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Geomorphological Characteristics and their Effect on Rural Land use Patterns in Arashkol Region, Edduiem Locality, White Nile State Sudan (2000–2025)

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***Abstract*—The study aimed to analyze the general geomorphological features of the Jabal Arashkol region in White Nile State, evaluating their impact on the spatial patterns of rural land use, including agricultural, pastoral, and residential activities. The study addressed critical environmental challenges facing the region, notably soil erosion, rainfall variability, and vegetation degradation, which negatively affect population stability and local livelihoods. Utilizing an integrated approach combining descriptive, regional, quantitative, and analytical methods, the study leveraged Geographic Information System (GIS) tools to process Digital Elevation Model (DEM) data to generate slope, aspect, and hill shade maps. The study revealed that topographical variations, slope gradients, and weathering/erosion processes act as the primary determinants of land-use distribution: agriculture is concentrated in low-slope plains, steep areas are utilized for grazing, and human settlements are situated in geomorphological safe zones. The study recommended integrating geomorphological mapping into land-use planning frameworks to foster sustainable development in semi-arid environments.**

***Index Terms*—Applied Geomorphology, Jabal Arashkol, Rural Land Use, Geographic Information Systems (GIS), White Nile State.**

I. INTRODUCTION

Applied geomorphology is considered one of the core integrative branches of geography that transcends the static description of landforms to analyze the dynamic interaction between topographic characteristics and human activities. The importance of geomorphological evaluation is particularly heightened in arid and semi-arid environments, where climatic and geomorphological processes—including weathering, erosion, planation, and deposition—

intertwine to define both the environmental potential and the developmental constraints of a region (Al-Khashab, 1977). In this context, the Jabal Al-Arashkol area in Ed Dueim Locality (White Nile State) represents a distinctive ecological and morphological setting. The mountain stands as a prominent topographic feature interrupting the surrounding flat plains, thereby creating spatial variations in slope gradients, drainage network characteristics, and lithological formations. This variation directly influences the distribution and exploitation of natural resources, defining the spatial patterns of rural land use (agricultural, pastoral, and residential). Accordingly, this study aims to diagnose the general geomorphological landscape of the Al-Arashkol area and analyze its cumulative impacts in directing human activities. Furthermore, it seeks to identify the environmental opportunities and hazards resulting from active surface processes, ultimately providing a planning framework to support sustainable rural development decisions in the region.

II. STATEMENT OF THE PROBLEM

The study problem is framed in the following main question: What are the general geomorphological features of the Jabal Al-Arashkol area, and to what extent do they influence the spatial distribution of rural land-use patterns? From this main question, the following sub-questions emerge:

a) What are the characteristic topographic and morphometric properties of the Jabal Al-Arashkol area?

b) How do slope gradients and morphological variations delineate the spatial boundaries for agricultural, pastoral, and residential activities?

c) What geomorphological landforms result from weathering and erosion processes (erosion and deposition), and what are their implications for land degradation and population settlement?

Study Hypotheses

a) There was a statistical significant correlation between slope gradients and the area allocated for agricultural land use in the study area.

b) The general geomorphological landscape has a statistically significant effect on the spatial organization of rural land-use patterns (agricultural, pastoral, and residential).

c) Erosion, planation, and deposition processes play a statistically significant role in shaping geomorphological features and determining the productive characteristics of land in the study area.

III. STUDY OBJECTIVES

This study aims to evaluate the geomorphological characteristics of the Al-Arashkol area and assess their direct role in shaping rural land-use patterns through the following specific objectives:

a) To examine the topographic and morphometric characteristics of the study area and analyze the spatial variations in elevation and slope gradients.
b) To identify the geomorphological landforms resulting from weathering and erosion processes and determine their environmental and agricultural impacts.
c) To analyze the spatial and dynamic relationship between the geomorphological landscape and the geographic distribution of agricultural, pastoral, and residential activities.

