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Landscape Evolution and Slope Dynamics in Arid and Semi-Arid Regions: A GIS and DEM-Based Assessment of the Abu Hadair Catchment in Southern Iraq

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Abstract: Slope systems in arid and semiarid watersheds are highly sensitive to episodic rainfall, weak vegetation protection, and litho-structural controls, making quantitative terrain analysis essential for understanding erosion hazards and landscape evolution in southern Iraq. This study aimed to characterize slope morphology, aspect, segmentation, and geomorphological stage development in the Abu Hadair Basin (8,341.36 km²) in the Al-Salman Desert, integrating GIS with a 30 m DEM (SRTM-derived processing in ArcGIS 10.8), Landsat ETM+8 imagery (2023), and topographic, geological, and hydrological maps. Following Young's (1975) slope classification and using four representative longitudinal/transverse terrain cross-sections, the basin was analyzed in relation to Davisian erosion-cycle stages and validated with DEM-derived profile metrics. Elevation spans ~20–440 m a.s.l. with an overall SW–NE gradient (~0.052 m/km) and six major sub-watersheds exhibiting increasing local gradients up to 9.567 m/km. The basin partitions into Youth (317–447 m; 3,679.56 km²; 44.112%), Maturity (178–317 m; 3,758.5 km²; 44.112%), and Aging (8–178 m; 903.3 km²; 10.829%) zones. Gentle slopes dominate: the 0–2° class covers 2,870.55 km² (34.67%), whereas >45° slopes occupy only 16.898 km² (0.204%). North-facing aspects are most extensive (1,184.78 km²; 14.309%), while southeastern aspects are least (558.964 km²; 6.751%). Slope segmentation peaks in the maturity zone (E–F; 68.33 segments), indicating maximal coupling of erosion, transport, and deposition, while aging segments (G–H) shorten and stabilize; the A–B reach exhibits extreme segment number/length and is hypothesized to archive geomorphic evolution. Overall, DEM–GIS integration delineates priority zones for slope-stability assessment, erosion-risk mitigation, and land-use planning under environmental change, including management of runoff pathways, sedimentation, and wetland-associated ecosystem services.

Keywords: Slope dynamics, landscape evolution, GIS modelling, Abu Hadair watershed.

1. Introduction:

Slope systems are crucial components of desert landscapes and represent one of the geomorphological features most responsive to shifts in the environment. Their shape and development are influenced by a complex interaction of factors, such as lithology, geological structure, relief, slope gradient, drainage properties, and surface runoff, in conjunction with climate. In regions characterized by arid and semiarid conditions, where vegetation is sparse and soils lack protection, intense rainfall can lead to significant surface runoff. This runoff can erode soil, cause gully formation, and alter the morphology of hillslopes. Consequently, understanding the spatial arrangement and geomorphological progression of slope systems is vital for interpreting landscape dynamics and addressing environmental vulnerabilities (Goudie, 2013).

In recent decades, the development of geographic information systems (GIS), remote sensing, digital elevation models (DEMs), and geospatial simulation has enabled researchers to examine geomorphological processes at more detailed spatial scales. These technologies offer effective methodologies for extracting terrain attributes, characterizing slope morphology, modeling drainage and runoff pathways, predicting erosional zones, and assessing the spatial variation of landform characteristics. Notably, the integration of terrain analysis with geospatial simulation allows researchers to transition from traditional descriptive geomorphological mapping to quantitative evaluation and spatially explicit assessment of geomorphic processes. This comprehensive approach is particularly advantageous in arid desert systems, where extensive field surveys are challenging, costly, and spatially limited (Lindsay, 2005).

Nevertheless, even with these developments, research on slope systems in subtropical deserts has often concentrated on individual morphometric indices or static landform categories. It has mainly depended on GIS-based mapping methods that permit only limited integration of diverse geospatial data sources and simulation techniques for comprehensive slope-system observation. This limitation is particularly significant in southern Iraq, where the combination of dry climatic conditions, sporadic rainfall, terrain influenced by structural factors, and intense runoff processes results in highly variable slope shapes and drainage patterns. Consequently, a thorough spatial understanding of these interactions is essential to unravel the processes governing slope evolution and to pinpoint areas susceptible to more severe erosion and geomorphic transformation (Bashar F Maarroof, 2022).

