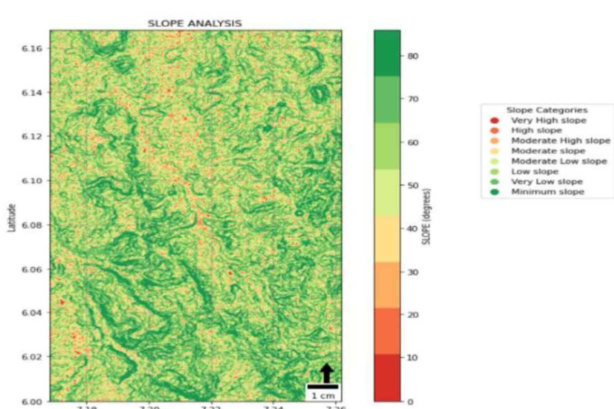

Figure 3. The slope analysis of the Study Area

4.1.3 Aspect analysis

The aspect analysis of the Aguata Agricultural Zone examines the direction slopes face, which influences solar radiation exposure, microclimate variations, vegetation distribution, and land use suitability. The study found that the mean aspect of the terrain is 175.03°, indicating an overall southward slope orientation as shown in Figure 4. However, due to the circular nature of aspect data, the mean alone may not fully capture the distribution of slope directions. The median aspect of 180° confirms that at least half of the slopes in the study area face directly south, suggesting a predominant south-facing terrain orientation. A high standard deviation of 107.46° reflects significant variability in slope directions, indicating that slopes face multiple orientations rather than being concentrated in a single direction. This suggests a complex and rugged landscape with ridges, valleys, and irregular terrain features. The predominance of south-facing slopes has important implications for solar radiation exposure, potentially affecting microclimates, vegetation patterns, and hydrological processes such as snowmelt and water retention. However, the high variability in aspect values highlights the diverse nature of the terrain, where different slope directions contribute to a heterogeneous environmental and agricultural landscape.

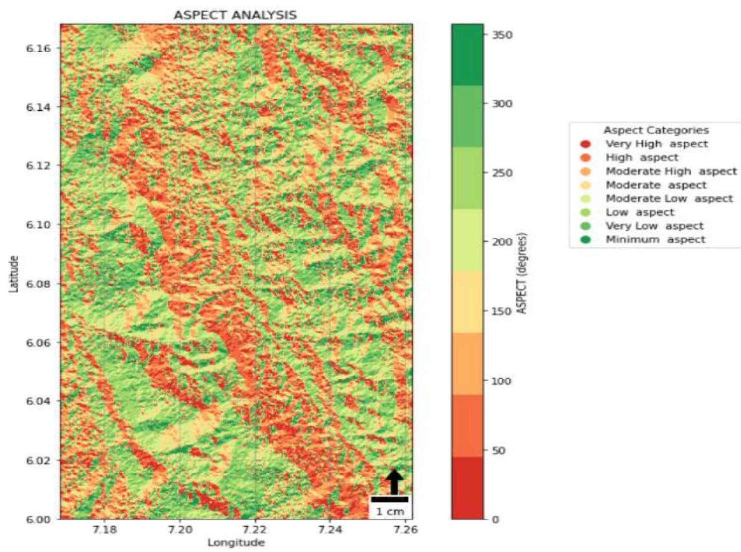

Figure 4. The Study Area Aspect Analysis

4.1.4 Landform analysis

The landform analysis of the Aguata Agricultural Zone classifies key geomorphological features, including valleys, hills, and plateaus, which impact hydrology, biodiversity, and land use planning. The study identified 2,694 valleys, 99,415 hills, and 1,029 plateaus as shown in Figure 5. The high hill count indicates a rugged, elevated landscape shaped by erosion and tectonic processes, while the lower valley and plateau counts suggest limited flat and low-lying areas. This terrain influences water flow, sediment transport, and habitat diversity. Hills create microclimatic variations, while valleys serve as drainage pathways, highlighting the region's complex geomorphological dynamics and environmental implications.