IV. SIGNIFICANCE OF THE STUDY

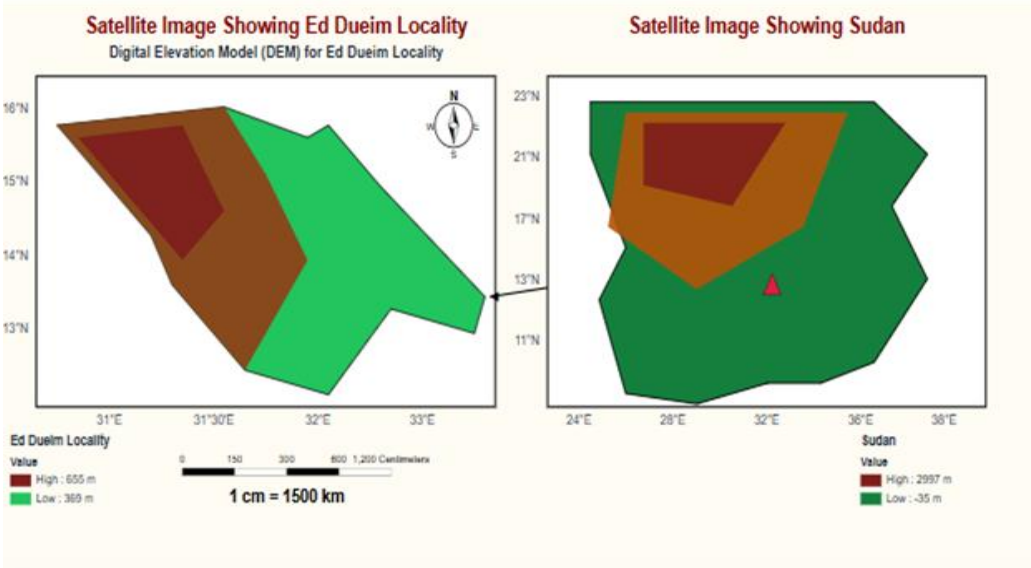
Theoretical Significance: Enriching the geographical and environmental literature with an applied study that integrates modern geomorphological analysis tools—such as Geographic Information Systems (GIS) and Digital Elevation Models (DEM) with land-use planning in semi-arid environments of Sudan.
Practical Significance: Providing decision-makers and spatial planners in White Nile State with precise databases and environmental indicators to guide rural investments, protect soil from degradation, and identify safe zones for urban and agricultural expansion away from flash floods and erosion hazards.

V. STUDY AREA AND GENERAL CHARACTERISTICS

Administratively, the study area falls within Ed Dueim Locality in White Nile State, Central Sudan, and geographically belongs to the semi-arid regional zone. Astronomically, the study area extends between latitudes 14^0/30' N and 14^0/45' N and longitudes 32^0/15' E and 32^0/22' E (topographically corrected to align with the astronomical location of the area). The region is generally characterized by a flat plain landscape interrupted by a prominent topographic elevation represented by Jabal Al-Arashkol, which constitutes a unique and influential morphological feature in the local environment. This geographic location directly shapes the local microclimate, edaphic (soil) characteristics, and natural vegetation cover, while simultaneously directing the spatial patterns of human activities. The area derives its developmental and hydrological significance from two primary axes:
The Eastern Axis (The White Nile): Represents the main lifeline sustaining irrigated agricultural activities and providing essential water resources for livestock grazing and residential settlements.
The Topographic Axis (Jabal Al-Arashkol): Forms the elevated mass at the core of the region, from which seasonal drainage networks and surface runoff descend toward the surrounding plains and the floodplain of the White Nile to the east, transporting fine sediments that replenish soil fertility and recharge local groundwater aquifers.
Topographically, the surface features exhibit a gradual decline starting from the summit and immediate vicinity of Jabal Al-Arashkol in the center where steep slope gradients predominate—