The Abu Hadair watershed, situated within the desert landscape of southern Iraq, serves as an ideal natural laboratory for examining these processes. The watershed exhibits significant topographic variations, including differences in elevation, slope gradient, relief, drainage density, and geomorphic configuration. These features facilitate the investigation of the impact of topographic and hydrological controls on the distribution and development of slope systems in an arid environment. However, the geospatial component necessary for monitoring and simulating the temporal and spatial behavior of these slope systems remains underdeveloped (Maarroof et al., 2025).

This study introduces a comprehensive geospatial methodology for monitoring geomorphological changes within the slope system of the Abu Hadair Watershed. It integrates Geographic Information Systems (GIS), remote sensing data, analyses derived from a digital elevation model (DEM), and regional-scale geo-simulation to examine the spatial variability of slope morphology, its predominant geomorphological controls, and areas of heightened geomorphic activity. The objective of this method is to inventory the current state of the slope system and quantitatively analyze its geomorphological functioning and potential evolution. Additionally, the study offers insights into the future development of a reproducible framework within desert geomorphology for high-resolution analysis of this significant slope system in arid and semiarid landscapes. The findings can aid in watershed management, erosion-risk assessment, land-resource planning, and environmental monitoring in southern Iraq or other desert regions with similar geomorphological and climatic characteristics.

2. Materials and Methods:

2.1. Study Site: The Abu Hadair watershed is situated in the Al-Salman Desert within the Al-Muthanna Governorate, part of the Lower Valleys region in southern Iraq (Figure 1). This valley is characterized by arid conditions, reflecting the historical climatic and hydrological patterns of the southern Iraqi desert. Geographically, it is positioned between latitudes 29°33'42.4078"N and 31°03'29.473"N and longitudes 43°57'14.087"E and 45°25'18.734"E. The entrance to the watershed is located 29 kilometers from the Batha region, associated with the city of Ur (Al-Mutawqi et al., 2021). The watershed encompasses an area of 8,341.36 km², with a perimeter measuring 758,182 km, a length of 203,357 km, and elevations ranging from 20 m to 440 m above sea level, exhibiting a gradient of approximately 0.052 m/km (Figures 2 and 3). It concludes as an alluvial fan at its northern outlet in the Sulaibate Depression. The Abu Hadair watershed, located in the southwestern plateau of Iraq, extends from southwest to northeast and features landforms such as playas, tectonic depressions (basins), fault scarps, and plateau hills. It is bordered by Al-Hussam and Al-Dudan to the north, Al-Tayyar and Al-Huwaimi to the west, the Iraqi-Saudi border to the south, and Al-Ashali and Al-Arjawi to the east. The watershed connects to the Sulaibate Depression through its alluvial fan (Ali et al., 2021).