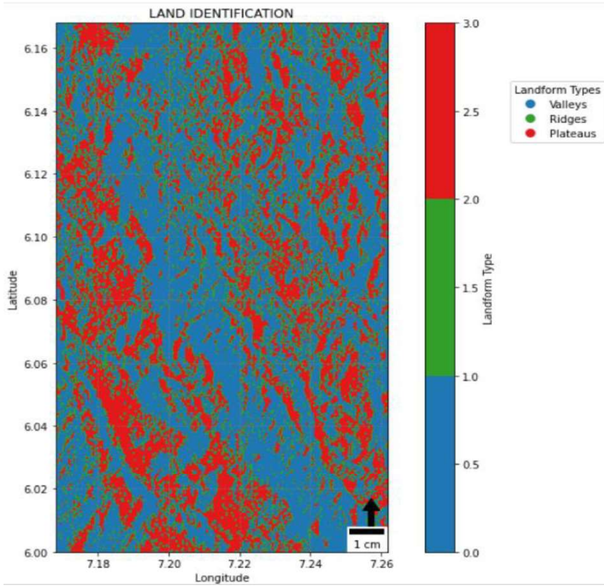

Figure 5. The Landform Analysis of the Study

4.1.5 Curvature statistics

The curvature analysis quantifies changes in slope and aspect, highlighting geomorphological processes like erosion and water flow. The study found a mean curvature of 0.0013, a median of 0.0, and a standard deviation of 1.69 as shown in Figure 6. A mean close to zero suggests a balanced terrain, while a slight positive value indicates rounded hilltops. The median of zero reflects an equal distribution of concave and convex areas, and the high standard deviation suggests significant variability. This indicates a dynamic landscape where convex areas may face erosion, while concave regions accumulate sediments, shaping the hydrological and geomorphological characteristics of the terrain.

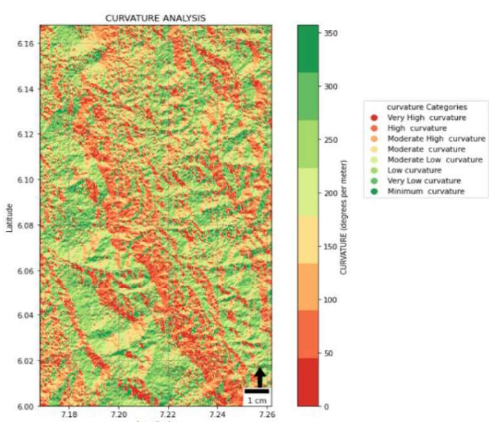

Figure 6. Curvature Descriptive Analysis of the Study Area

4.1.6 Hillshade

The hillshade analysis simulates terrain illumination by calculating light interaction based on slope and aspect. The study found a mean hillshade value of 3.44 and a standard deviation of 158.56 (Figure 7). The low mean suggests most of the terrain is shadowed, likely due to steep slopes or unfavorable light alignment. The high standard deviation indicates a mix of bright and dark areas, reflecting a rugged landscape with sharp elevation changes. Shadowed areas may retain moisture longer, affecting drainage and vegetation. This highlights the terrain's complexity, where valleys and steep slopes create uneven light distribution and varied microclimatic conditions.

