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Estimation of soil erosion and risk assessment in Somalia

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ABSTRACT

Soil erosion is a pressing issue that threatens environmental stability and agricultural productivity across the globe. In Somalia, where the population already contends with severe socioeconomic and environmental challenges, the effects of erosion compound problems like food insecurity and land degradation. This study investigates erosion patterns and identifies areas prone to soil loss, aiming to provide actionable insights for improving land use practices and resource management. The research employs advanced analytical tools to study how erosion factors are distributed geographically. Data such as terrain characteristics, rainfall intensity, vegetation cover, soil quality, and land usage are systematically analyzed. Cutting-edge modeling techniques, supported by historical erosion trends, help to develop accurate predictions about future soil loss, offering a robust basis for creating effective intervention strategies. The findings show that many regions in Somalia are highly susceptible to erosion, particularly where unsustainable human activities such as overgrazing, deforestation, and improper farming methods are prevalent. These insights underscore the urgent need for targeted policies to mitigate erosion and protect valuable soil resources. By forecasting potential erosion scenarios, this research equips decision-makers with the tools needed to prioritize interventions that enhance agricultural output, preserve ecosystems, and ensure long-term sustainability. This research aids policymakers, land managers, and stakeholders in formulating focused, evidence-based plans for soil conservation and sustainable land use, ultimately facilitating the preservation and enhancement of Somalia's natural resources and agricultural resilience.

Keywords: Erosion, Soil loss models, SLEMSA, RUSLE, CORINE

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Introduction

Soil erosion in Somalia is driven by the removal of vegetation cover, unsuitable land use practices, and urbanization, significantly exacerbating land degradation across the country (Nur *et al.*, 2024a). Soil erosion plays a significant role in environmental changes by contributing to land degradation (Oldeman *et al.*, 1991; Lal *et al.*, 1998). It affects the land's ability to regulate ambient temperatures, impacts agricultural productivity, deteriorates surface water quality, and alters the visual appeal of landscapes by disrupting soil structure (Feddema, 1998; FAO, 2003; Gisladottir and Stocking, 2005). To address this issue, land managers focus on identifying areas prone to erosion or showing early warning signs and implementing strategies tailored to control and prevent further degradation. The intensity of soil erosion depends on soil erodibility and the erosive agent. Precipitation and runoff constitute the primary source of energy for soil separation and transport in water erosion mechanisms. Erosivity refers to the potential capacity of precipitation to induce erosion. It relies on the physical attributes of precipitation, encompassing raindrop size, drop size distribution, kinetic energy, and velocity. Rainfall erosivity, like other rainfall characteristics, is governed by the rainfall drop size distribution (DSD) (Abd Elbasit, 2013). Due to the qualitative nature of the rainfall DSD, various indicators have been proposed to quantify rainfall erosivity. Soil erosion results from the interaction of soil erodibility and erosivity (Kertesz and Gergely, 2011). Rainfall erosivity has been examined globally, with factors such as intensity, velocity, size, and kinetic energy of raindrops being commonly utilised to formulate erosivity indices. Rainfall erosivity significantly contributes to sediment and nutrient loss globally, potentially exposing farmers to crop failures and resulting in unstable equilibrium states in landscapes. The exposure of the Earth's surface to intense rainfall is a critical factor influencing water erosion in terrestrial ecosystems and other detrimental hydrological phenomena, including floods and flash floods. Hydrological extremes and the resultant sediment loss during rainfall events are pivotal elements of the global climate system, as global fluctuations in temperature and precipitation patterns induce comparable alterations in the emergence of natural hazards. Extreme storms and rainfall-runoff erosivity are thought to be increasing in frequency as a result of climate change (Bellocchi and Diodato 2020). Erosion poses a significant global challenge, resulting in detrimental economic and environmental consequences, including the depletion of land resources and diminished land productivity, particularly through the transport of nutrient-rich sediments that contribute to eutrophication and decrease the storage capacity and lifespan of reservoirs (Eroglu *et al.*, 2010). In Africa, particularly in sub-Saharan nations experiencing substantial rainfall, water erosion poses a significant challenge to agriculture and the environment. Water erosion primarily caused soil loss in the North. Soil loss from wind erosion was significant along the north-western coast of the Indian Ocean in Somalia (FAO SWALIM, 2009). The soil of Somalia is predominantly composed of well-developed and highly weathered material, except in degraded regions and recent alluvial and sand dune deposits. The WRB (2024) indicates that Somali soils exhibit significant variability about their source rock. Soil erosion is a significant environmental challenge, particularly in regions like Somalia, where vegetation loss, urbanization, and unsustainable land use practices drive severe land degradation. Rainfall erosivity, major factor influencing soil erosion, directly impacts the detachment and transport of soil particles, posing serious threats to agriculture, water resources, and ecosystem stability (Mohamed, 2013). In East Africa, the interplay between socio-economic and natural factors further exacerbates erosion risks, necessitating urgent interventions (Wynants, 2019).