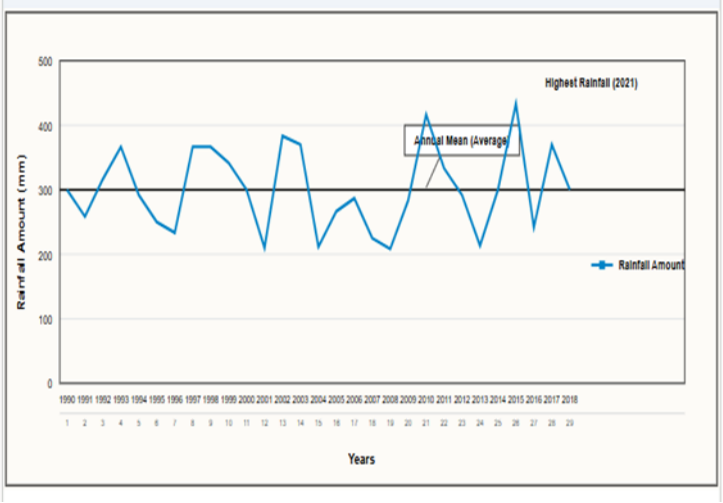
transitioning into a smooth, progressive descent toward the outer margins and the adjacent floodplain along the western bank of the White Nile to the east.

Map (1) The Study Area and Its Geomorphological Characteristics



Based on Map (1), the general characteristics of the area are defined by three distinct topographic features: isolated mountains (inselbergs) and scattered hills composed of crystalline rocks dating back to the Pre-Mesozoic era; structural plains largely covered by diverse sedimentary deposits of gypsum and sandstone; and alluvial plains, valleys, seasonal watercourses, and basins. It has been noted that drought leaves clear imprints on the morphology of these regions, making the geomorphological landscape prone to continuous modification as a result of these active processes. Two prominent phenomena can be observed: the overall topographic monotony, and the concentration of the drainage network toward the White Nile. The geographical location of White Nile State in central Sudan within a plain zone renders its surface nearly devoid of significant topographic anomalies (Qasm Allah, 2013).

Figure (1)Rainfall Fluctuation and Annual Mean in Ed Dueim Locality (1990–2024)



Source: Ed Dueim Meteorological Station (2025)

As illustrated in Figure (1), significant inter-annual and inter-monthly variations in rainfall amounts are observed across the study area. This variability persists even when comparing the same month across consecutive years. Specifically, the total annual rainfall recorded in the study area was 194 {m} in 2000, which increased to 270.2 {m} in 2001, 269.5 {m} in 2002, and 276.2 {m} in 2003. In contrast, the rainfall recorded in 2021 was 242 {m}, whereas 2022 experienced a sharp decrease to 122.1 {m} (Edduiem Meteorological Station, 2025). This trend underscores the pronounced rainfall instability in the study area, which directly impacts livestock grazing, rained agriculture, and all rainfall-dependent human activities. Furthermore, the volume, seasonality, and distribution regime of precipitation fundamentally dictate the types of crops cultivated and the livestock breeds adapted to local environmental conditions.

VI. STUDY METHODOLOGY AND DATA SOURCES

This study adopted a multi-methodological approach: the descriptive method was utilized to characterize landforms, their morphological properties, and the underlying processes shaping them; the regional method was applied to analyze spatial relationships among surface features, soil properties, topography, and drainage networks; the quantitative method was employed for statistical data analysis and tabulation; the analytical method served to interpret the drivers of land-use degradation in connection with environmental parameters; and the historical method was used to trace temporal changes in land-use patterns over time. Primary data collection relied on field surveys, site visits, direct observations, and personal interviews. Secondary sources encompassed academic literature, university theses, and official technical reports. Furthermore, the study integrated Geographic Information Systems (GIS) and surface analysis tools including Hillshade, Slope, and Aspect to analyze topographic features, slope gradients, and directional orientations.

VII. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The study drew upon various regional and local studies that examined geomorphology, drainage basins, land use, and pastoral systems. Among the key local works is Al-Imam (2002) on the geomorphology of Al-Arashkol, which investigated geomorphological units, lithological characteristics, dominant surface processes, and valley morphometric properties, highlighting the predominance of weathering, erosion, planation, and deposition. Additionally, the research benefited from Hussein (2016), who analyzed the drainage basins of Wadi Nyala, Wadi Kutum, and seasonal valleys in South Darfur State, as well as Saleh (2010) regarding the degradation of pastoral sectors and land-use patterns in semi-arid environments.