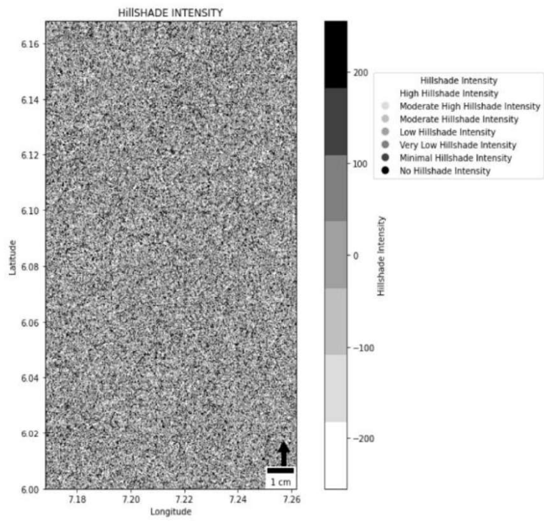

Figure 7. Curvature Descriptive Analysis of the Study Area

4.2 Morphometric Parameters

The morphometric analysis quantifies the terrain's geometry and hydrological properties, highlighting its susceptibility to soil erosion, particularly under climate change. The study reveals a watershed area of 0.0086 m^2 with a high perimeter-to-area ratio, indicating an irregular shape that promotes uneven runoff distribution and localized erosion. A low circularity value of 0.0671 suggests an elongated watershed prone to increased flow velocity and concentrated erosion pathways. The high drainage density of 3600.0000 m^{-1}, and stream frequency of 115.8705 m^{-2} indicate an extensive stream network, leading to rapid runoff and heightened erosion risks.

The compactness coefficient of 3.8598 and shape factor of 0.0053 confirm a highly elongated watershed, which enhances concentrated flow and erosion. The very high elongation ratio of 377.3733 further suggests rapid water movement, increasing erosion vulnerability, especially with intensifying rainfall due to climate change. High stream frequency implies continuous soil displacement, exacerbating land degradation. These characteristics suggest a fragile watershed with limited infiltration capacity, making it prone to severe erosion, land degradation, and soil fertility loss. To mitigate these effects, conservation practices such as contour farming, terracing, reforestation, and check dams are recommended. Managing the existing stream network and increasing vegetation cover will help reduce runoff speed and minimize soil erosion risks.

4.3 Hypsometric Analysis

Hypsometric analysis assesses elevation distribution within a landscape, revealing its erosional stage and geomorphological characteristics. The study results show a hypsometric integral (HI) of 0.7403, mean elevation of 97.46 m, elevation range of 173.00 m, and relief of 173.00 m as shown in Figure 8. An HI of 0.7403 suggests a youthful erosional stage, with steep slopes and active geomorphic processes. This implies a high potential for erosion, particularly under increased rainfall due to climate change. The mean elevation of 97.46 m indicates a relatively low-lying area. Lower elevations can be prone to erosion if steep slopes exist within this range. Additionally, low-lying areas are more susceptible to flooding, particularly during heavy rainfall events. While the elevation range of 173.00 m suggests moderate topographic variation, meaning both steep and flat areas exist. Steeper slopes are more prone to erosion, while flatter areas may experience sediment accumulation and water pooling. Increased rainfall can intensify these effects, leading to higher erosion in elevated areas and flooding in lower regions. However, a relief of 173.00 m indicates a mix of high and low elevations. Steep areas are vulnerable to erosion, while low-lying regions are at higher risk of flooding, particularly if the terrain lacks sufficient drainage infrastructure.