Soil erosion is a significant global challenge that has detrimental effects on both the environment and public health. Each year, large portions of cultivable land are lost, reducing the land available for food production and worsening global hunger issues. This rapid loss of soil, happening much faster than it can naturally replenish, threatens the sustainability of agriculture and the long-term health of ecosystems. Regions such as East Africa, with their steep landscapes, vulnerable soils, and heavy rainfall, are particularly at risk of erosion. In Somalia, the consequences of this erosion are felt in the form of reduced agricultural productivity, deteriorating water quality, and altered landscapes. Human activities, including overgrazing, deforestation, and poor land management practices, significantly worsen the erosion problem. While research into improving soil erosion assessment techniques continues to grow, there is still a gap between research findings and the implementation of solutions. This study aims to bridge that gap by evaluating erosion risks and predicting soil loss in Somalia, offering valuable insights to support better land management and resource planning.

Overview of erosion

Soil erosion results from both natural processes and human activities. Factors such as high rainfall intensity, deforestation, and poor land management practices leave soil exposed and vulnerable to degradation. In sub-Saharan Africa, erosion hotspots are linked to rainfall patterns and anthropogenic activities, emphasizing the need for proactive land management strategies (Zubair and Durrani, 2019). Sediment transport in watersheds is also a critical issue, highlighting the interconnected nature of erosion and hydrological systems (Gao, 2008). Globally, the environmental and economic impacts of soil erosion make it a pressing concern, with far-reaching implications for food security and ecosystem services (Pimentel, 2006). Soil erosion represents a major challenge to global agriculture, threatening the sustainability of soil resources and agricultural productivity, particularly in farming and grazing areas. While erosion has been a concern since the beginning of agriculture, its scale and effect on human well-being and the environment have grown more severe over time. Despite short-term improvements in crop yields from fertilizers and other agricultural inputs, continuous erosion will lead to a long-term decline in productivity. This is one of the hidden costs associated with soil erosion. Additionally, erosion contributes to environmental degradation, causing downstream flooding, sediment build-up in water reservoirs, and a deterioration in water quality. Reduced soil health is often linked with declines in both water and air quality, reflecting the broader off-site effects of erosion (Lakew and Belayneh, 2012).

International recognition of soil erosion

Soil erosion by water is affected by both anthropogenic activities and physiographical factors, including rainfall intensity, topography, soil texture, and discharge. The significance of this subject has resulted in considerable international studies focused on comprehending soil erosion caused by water. Various methodologies have been utilised to evaluate soil erosion, spanning from tiny agricultural plots to broader regional extents. In recent years, the application of numerical modelling for evaluating soil erosion has attracted considerable attention and interest from researchers globally, showing a significant increase. The utilisation of numerical models in evaluating soil erosion presents numerous benefits. The benefits of soil erosion modeling include helping researchers better understand the processes involved in sediment formation, movement, and deposition. This improves their ability to analyze and predict erosion dynamics (Ding and Richards, 2009).