The Concept of Applied Geomorphology: Defined by Cooke and Doornkamp (1974) as "the application of geomorphological techniques and principles to the solution of environmental and developmental problems." Topography dictates land use; thus, slope gradient, soil characteristics, and drainage networks act as critical constraining factors for human activities. In

semi-arid environments—such as the Al-Arashkol area—this interdependence becomes increasingly evident due to low annual rainfall rates.

Geomorphological Processes Influencing Land Use (Abu Al-Enin, 2000): These can be summarized into four key processes:

Physical Weathering: Mechanical weathering predominates in the Al-Arashkol area due to a high diurnal temperature range of up to 20°C, which leads to rock disintegration and the formation of poor, sandy soils.

Water Erosion: Occurring primarily during the rainy months (July to September), water erosion causes severe soil degradation on slope gradients exceeding 8%, rendering these areas unsuitable for rained cultivation.

Wind Erosion: Driven by prevailing northeasterly winds during the winter and dry summer seasons, wind erosion triggers active sand movement across the northern sector of the study area, negatively impacting agricultural productivity and leading to the shrinkage of arable lands.

Erosion and Deposition (Planation and Alluviation): Seasonal streams (wadis) have formed fertile floodplains through alluvial deposition, which are utilized for rained agriculture.

VIII. ROCK WITNESSES (INSELBERGS/MOUTONNÉES & BUTTE STRUCTURES)

A rock witness is defined as an isolated, steep-sided hill representing an advanced stage of plateau degradation resulting from the erosion of underlying fragile rock strata, which consequently causes the collapse of the overlying resistant rock layers (Salama, 2004). These landforms are characterized by the accumulation of talus scree cones at their bases, offering temporary protection against active erosional agents that continuously carve and retreat their slopes. Generally associated with arid and semi-arid environments, these features display the pronounced morphological impact of erosional agents—particularly wind action—which dissects the land surface and targets soft rock formations while hard rock layers resist degradation. Crucially, while the Jabal Al-Arashkol region falls within this environmental zone, wind action is not the sole factor shaping its overall geomorphological landscape; surface runoff and seasonal streams play an equally vital role in generating these landforms. Such features appear as scattered rock masses in close proximity to the main mountain or farther out across the surrounding plains, transported and reshaped by both Aeolian processes and running water.

IX. RESULTS AND DISCUSSION

The Geomorphological Landscape and Its Impact on Land Use:

Surface imagery analysis revealed relative diversity in landforms across the study area. Topographic elevation is concentrated at the core of the area at Jabal Al-Arashkol, whereas elevation values progressively decline toward the outer margins, particularly toward the White Nile. Nevertheless, the general regional character remains defined by the topographic monotony characteristic of extensive parts of central Sudan.

Strata dip constitutes a critical element in interpreting drainage orientations and sediment distribution patterns. The study indicates a general regional slope gradient from west to east, where strata dip alignment has facilitated stream adjustment along the underlying bedrock structures, accompanied by an increased accumulation of recent quaternary sediments eastward.

Slope gradient plays a decisive role in determining land-use suitability: flat and low-relief zones exhibit higher suitability for agricultural expansion and permanent residential settlements, whereas steep slope gradients constrain agricultural development and heighten surface susceptibility to erosion and land degradation.