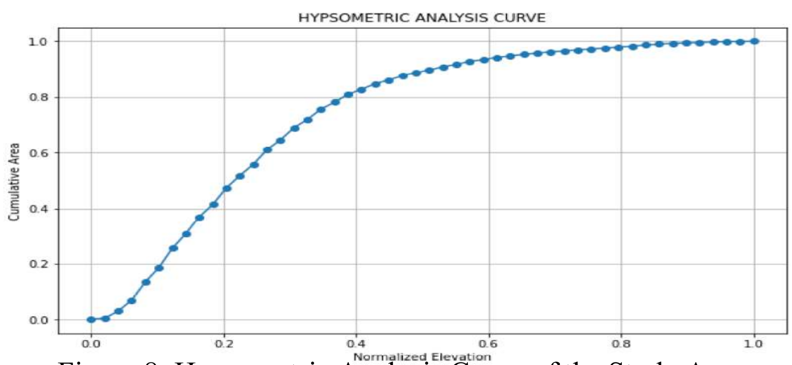

Figure 8. Hypsometric Analysis Curve of the Study Area

4.4 Soil Erosion Modeling

4.4.1 Soil erosion parameters

The soil erosion parameters (Figure 9) of R-Factor, calculated as 8.80 in the Aguata Agricultural Zone, indicates moderate-to-high rainfall erosivity, suggesting vulnerability to soil erosion and flooding. High rainfall intensity in the region contributes significantly to soil degradation, increasing runoff and flood risks. The K-Factor of 0.396 reflects moderate soil erodibility, making the area prone to erosion, especially under intense rainfall. This can impact agricultural productivity and infrastructure, with sediment clogging drainage systems. Likewise, The LS-Factor of 1.25 highlights moderate topographic influence on erosion, with steep, long slopes accelerating runoff and increasing erosion risks. The C-Factor of 0.262 shows that land cover offers moderate protection against erosion, with partial vegetation cover providing some mitigation. The P-Factor of 0.39 suggests moderate implementation of erosion control measures, indicating room for improvement in soil conservation practices. Together, these factors emphasize the need for enhanced erosion control and flood management strategies in the region, especially with climate change intensifying rainfall and runoff.

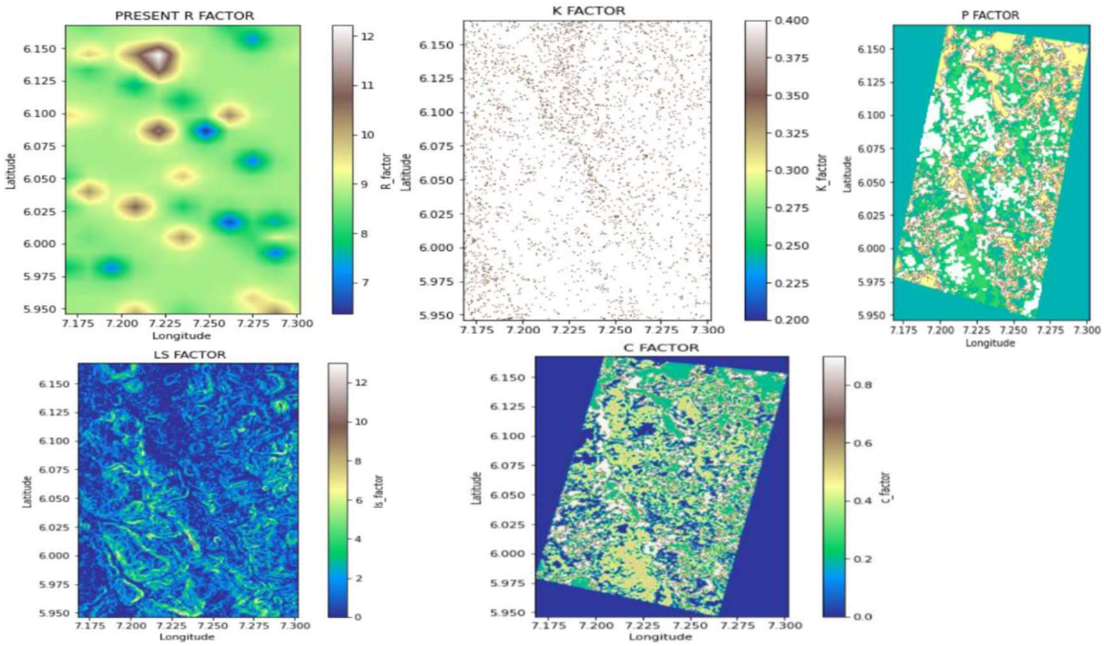

Figure 9. Soil Erosion Model Map of the Study Area

4.4.2 Present and predicted soil erosion model

The developed soil erosion model shows that the mean soil erosion rate in the Aguata Agricultural Zone is 0.79 tons per hectare per year as shown in Figure 10, representing a low to moderate level of soil loss. This suggests that while the soil loss is manageable, it still poses a risk to soil fertility, agricultural productivity, and increases the likelihood of flooding due to sediment deposition in waterways. Climate change, with its effects on rainfall variability and storm intensity, could further exacerbate these erosions and flooding risks. this is in agreement with the study of Akanbi and Adepoju (2017) who in their studies highlights how moderate soil erosion in agricultural zones contributes to sediment deposition in rivers, increasing flood risks and infrastructure vulnerabilities.