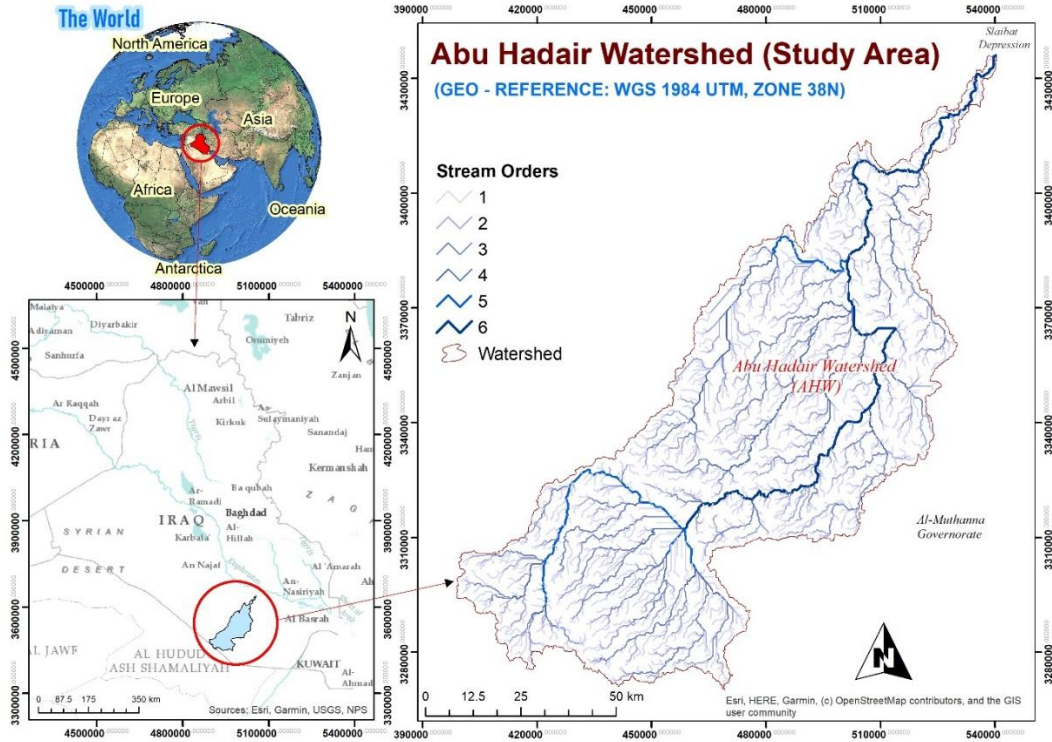


Figure 1. Geographic position, spatial extent, and drainage network of the Abu Hadair watershed in southern Iraq, showing stream orders 1–6 and the watershed boundary in WGS 1984 UTM Zone 38N.

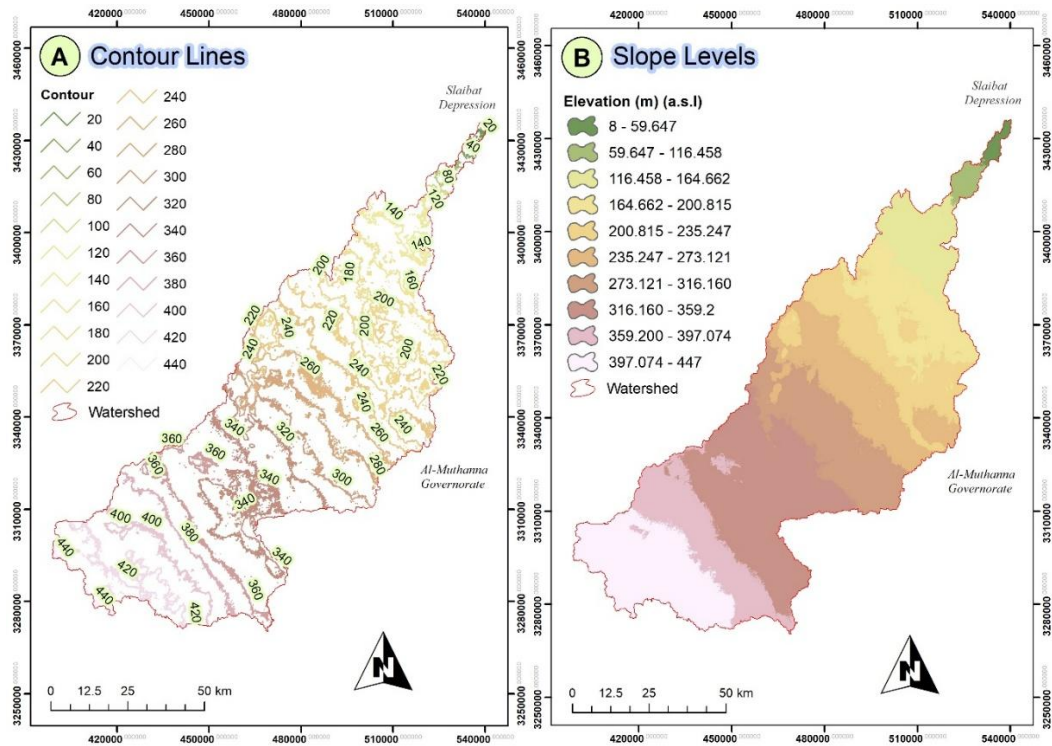


Figure 2. Spatial distribution of (A) contour lines and (B) elevation classes across the study watershed in the Al-Muthanna Governorate, southern Iraq.