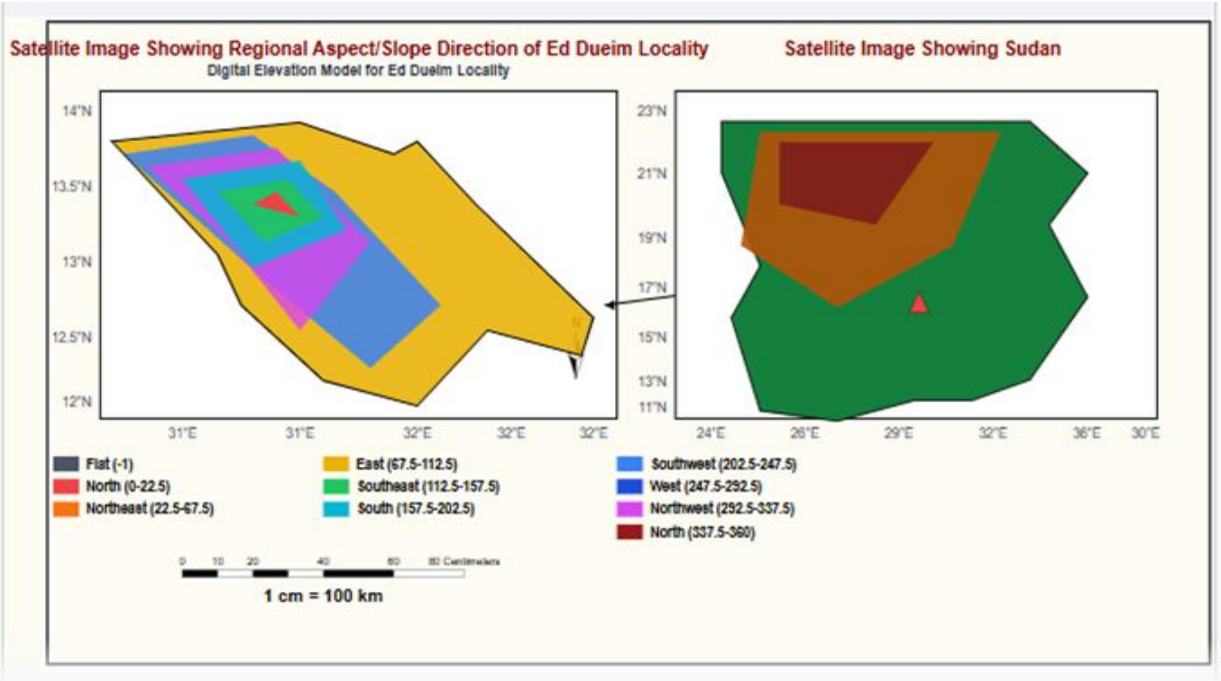
The empirical findings of this study align with the conclusions of Al-Imam (2002) regarding the dominance of active weathering and erosional processes. Furthermore, the results validate the research hypotheses, confirming that topography serves as the primary determinant governing the spatial distribution of human activities, and that rained and irrigated agricultural expansion in high-relief or highly susceptible terrain remains ecologically and topographically unsuitable.

Table (1) The Relationship Between Topography and Land Use

Topographic Unit	Slope Gradient (%)	Dominant Land Use	Environmental Problems
Alluvial Plains	0–5%	Rained and mechanized agriculture	Desertification and soil fertility decline
Footslopes / Pediments	5–15%	Livestock grazing and dispersed settlement	Water-induced soil erosion
Summits and Hills	>15%	Seasonal grazing only	Severe weathering and soil loss

Source: Field Survey, 2025

Map (2) Satellite Image Showing the Regional Slope Gradient of the Study Area



Based on the analysis of Map (2), it is evident that the study area exhibits relative diversity and variations in surface landforms. Topographic elevation reaches its peak at the core of the area around Jabal Al-Arashkol, recording a maximum value (High: 181). Conversely, elevation values progressively decline toward the outer margins and along the White Nile floodplain, reaching a minimum value (Low: 0). Overall, the satellite imagery confirms that the regional surface is defined by a general topographic monotony, mirroring the characteristic landscape features of central Sudan.