Looking ahead, the next 10-year soil erosion model predicts a slight increase in the erosion rate to 0.82 tons per hectare per year as shown in figure 11, totaling 13.20 tons of soil loss over the decade. This reflects the growing impact of climate change, including more intense rainfall and land use changes like deforestation, which increase soil exposure and erosion. Such erosion will likely reduce agricultural yields, increase sedimentation in rivers, and heighten flood risks, making soil management and conservation practices critical for the region's sustainability.

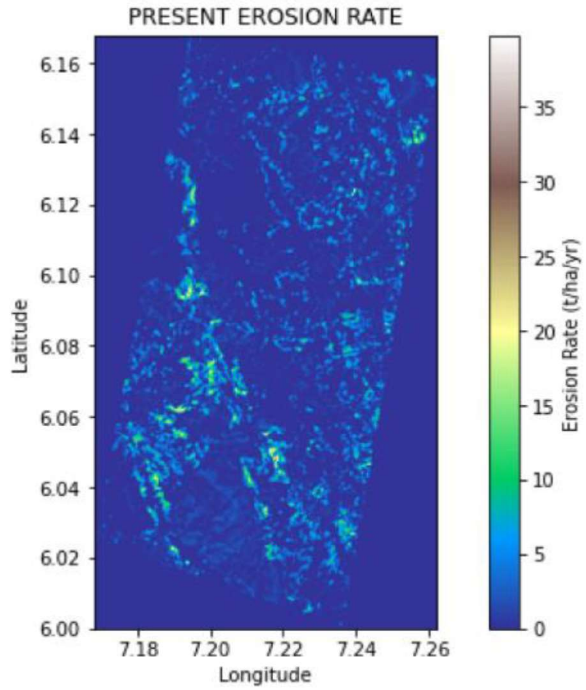

Figure 10. Present Soil Erosion Model of the Study Area

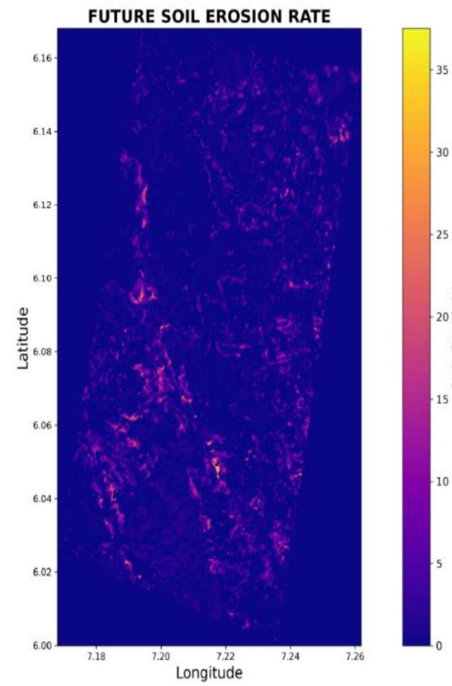

Figure 11. 10-year Predicted Soil Erosion Model of the Study Area

5. CONCLUSION AND RECOMMENDATIONS

The integration of GIS-based modeling provides a robust framework for understanding and addressing soil erosion challenges in climate-vulnerable regions. This study highlights a gradual but significant increase in soil erosion due to climate change in the Aguata Agricultural Zone. To mitigate these effects, the following measures are recommended: adoption of sustainable land management practices, enhanced flood management strategies, policy interventions. Future research should focus on integrating machine learning techniques to improve predictive accuracy and enhance climate adaptation strategies.

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