Soil erosion modelling

Various models have been developed to estimate and mitigate soil erosion. The Modified Universal Soil Loss Equation (USLE) is a foundational tool used to evaluate soil loss based on factors such as rainfall erosivity, soil erodibility, and land use. When integrated with digital terrain models, USLE enhances the precision of erosion risk assessments (Flacke *et al.*, 1990). GIS-based sediment assessment tools and remote sensing technologies offer advanced methods for prioritizing conservation efforts in watersheds (Lim *et al.*, 2005; Pretorius, 1998). Additionally, simple and practical estimation methods continue to provide accessible solutions for managing soil erosion in resource-constrained areas (Elwell and Stocking, 1982).Over the past decade, various models have been employed to estimate soil loss and sediment production, proving valuable in understanding and managing erosion. Given the complexity and long duration of soil erosion field surveys, modeling has become essential. Field-based data collection alone presents challenges, particularly in tracking the effects of land use changes and managing erosion over time. Moreover, establishing a comprehensive database for such studies can be time-consuming (Morgan, 2005). Erosion models address these limitations by offering accurate predictions under various environmental conditions, with validation through comparison to actual measurements (Morgan, 2005).

According to Morgan (1995), there are two primary reasons for using erosion models: to understand the fundamental processes and their relationships, and as tools to predict soil loss in conservation efforts. Since the 1930s, scientists have worked to overcome the challenges of predicting and assessing soil erosion, leading to the creation of several different models (Lal, 2001). These models are generally classified into three categories: physical process-based models, semi-empirical models, and empirical models. Empirical models rely heavily on statistical methods and observed data, while semi-empirical models combine aspects of both physical and empirical approaches, using equations to model water and sediment continuity. Physical process-based models, on the other hand, aim to simulate the actual processes driving erosion, incorporating various factors and their spatial and temporal variations (Jha and Paudel, 2010).

RUSLE Modelling

Erosion models are crucial for predicting soil loss and understanding the intricate dynamics within watersheds, where various factors influence erosion rates. The Revised Universal Soil Loss Equation (RUSLE) is widely used for this purpose, quantifying soil loss from hillslopes by considering variables such as soil type, climate, vegetation, topography, and human activities (Shi *et al.*, 2004; Teng *et al.*, 2018). RUSLE is particularly valuable for evaluating erosion risk across different spatial scales, allowing for the formulation of effective soil conservation strategies. Its simplicity makes it applicable even in areas with limited data, such as developing nations. Additionally, when integrated with Geographic Information Systems (GIS), RUSLE can be adapted to different regions and environments, enhancing its versatility (Zhou, 2008). The applicability of RUSLE has been demonstrated in numerous studies assessing soil erosion risk at both watershed and basin levels. For example, Cohen *et al.* (2005) applied RUSLE in Kenya, while Irvem *et al.* (2007) used it in Turkey's Seyhan River Basin. These studies showcase how RUSLE helps in identifying erosion-prone areas, facilitating targeted conservation and informed land management decisions. Similarly, Yılmaz (2006) used the USLE model to estimate soil loss in the 722 km2 Çamlıdere Dam Basin in Turkey, where water supply for Ankara is sourced. The model revealed an average soil loss of 7.3 tonnes per hectare annually, with vegetation and topography being significant contributors to erosion patterns. RUSLE includes general databases that can be customized, such as climate data, crop characteristics, and farming operations. These datasets provide a broad framework, but adjustments may be needed for specific sites requiring precise soil loss estimates (Renard and Ferreira, 1993). Six key parameters are used to calculate soil loss in a region, each representing a factor that influences erosion intensity. These parameters may vary based on weather conditions, and RUSLE offers a way to estimate long-term averages (Renard *et al.*, 1997a). The model's formula, A = R * K * LS * C * P, calculates the average annual soil loss, incorporating factors like rainfall, soil erodibility, slope, land cover, and conservation practices. One of the model's strengths lies in its integration with GIS techniques, allowing for precise estimations at the grid cell level. By combining spatial analysis with data processing, RUSLE provides accurate assessments of erosion risk across large areas. This has made it a widely used tool for erosion control planning and soil loss evaluation, particularly in agricultural watersheds, helping researchers and land managers make informed decisions to prevent erosion and protect agricultural landscapes (Renard *et al.*, 1997b).