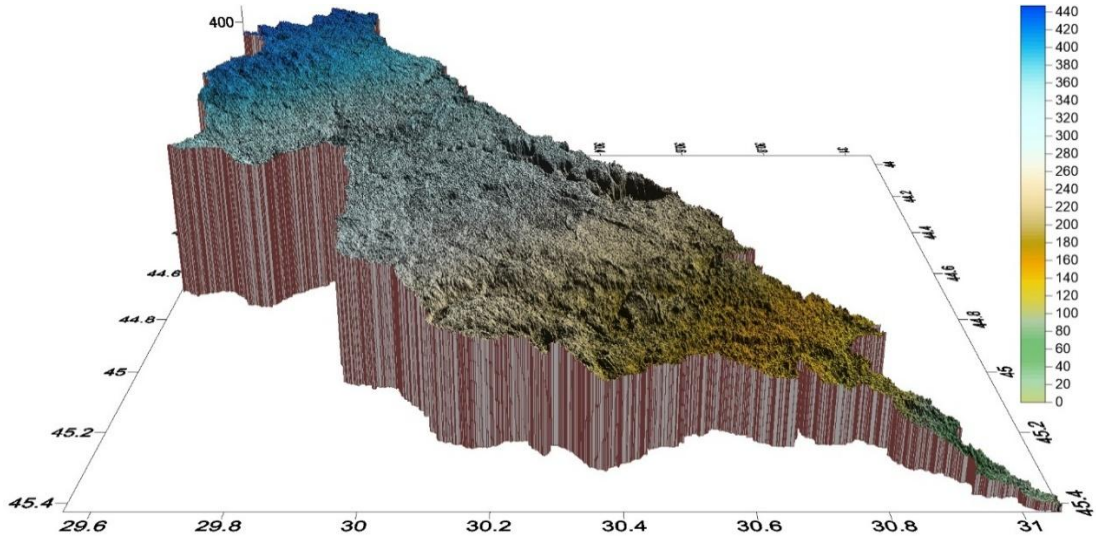


Figure 3. Digital elevation model (DEM)-based 3D rendering of the study watershed, illustrating the spatially variable character of height variation and the terrain's characteristic topographic relief.

The Abu Hadair watershed was divided into six sub-watersheds:

1. Abu Hadair sub-watershed (1) (AHSW1): The sub-watershed covers an area of 3378.18 km², with a perimeter measuring 584.053 km and a total length of 164.801 km. The elevation ranges from 15 to 360 meters above sea level, indicating a gradient of 2.184 m/km, as detailed in Table 1 and Figure 4.

2. Abu Hadair sub-watershed (2) (AHSW2): The sub-watershed covers an area of 1221.74 km², with a perimeter measuring 253.521 km and a total length of 78.275 km. The elevation ranges from 165 to 360 meters above sea level, indicating a gradient of 4.599 meters per kilometer (refer to Table 1 and Figure 4).

3. Abu Hadair sub-watershed (3) (AHSW3): The sub-watershed covers an area of 982.047 km², with a perimeter measuring 222.216 km and a total length of 75.986 km. The altitudes within this region vary from 180 to 360 meters above sea level, indicating a gradient of 4.737 meters per kilometer (refer to Table 1 and Figure 4).

4. Abu Hadair sub-watershed (4) (AHSW4): The sub-watershed covers an area of 1545.86 km², with a perimeter measuring 256.144 km and a total length of 63.447 km. The elevation varies from 315 to 435 meters above sea level, indicating a gradient of 6.856 meters per kilometer (refer to Table 1 and Figure 4).

5. Abu Hadair sub-watershed (5) (AHSW5): The sub-watershed covers an area of 519.653 km², with a perimeter measuring 128.553 km and a total length of 43.899 km. The altitudes range from 215 to 420 meters above sea level, indicating a gradient of 9.567 meters per kilometer (refer to Table 1 and Figure 4).

6. Abu Hadair sub-watershed (6) (AHSW6): The sub-watershed covers an area of 694.201 km², with a perimeter measuring 184.495 km and a total length of 55.707 km. The altitudes range from 215 to 420 meters above sea level, indicating a gradient of 7.539 meters per kilometer (Table 1, Figure 4).

Table 1. Area, perimeter, length, elevations, and slope rates of the Abu Hadair sub-watersheds

Sub-watersheds	Area (km ²)	Perimeter (km)	Length (km)	Elevations (m)	Slope rate (m/km)
Abu Hadair sub-watershed (1) (AHSW1)	3378.18	584.053	164.801	15 – 360	2.184
Abu Hadair sub-watershed (2) (AHSW2)	1221.74	253.521	78.275	165 – 360	4.599
Abu Hadair sub-watershed (3) (AHSW3)	982.047	222.216	75.986	180 – 360	4.737
Abu Hadair sub-watershed (4) (AHSW4)	1545.86	256.144	63.447	315 – 435	6.856
Abu Hadair sub-watershed (5) (AHSW5)	519.653	128.553	43.899	215 – 420	9.567
Abu Hadair sub-watershed (6) (AHSW6)	694.201	184.495	55.707	215 – 420	7.539