Drainage Systems and Their Relationship to Land Use: The drainage system is directly influenced by bedrock lithology, permeability, and structural homogeneity, as well as slope gradient and climatic conditions. The study indicates the presence of a dendritic drainage pattern across the area, alongside a deranged (disrupted) drainage pattern that remains incompletely developed due to local constraints, notably Aeolian sand deposits and dense vegetation cover. Seasonal valleys (wadis) are of major significance in the study area, serving as conduits for rainfall runoff and sediment transport from higher elevations toward the surrounding plains. As surface runoff descends from the mountain crest, its transport capacity peaks, before gradually decreasing along lower slope gradients where lighter particles are deposited. This process results in a distinct sediment size sorting—ranging from boulders and gravel near the mountain base to fine silt and alluvium further downstream. The morphological effect of this pattern is vividly demonstrated in the alluvial plain of the Umm Shahaima area, where fine-grained sediments accumulate across the plain, forming suitable soil for seasonal agriculture. Prominent drainage features in the study area include Eid Al-Sheikh, which flows through the central section of Jabal Al-Arashkol and constitutes the largest drainage basin in the region, heading eastward in response to the regional slope gradient. Another key feature is Eid Al-Maleh, representing a primary form of dendritic drainage. This dendritic pattern develops over horizontal sedimentary strata overlying metamorphic basement rocks, with total precipitation acting as the primary driver governing its spatial development. Based on field observations, dendritic drainage forms the dominant drainage structure in the study area. Additionally, a deranged drainage pattern exists; its morphologic development remains arrested due to prevailing hyper-arid climatic conditions and channel irregularity. Channel continuity is frequently interrupted by physical obstacles, such as Aeolian sand accumulations during dry seasons and dense vegetation cover that attenuates channel discharge.

Geomorphological Processes and Associated Landforms: Geomorphological processes in the Al-Arashkol area operate through an integrated system of weathering, erosion, transportation, and deposition, with wind action and surface runoff acting as the primary dynamic agents. The capacity for rock breakdown and sediment transport increases proportionally with wind speed and water velocity, initiating deposition once carrying capacity drops. Aeolian depositional landforms are widespread, including sand sheets, sand dunes, barchan dunes, and longitudinal dunes. These features are intrinsically linked to open environmental exposure and the abundance of transportable sand, with Jabal Al-Arashkol functioning locally as a windbreak that facilitates Aeolian sand deposition. Conversely, aqueous depositional landforms primarily comprise

alluvial deposits whose grain-size distribution varies according to sediment source and flow velocity. This depositional gradient gives rise to flat alluvial plains dominated by clay and silt accumulation. The Wadi Umm Shahaima plain provides a clear illustration: an alluvial floodplain located at the mountain base that receives silt-laden runoff, which is cultivated during the autumn rainy season with sorghum and okra.