RUSLE Model Parameters

Using a combination of remote sensing and GIS, the RUSLE model was utilized to map and identify soil erosion risk regions in Hirshabelle and calculate the mean annual soil loss rate (t/ha/year) on a cell-by-cell basis. The following was constructed and discussed after raster maps of each RUSLE parameter obtained from several data sources. This model works on all continents where soil erosion due to water erosion is an issue (Laflen *et al.*, 2003). The model can be expressed as:

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

Where, A=average soil loss per unit of area (t/ha/year); R=rainfall erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1}); K=is the soil erodibilty factor (t h MJ^{-1} mm^{-1}); Ls=topographic factor (dimensionless) including slope length (L) and steepness (S) factors; C=cover management (dimensionless); and P=support (or conservation) practice factor (dimensionless). The schematic representation of the RUSLE model is presented in Figure 1.

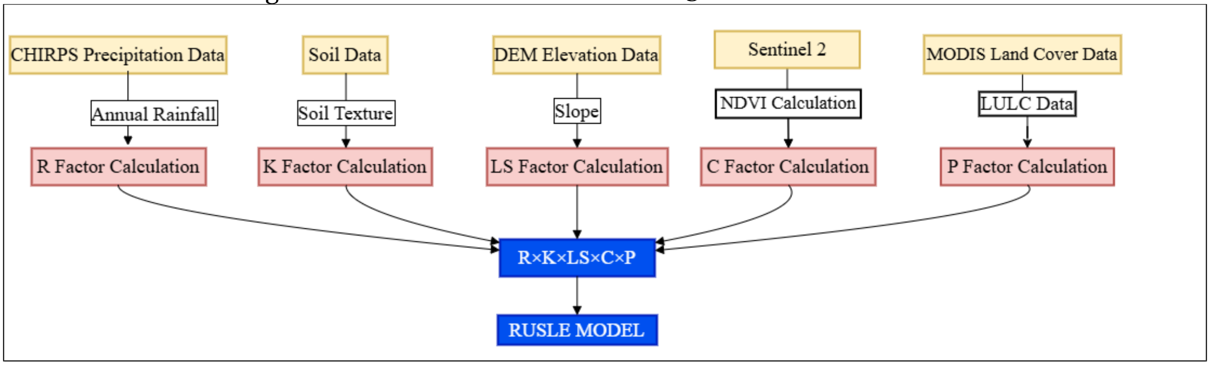

Figure 1. This flowchart illustrates the data sources and factor calculations required to apply the Revised Universal Soil Loss Equation (RUSLE) model for soil erosion assessment.

A. Rainfall Erosivity (R-factor)

The Rainfall Erosivity (R-factor) is a key parameter in the RUSLE (Revised Universal Soil Loss Equation) model, representing the impact of rainfall intensity on soil erosion (Wagari and Tamiru 2021). It is calculated by multiplying the total kinetic energy of a rainfall event by its maximum 30-minute intensity. This factor serves as an index for assessing the potential erosive power of rainfall, enabling predictions of soil erosion risks (Mikhailova *et al.*, 1997). Accurate computation of the R-factor helps to estimate and manage soil erosion in areas where there is a lack of time-series precipitation data. In such cases, monthly satellite precipitation data can be used to determine average annual erosivity (Pandey and Gautam, 2015). Thus, estimating precipitation erosivity is crucial in data-scarce regions and can be achieved using various methods, leveraging precipitation erosivity data and satellite-based precipitation.