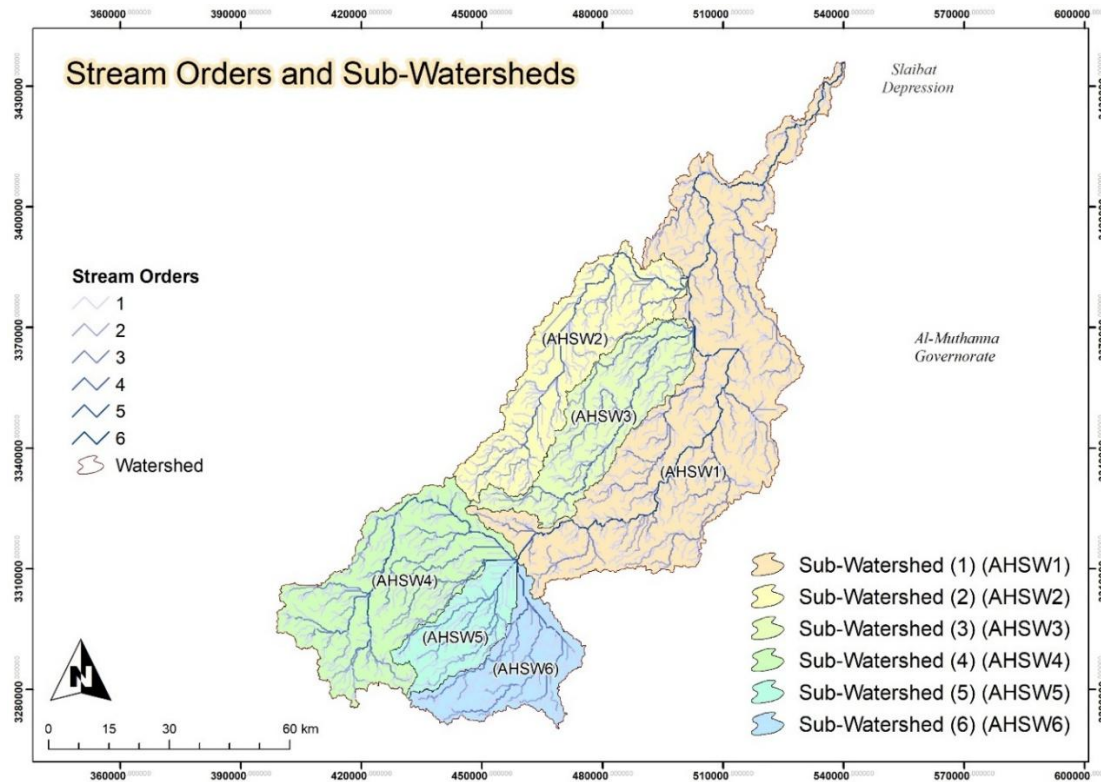


Figure 4. Stream orders and sub-watersheds show the hierarchical organization of the drainage network and delineation of six large sub-watersheds.

The geological formations within the study area reveal their sedimentary environments, with some developing under continental conditions during periods of marine regression, while others formed during marine transgressions. These formations, dating from the Upper Eocene to the Holocene, illustrate geological land movements influenced by changes in sea level and climate (Mahdi et al., 2025). The Dammam Formation is the most notable in the region, extending from

the Eocene to the Miocene epochs and comprising carbonate rocks like limestone and dolomite, which serve as excellent groundwater sources. This formation can reach a thickness of up to 100 meters and features distinct lithological sections. Predominantly found in the south, the Umm Er Radhuma Formation has a maximum thickness of 303 meters and is composed of dolomitic marl and clayey dolostone (Figure 5a). Quaternary deposits, spanning from the Pleistocene to the Holocene, include terraces and valleys (Maziqa et al., 2024).