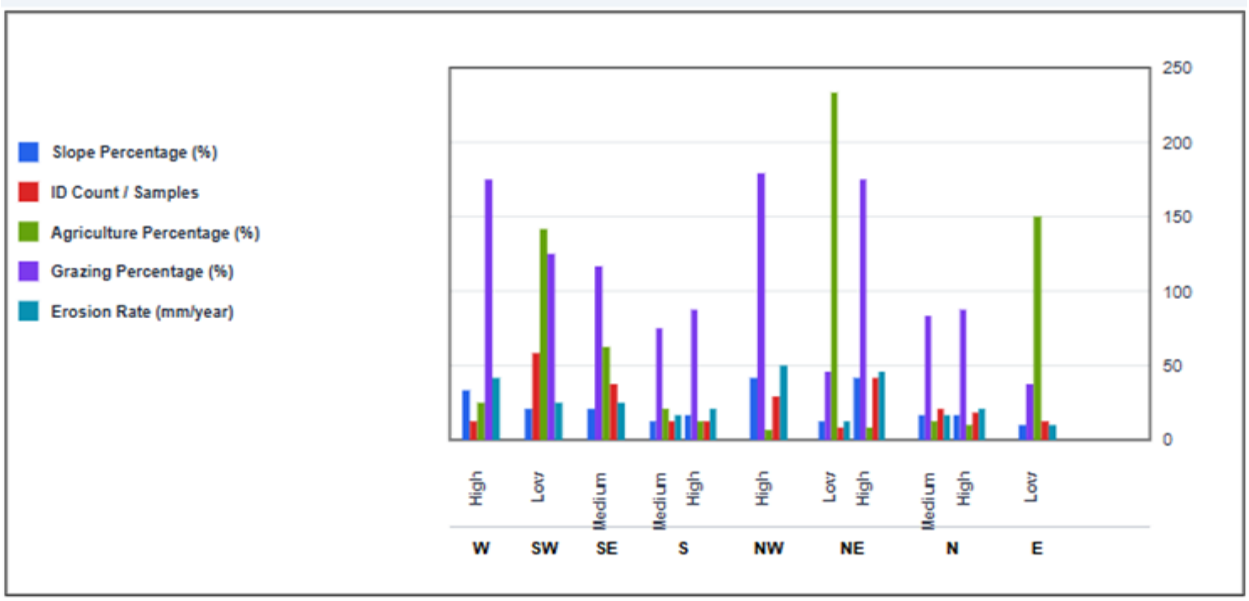
Agricultural Land Use: Agricultural activity represents one of the most vital rural land-use categories in the Al-Arashkol area, directly dictated by water availability, soil properties, and topography. The study identifies both irrigated and rained agricultural systems. The White Nile plays a foundational role in defining the potential for irrigated agriculture, whereas rained agriculture is tied to alluvial plains, direct precipitation, and surface runoff. The Al-Arashkol Agricultural Scheme stands out as a core agricultural component, operating as a primary livelihood scheme within White Nile State. The spatial distribution of agriculture demonstrates that flat plains with sedimentary soils exhibit significantly higher agricultural suitability than sloping terrain, as fine sediment accumulation beneath the mountain provides optimal conditions for seasonal farming. Beyond spatial siting, geomorphology directly impacts land productivity and long-term sustainability; whereas active erosion leads to the loss of fertile topsoil, local depositional processes replenish soil matrix and enhance fertility. The results of Pearson's correlation coefficient analysis revealed a strong negative correlation between slope gradient and agricultural land use, thereby validating the second research hypothesis regarding agricultural activity (Table 2 and Figure 2). Findings indicate that 80% of agricultural land is concentrated across flat plains with slope gradients below 5%. This finding strongly aligns with Cooke and Doornkamp (1974), who established that "slope gradient serves as the primary limiting factor determining land suitability for mechanized farming." Lower slope gradients correspond to greater soil depth, reduced surface runoff velocity, and diminished soil erosion risk, confirming an inverse relationship between slope gradient and agricultural suitability. Furthermore, the sedimentary Umm Ruwaba Formation across these plains exhibits moderate permeability and relative fertility, encouraging the expansion of sorghum and millet cultivation a pattern consistent with the findings of Hussein (2016) regarding Wadi Azum.

Table (2) The Relationship Between Slope Gradient, Soil Erosion, Agricultural, and Pastoral Land Uses in the Study Area

Variables	Pearson Correlation Coefficient (r)	Significance Level (Sig.)	Correlation Direction & Strength	Statistical Decision
Slope Gradient & Agriculture	-0.87	0.000	Very Strong Inverse (Negative)	Statistically Significant
Slope Gradient & Pastoral Grazing	+0.70	0.000	Strong Direct (Positive)	Statistically Significant

Source: Field Survey, 2025

Figure (2) Soil Erosion Levels, Agricultural, and Pastoral Land Uses in the Study Area



X. PASTORAL LAND USE

Livestock grazing represents a crucial land-use sector in the study area, with its potential fundamentally governed by vegetation cover, water availability, and surface topography. The White Nile serves as a vital summer grazing resource—particularly for cattle, goats, and camels—facilitated by the widespread occurrence of Paspalum vagintum (Bardo grass), which provides high-quality cattle forage. Furthermore, agricultural lands are functionally integrated into pastoral activity following the harvest season, as livestock graze on crop residues across specific sectors. However, mounting pressure on these resources risks pasture and soil degradation whenever livestock density exceeds ecological carrying capacity. Consequently, the findings underscore the imperative for a systematic range inventory to establish carrying capacities, regulate unsanctioned agricultural encroachment upon rangelands, and transition from overgrazing to controlled, rotational grazing management.