B. Soil Erodibility (K-factor)

The K-factor is critical in calculating sediment detachment and distribution on a region's surface (Veith *et al.*, 2017). It represents the resistance of soil to erosion when impacted by raindrop impact and concentrated flow, as defined by the RUSLE model (Bayramin *et al.*, 2007). This factor reflects soil erodibility and helps quantify how changes in ecosystems or land management practices can reduce erosion susceptibility. In the RUSLE model, the K-factor estimates soil erosion potential based on various soil parameters, including soil texture, organic matter, and water content. Several modified algorithms exist to calculate the soil erodibility factor for different soils at specific sites (Rodrigo-Comino *et al.*, 2020).

C. Slope Length and Steepness Factors (LS)

Slope length and steepness are the main topographical factors affecting soil erosion. According to Ozsoy and Aksoy (2015), erosion rates-whether water or soil erosion-are directly dependent on flow velocity. Erosion occurs at a higher rate on longer slopes (Dudiak *et al.*, 2019). Steeper slopes gain less energy from water flowing down, leading to more significant soil displacement. In the RUSLE model, the LS factor is a dimensionless parameter that identifies variations in soil erosion intensity proportional to slope length and steepness. This factor effectively predicts and controls erosion threats by considering the slope's impact (Gashaw *et al.*, 2017). Studies, for example, Prasannakumar *et al.* (2012), highlight the importance of the LS factor in understanding soil erosion risk based on slope characteristics.

D. Land Cover Management Factor (C-factor)

The C-factor in the RUSLE model is an important parameter that measures soil loss based on land cover, crops, and treatment practices (Gashaw *et al.*, 2017). It is a dimensionless quantity indicating the reduction in soil loss per unit area due to specific land use practices. Monitoring or estimating soil loss due to plant cover and residual matter and evaluating efficiency levels in relation to farmland management are necessary for determining potential mitigation methods and durations (Saha, 2018, Zhao *et al.*, 2012). Different types of vegetation, structural canopies, and management strategies significantly influence soil loss and erosion rates, as defined by the C-factor.

E. Support Practice Factor (P-factor)

The P-factor in the RUSLE model represents the effectiveness of soil conservation practices in reducing erosion. It is calculated by dividing soil loss from a particular support practice by the soil loss from up-and-down slope cultivation (Renard *et al.*, 1997a).