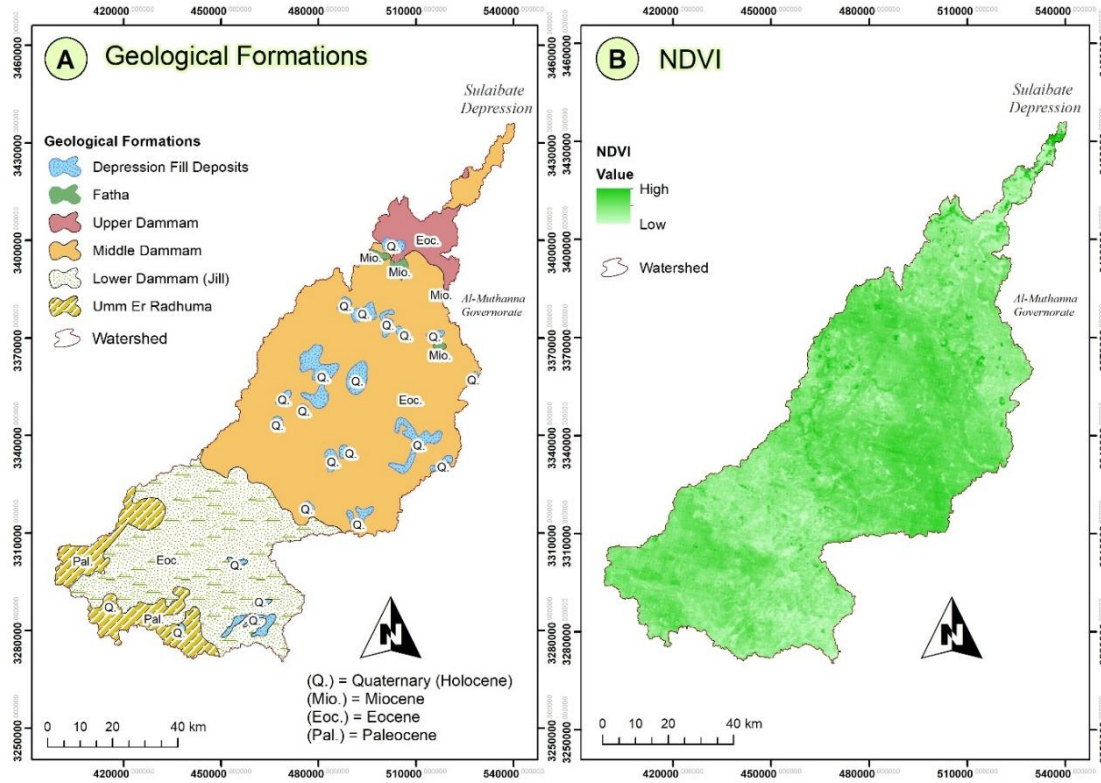


Figure 5. Spatial distributions of (A) geologic formations and (B) the Normalized Difference Vegetation Index (NDVI) over the study watershed in Al-Muthanna Governorate, southern Iraq.

In response to low rainfall and dry soils, native plants have evolved their life forms, with the area's vegetation largely influenced by climate and soil characteristics. The natural vegetation reflects a humid climate and frequent soil conditions, with significant plant density found in valley bottoms and alluvial plains (Figure 1b). Predominantly, the vegetation consists of scattered shrubs and grasses. Plants are categorized into two types: perennial plants, which survive throughout the year with adaptations for drought resistance, and annual plants, which bloom in favorable seasons and serve as food or fodder for grazing animals until the next cycle. Common examples of perennials include *Artemisia* and *Haloxon Articulata*, while *Stipa* and *Aegilops* are typical annuals (Harris, 1960).

Abu Hadair watershed is characterized by an arid climate, with temperatures peaking at 35.8 °C in July and dropping to around 18 °C in the colder months from November to mid-April (Al-Hasani et al., 2025). The area receives a mere 99.3 mm of rainfall annually, occurring between

October and May, predominantly in the form of intense showers, with events exceeding 35 mm being uncommon. Winds, driven by external atmospheric pressure, consistently blow from the north and northeast throughout the year (Figure 6), maintaining an average velocity of 3.6 m/s. Typically, wind speeds rise in the summer and fall during the winter (Alattar & Attiya, 2023).