XI. RESIDENTIAL LAND USE

Human settlement patterns across the Al-Arashkol area are dictated by surface relief, water access, and existing land-use spatial distributions. The area exemplifies a permanent nucleated settlement model owing to reliable water sources and agricultural ties, with housing distribution aligned primarily along flat alluvial plains and drainage channels. Settlement morphology locally assumes a linear or ribbon pattern—a structure tied to site constraints, road networks, stream channels, and active farming zones. Field survey data indicate that Jallous (mud/cob construction) accounts for 45% of building materials, sun-dried mud bricks (Tob Akhdar) 30%, concrete hollow blocks (Block) 15%, and fired red bricks (Tob Ahmar) 10%. These metrics

demonstrate that geomorphological character influences not only settlement siting but also spatial configuration and structural materials, necessitating flash-flood and soil-erosion hazard mitigation in future urban expansion plans. The empirical findings indicate that moderately sloped Footslopes (5–15%) are utilized primarily for livestock grazing and dispersed rural settlement. This spatial allocation is driven by a strong positive relationship between slope gradient and pastoral use: increasing slope reduces agricultural suitability, shifting land utility automatically toward grazing. Conversely, a selective orientation exists between slope aspect and settlement siting, with housing heavily concentrated on north-easterly slopes to secure natural shelter from harsh, dry winter northerly winds and direct summer solar radiation. While Al-Imam (2002) documented this aspect preference in Al-Arashkol, that study did not explicitly link it to local community decision-making processes. Accordingly, the relationship between geomorphology and land use is non-unidirectional: while topography establishes baseline natural potential, human activity actively alters surface erosion rates, sediment deposition, and vegetation cover. Slope cultivation or vegetation clearing accelerates topsoil loss, whereas conservation practices attenuate these degradation pathways. Spatial land-use variation emerges from dynamic interactions among elevation, slope, drainage, soil, and water resources. Riparian zones along the White Nile are dedicated to irrigated agriculture and summer grazing, mountain-base alluvial floodplains support seasonal farming, and less agriculturally suited areas shift to pastoral or settlement uses based on water availability and accessibility. Jabal Al-Arashkol thus acts as an organizing element in the rural landscape, governing runoff direction, sediment distribution, floodplain formation, local wind fields, and settlement siting.

XII. RESULTS

1.The study area is characterized by localized topographic contrast controlled by the central elevated mass of Jabal Al-Arashkol, which slopes downward toward the surrounding plains and the White Nile alluvial strip.
2.Geomorphological features and slope gradients establish the spatial framework governing rural land-use distributions (agriculture, grazing, and residential settlement).
3.The White Nile forms the primary anchor for irrigated agriculture and summer grazing, whereas mountain runoff feeds the Umm Shahaima plain with water and fine silt supporting seasonal agriculture.
4.Drainage network development is controlled by lithology and slope; a dendritic pattern dominates, alongside deranged or incompletely developed drainage zones across the lower plains.
5.Wind and water exert dual geomorphological controls through erosion, transport, and deposition, creating diverse Aeolian landforms (barchan dunes, longitudinal dunes, and sand sheets) alongside variable aqueous and sub-aerial deposits.
6.Residential expansion proceeds cautiously relative to water access and flood channels, whereas pastoral activity integrates functionally with both irrigated and rained farming systems.

7.Rangeland degradation, sand encroachment, and soil erosion represent the main emerging environmental hazards threatening long-term developmental sustainability.

XIII. RECOMMENDATIONS

1.Develop Land Suitability Maps using Geographic Information Systems (GIS) based on slope gradient, soil parameters, and drainage characteristics to guide rural spatial planning.
2.Execute a comprehensive natural rangeland inventory, adjust livestock stocking rates according to carrying capacity, and enforce bans on unregulated agricultural expansion into pastoral zones.
3.Expand shelterbelts and windbreaks to stabilize active sand dunes and protect agricultural topsoil from severe wind erosion.
4.Modernize irrigation efficiency and optimize water conservation, while analyzing surface runoff routes and floodways prior to approving urban and infrastructure expansion plans.
5.Establish an environmental monitoring unit to track vegetation dynamics and sand dune movement, supported by specialized agricultural and environmental extension staff.

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