CORINE Model

The CORINE (Coordination of Information on the Environment) model is a powerful framework for assessing soil erosion and aridity risks. Originally developed in Europe, it has been successfully adapted for applications in regions such as Somalia, where rainfall erosivity and land degradation are pressing concerns. By incorporating indices such as the Modified Fournier Index (MFI) and the Bagnouls-Gaussen Index (BGI), the model identifies areas at high risk of erosion and supports the development of targeted conservation strategies (Nur *et al.*, 2024a). Its integration with GIS tools makes it particularly effective for large-scale environmental assessments, enabling policymakers and land managers to prioritize interventions (Mitasov *et al.*, 1996). The CORINE Model is an experimental model that has the capability to provide spatially accurate predictions of soil erosion. It is a semi-qualitative cartographic approach that includes developing and combining multiple thematic map layers within a GIS framework. This model allows for the demonstration of the geographic variations in soil erosion risk. The implementation of the CORINE model using GIS is relatively simple and benefits from its straightforward structure. The model has been successful in accurately identifying areas with high erosion risk, particularly in Mediterranean regions (Gobin *et al.*, 2003). CORINE model is an environmental process model (Beck *et al.*, 1993) which integrates existing knowledge about the soil erosion processes in the real world into a set of relationships and equations for quantifying the process and dealing with the interaction of two main parameters including actual soil erosion risk (EA) and potential soil erosivity (EP). The CORINE model (Coordination of information on the environment) was created in 1985 by the European Commission program (Elzbieta and Jenerowicz, 2019). CORINE model is not for the Europe continent only, in Ethiopia(Africa), (Gurebiyaw and Teshome, 2018) has used it to assess spatial heterogeneity of soil erosion in the Gumara-Maksegnit Watershed in an effort to address soil erosion and protect soil and water resources in the Danjiangkou area of China, Zhu (2012) conducted a comprehensive study. This study integrated SER DRR, and CORINE models, utilizing GIS and RS techniques. The primary objective was to identify areas with high erosion risk (based on the SER) and develop appropriate erosion control strategies. The findings revealed that approximately 59.1% of the study area exhibited a low erosion risk, while 31.2% had a medium risk, and 2.3% were classified as high risk. This study exemplifies the effectiveness of employing integrated models and spatial analysis tools in identifying erosion-prone areas and informing targeted erosion mitigation efforts. Dindaroğlu and Canpolat (2013) carried out a study at Kuzgun Dam Lake to establish the places where soil losses are effective and to give management recommendations to fix the problem. According to the CORINE model, soil characteristics were evaluated based on land use conditions using Landsat satellite images of Erzurum Province, and they identified areas that were or may be degraded based on the model. According to the map results, 39% of the soils are at moderate risk, while 34% are at severe risk of degradation. Based on the model results, researchers discovered that 53% of the basin's soils are at risk of severe degradation. In addition, they claimed that, despite the fact that lands with forested areas are protected from loss, studies should be conducted to prevent loss on agricultural lands and grazing fields with steep slopes. The study assessed soil erosion risks in northwest Somalia, revealing that most of the area faces moderate erosion risk. The northern region, including Bossaso and other weather stations, demonstrates low erosivity risk due to lower annual precipitation. In contrast, southern regions, despite their steep slopes, experience higher erosion risk. These findings highlight the critical influence of precipitation and topography on soil erosion (Nur *et al.*, 2024b). To understand the key soil erosion factors read Table 1.

Table 1. Key soil erosion factors and their significance based on CORINE model.

Factor	Definition	Significance in Erosion	Reference
Soil Texture	Proportion of sand, silt, and clay	Influences water retention, nutrient availability, and erosion susceptibility	(Středová *et al.*, 2015)
Soil Depth	Thickness of soil layer for rooting	Shallow soils are more prone to erosion due to weaker root anchorage	(Evans, 1990)
Stoniness	Proportion of rocks or stones	Reduces erosion by protecting soil surface from raindrop impact	(Nearing *et al.*, 1999)
Fournier Index	Measures erosive power of rainfall	High values indicate areas with significant rainfall intensity and erosion risk	(Dengiz and Akgül, 2005)
Bagnouls-Gaussen Aridity Index	Combines temperature and precipitation for dryness assessment	Identifies arid regions more prone to erosion	(Soydan, 2023)
Soil Erodibility	Soil's inherent susceptibility to erosion	Affected by soil organic matter, texture, and structure	(Vermang *et al.*, 2009)
Slope	Land gradient	Steeper slopes increase runoff velocity, raising erosion risk	(Römkens *et al.*, 2002)
Erosivity	Potential of rainfall to cause soil detachment	High erosivity is associated with intense rainfall and high erosion	(Boardman *et al.*, 2003)
Potential Soil Erosion Risk	Inherent risk based on natural factors like soil, slope, and climate	Assesses erosion risk without considering human interventions	(Soydan, 2023)
Land Cover	Vegetation or surface cover present	Reduces erosion by stabilizing soil and intercepting rainfall	(Dunaway *et al.*, 1994)
Actual Soil Erosion Risk	Real-world erosion risk considering both natural and human factors	Combines all natural factors and human impacts, such as agriculture	(Khallouf *et al.*, 2021)

Soil Loss Estimation Model of Southern Africa (SLEMSA)

In African environments, in southern Africa, the SLEMSA model is widely recognized for predicting soil erosion, particularly for estimating sheet erosion in cultivated areas. Unlike models based on detailed physical processes, SLEMSA is more of a framework that adapts to different conditions of land, climate, and land use. It was initially designed for Zimbabwe's highveld, but its utility has extended to other regions in southern Africa where there is a lack of specific data (Elwell, 1996).