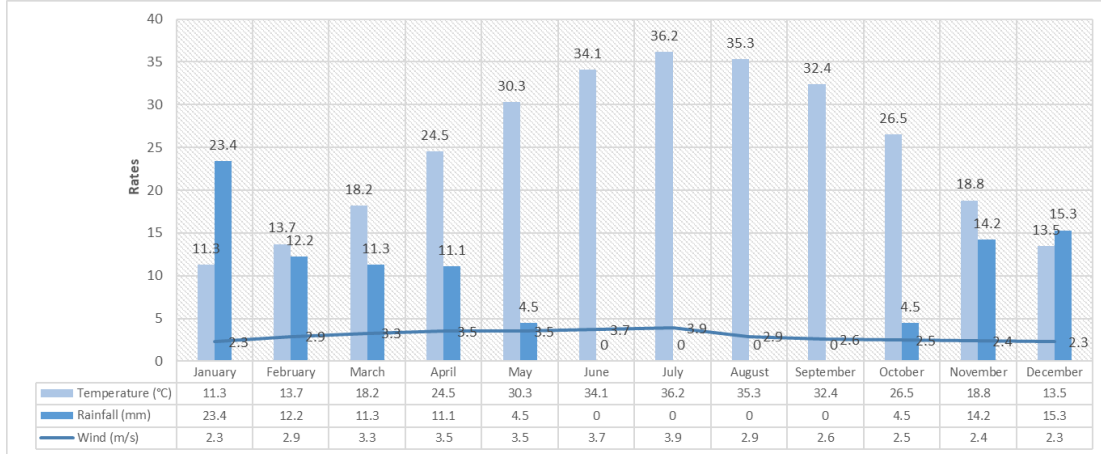


Figure 6. Monthly variations in the mean temperature (°C), rainfall (mm), and wind speed (m/s) throughout the year in the study area.

2.2. Data Sources and Processing: This research utilized a 30m Digital Elevation Model (DEM) as detailed in Table 2 and Figure 7, incorporating topographical, geological, and hydrological data derived from existing geological maps and 2023 Landsat ETM+8 satellite imagery. We explored the spatial correlations between slope models and geomorphological classifiers through various geoinformatics methods, following Young's classification from 1975, which included digitization processes. The study region was segmented into four terrain cross-section units, each differing in length, gradient, and slope type—straight, bounded, sloped, and flat. Validation involved using graph metrics generated from the SRTM DEM within ArcGIS 10.8 to assess slope types throughout the study area (B. Maarroof et al., 2025). Additionally, this research offers insights into geomorphological evolution, slope dynamics, and landscape transformations, which are crucial for future investigations. The results enhance comprehension of natural hazards such as landslides and erosion and could inform land-use planning and strategies to mitigate their effects. Integrating this knowledge into planning supports data-driven decision-making, facilitating effective hazard management, environmental conservation, sustainable development, readiness for extreme events, and traditional ecosystem restoration (Bashar F Maarroof, 2025).

Table 2: Data and their sources

Data types	Data sources	Description
SRTM Digital Elevation Model (DEM)	<u>Earthdata Search - Earthdata Search</u>	30*30 m resolution
ALOS PALSAR-Digital Elevation Model (DEM)	ASF Home Alaska Satellite Facility	Spatial resolution: 12.5 m; used for terrain analysis, watershed delineation.

Landsat ETM+8 Satellite Image			EarthExplorer	15*15 m resolution
Sentinel-2 Satellite Image			Copernicus Data Space Ecosystem	Resolution: 10 m, 20 m, and 60 m, depending on the spectral band
Rainfall data			MeteoWorld	High resolution ($0.05^\circ \times 0.05^\circ = 5 \text{ km} \times 5 \text{ km}$)
Topographic, geological, and hydrological maps			Geosurviraqi	Scale: 1:100000 and 1:250000
Watershed and drainage basin			HydroSHEDS data products	Information regarding the watershed's condition
3D Surface Model			Home OpenTopography	30*30 m resolution
MODIS (Moderate Resolution Imaging Spectroradiometer)	Resolution	Imaging	MODIS Web	Vegetation indices, produced on 16-day intervals and at multiple spatial resolutions
USGS Map Locator			Map Locator USGS Store	Topographical maps for a specific location
Slope Cartographic Information			Natural Earth - Free vector and raster map data at 1:10m, 1:50m, and 1:110m scales	1:10m, 1:50m, and 1:110m scales