While SLEMSA is useful, it does have limitations, especially in mountainous regions. Studies have shown that the model's accuracy is significantly influenced by variations in slope steepness (S) and rainfall intensity (E), which may lead to exaggerated estimates of soil erosion. This is particularly problematic when slope steepness and slope length are closely linked. To address these issues, adjustments to the model are necessary for better application in rugged terrains (Hudson, 1987). Despite these challenges, SLEMSA serves as an essential tool for identifying areas most vulnerable to erosion and helps in planning soil conservation efforts.

The SLEMSA model, when integrated with large-scale databases like SOTER, can assist in creating detailed erosion risk maps, as seen in the application of the Water Erosion Assessment Program (SWEAP) (Dukshoorn, 1995). By incorporating various erosion models such as USLE and SLEMSA into the SWEAP framework, it becomes possible to assess soil erosion risks on a broader scale, guiding land management and conservation initiatives effectively.

In recent years, Geographic Information Systems (GIS) and remote sensing technologies have revolutionized soil erosion studies. These methods are now critical for large-scale assessments, offering accurate and cost-efficient data on soil composition, vegetation cover, and topography (Sheikh *et al.*, 2011). The combination of GIS and remote sensing provides a powerful tool for erosion forecasting, enabling precise mapping of soil degradation and improving soil conservation planning.

Geographic Information System and Modelling of Soil Erosion

In the last ten years, multiple scientific investigations have utilised GIS and RS technologies to assess soil erosion across extensive areas (Sheikh *et al.*, 2011). These investigations have illustrated the efficacy and cost-effectiveness of these methods in delivering precise information regarding eroded regions, encompassing soil types, lithological units, and vegetation, at a fair expense. Numerous integrated models that amalgamate GIS and remote sensing have been developed for the prediction of water and soil erosion (Fullen, 2003; Merritt *et al.*, 2003). Remote sensing can be studied within the Arc GIS software environment in conjunction with GIS (Karabulut and Küçükönder, 2008). Geographic Information Systems (GIS) are becoming vital for landscape planning and conservation efforts. Estimating erosion in soil conservation and planning studies is a comprehensive and beneficial approach, with enhanced accuracy achievable through the use of GIS technology (Okatan *et al.*, 2007).

Table 2. The relationship between Geographic Information Systems (GIS) and soil erosion modeling.

Aspect	GIS in Soil Erosion Modeling	Key Contributions
Data Collection	GIS helps collect spatial data, including topography, land use, soil type, rainfall, and vegetation covers.	GIS allows the integration of various data sources for a comprehensive soil erosion model.
Data Processing	GIS tools process and analyze raster and vector data to create models.	Data processing in GIS helps identify erosion-prone areas and estimate erosion risk.
Topographic Mapping	GIS is used to create digital elevation models (DEMs) that are essential for analyzing slope and elevation.	DEMs are critical for understanding the impact of terrain on soil erosion.
Erosion Risk Mapping	GIS models, such as the Revised Universal Soil Loss Equation (RUSLE), can predict erosion risk zones.	Predicts areas susceptible to soil erosion based on rainfall, soil, and slope data.
Land Use Analysis	GIS helps in assessing the impact of land use changes on soil erosion.	Modeling changes in land use allows for better planning and erosion control strategies.
Vegetation and Cover Analysis	GIS integrates vegetation data (e.g., NDVI, LST) to understand the role of vegetation in preventing erosion.	Vegetation cover impacts soil erosion; GIS helps identify areas with insufficient cover.
Temporal Analysis	GIS tracks changes over time by integrating satellite images and other time-series data.	Temporal analysis helps monitor soil erosion trends and the effectiveness of mitigation strategies.
Modeling Soil Loss	GIS integrates models like RUSLE, WEPP (Water Erosion Prediction Project), or SWAT (Soil Water Assessment Tool) for erosion prediction.	Predicts and quantifies soil erosion rates across large regions.
Erosion Control	GIS assists in identifying potential areas for erosion control interventions, such as reforestation or terracing.	Helps target regions needing intervention to reduce erosion impacts.
Decision Support	GIS provides a visual platform for decision-making and policy development regarding soil conservation.	Helps policymakers visualize erosion data for better land management decisions.

Summary and Discussion

Soil degradation, particularly erosion, presents significant challenges in East Africa. This issue directly impacts agriculture, water quality, and overall ecosystem health. Accurate predictions of soil erosion are necessary to inform effective land management and conservation strategies. Various mathematical models, which assess erosion by considering factors like rainfall, soil types, vegetation cover, and landscape characteristics, are essential tools in this context. Prominent among these models are the Universal Soil Loss Equation (USLE), the Revised USLE (RUSLE), and the Soil Loss Estimation Model of Southern Africa (SLEMSA). These models have been customized for specific regions to account for variations in climate and soil types. Despite their utility, these models often face limitations in providing precise erosion predictions, mainly due to inconsistent or insufficient data. While they effectively highlight areas vulnerable to erosion, they may not always deliver accurate erosion rate estimates. The integration of GIS (Geographic Information Systems) and remote sensing technologies has enhanced the spatial accuracy of these models. GIS enables a more thorough analysis of erosion patterns by offering tools to analyze large-scale spatial data efficiently.

The study by Nur *et al.* (2025) evaluates soil erosion risks in Hirshabelle State, Somalia, highlighting its adverse effects on agricultural productivity, land degradation, and ecosystem health. Utilizing the Revised Universal Soil Loss Equation (RUSLE) integrated with GIS and remote sensing techniques, the research emphasizes the significance of spatial analysis in identifying high-risk erosion areas. It provides critical insights for sustainable land management, addressing challenges such as deforestation, unsustainable land-use practices, and the impacts of climate variability.

The study by Mohamed and Başayiğit (2023) evaluates soil erosion risks in Somalia, focusing on its detrimental effects on agricultural productivity, water quality, and land degradation. Utilizing empirical models like RUSLE and SLEMSA alongside GIS-based techniques, the research underscores the importance of spatial analysis for identifying erosion-prone areas. It provides valuable insights for sustainable land management, addressing challenges such as deforestation, poor agricultural practices, and the impacts of climate change.

In countries such as South Africa, the combination of GIS and RUSLE has been used successfully to identify high-risk erosion zones, which then informs targeted conservation interventions. However, the success of these models is heavily dependent on the quality of data inputs. In regions with limited access to detailed soil, climate, and land use data, the accuracy of predictions can be compromised. To improve prediction quality, some experts are exploring process-based models, which simulate the physical processes driving erosion. These models provide a more in-depth understanding of erosion dynamics, especially when localized data is available. A key challenge in soil erosion modeling is obtaining reliable data. Many parts of East Africa still face significant gaps in the availability of detailed information on soil properties, rainfall, and land use, which are critical for accurate modeling. Enhancing data collection systems and improving access to reliable information is essential for refining erosion models. Additionally, successful soil conservation efforts must consider local socio-economic conditions. Engaging communities in soil conservation initiatives is vital, as cultural and economic factors heavily influence the adoption of erosion control practices. The impacts of climate change, such as more intense rainfall and shifting weather patterns, will further exacerbate soil erosion in the region. This makes it crucial to continually update erosion models to reflect new climate data. A holistic approach that combines advanced technology with local knowledge and practices will be crucial for creating effective and sustainable soil erosion management strategies.

In conclusion, while models like USLE, RUSLE, and SLEMSA are important for understanding soil erosion risks, their effectiveness depends on integrating high-quality data, GIS technology, and local community involvement. By refining these models and fostering collaboration, more accurate and actionable strategies for erosion control can be developed for East Africa.

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