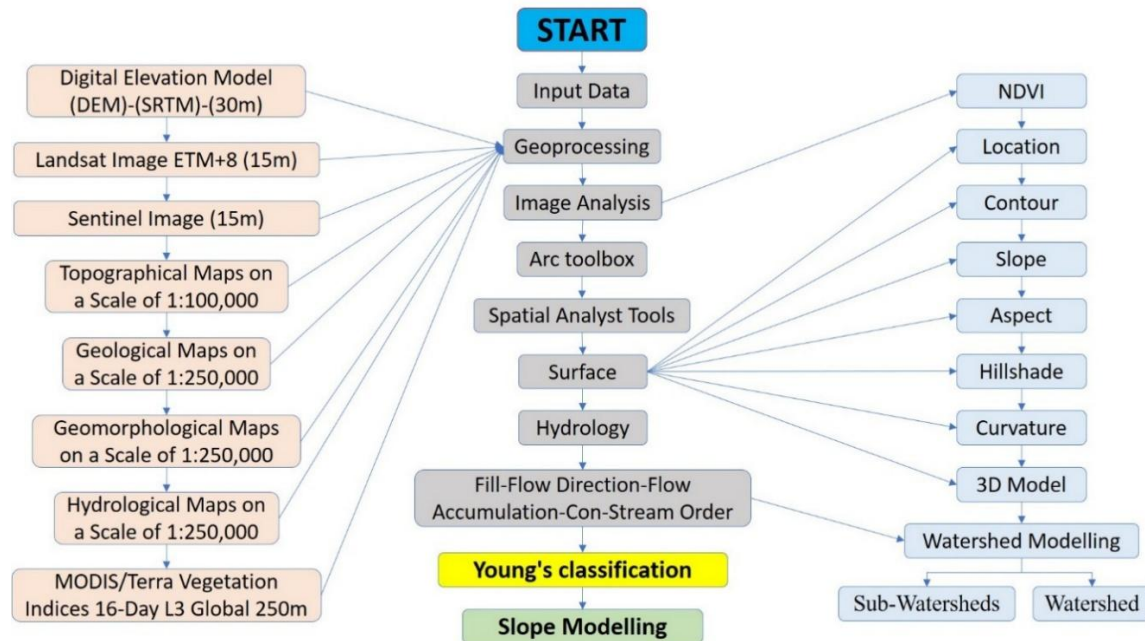


Figure 7. Workflow illustrating the integration of DEM, satellite imagery, and topographic, geological, geomorphological, and hydrological datasets with GIS and remote sensing techniques for geoprocessing, terrain analysis, hydrological modelling, slope classification, and watershed/sub-watershed delineation.

3. Results:

3.1. Slope levels associated with the phases of the Davisian erosion cycle: The Abu Hadair watershed is divided into three regression zones based on the Davisian erosion cycle stages: Youth, maturity, and aging. The Youth phase is located at elevations ranging from 317 to 447 meters above sea level, covering an area of 3,679.56 square kilometers with a perimeter of 406.797 kilometers, accounting for 44.112% of the watershed (Table 3). This phase represents the watershed's highest

point and source, appearing as a plateau with varying altitudes (Figures 8 and 9a). The steep valley slopes, typical of the Davisian cycle's immature stage, lead to more erosion than sediment deposition (Zhang et al., 2023). Due to its rocky terrain, it is termed a badland, indicating low land usability and transport (Figure 9b). The maturity stage of the Abu Hadair watershed is found between 178 and 317 meters above sea level, encompassing an area of 3,758.5 km², with a perimeter of 406.797 km, also representing 44.112%. This region features well-defined eroded surfaces at plateau and hill levels, depressions, and extensive river drainage networks (Figures 8 and 9c), exemplifying the late-maturity phase of the Davisian cycle, where erosion, transport, and sedimentation peak. The Aging phase occurs at altitudes from 8 to 178 meters above sea level, covering an area of 903.3 square kilometers with a perimeter of 322.337 kilometers, making up 10.829% of the total area. This stage starts at the confluence of sub-watersheds and the main valley, characterized by low elevation and flat terrain (Figures 8 and 9d). The oral cavity is a flat, arid area with remnants of eroded terrain, visible as small patches, mostly a few meters high. As we move towards the estuary, we reach the erosion plain stage.

Table 3. Area, perimeter, gradient levels, and phase percentages in the Davisian erosion cycle in the Abu Hadair watershed

Phases	Area (sq. km)	Perimeter (km)	Slope levels (m) (a.s.l)	Percentage (%)
Youth	3679.56	406.797	447 - 317	44.112
Maturity	3758.5	395.117	317 - 178	45.058
Aging	903.3	322.337	178 - 8	10.829

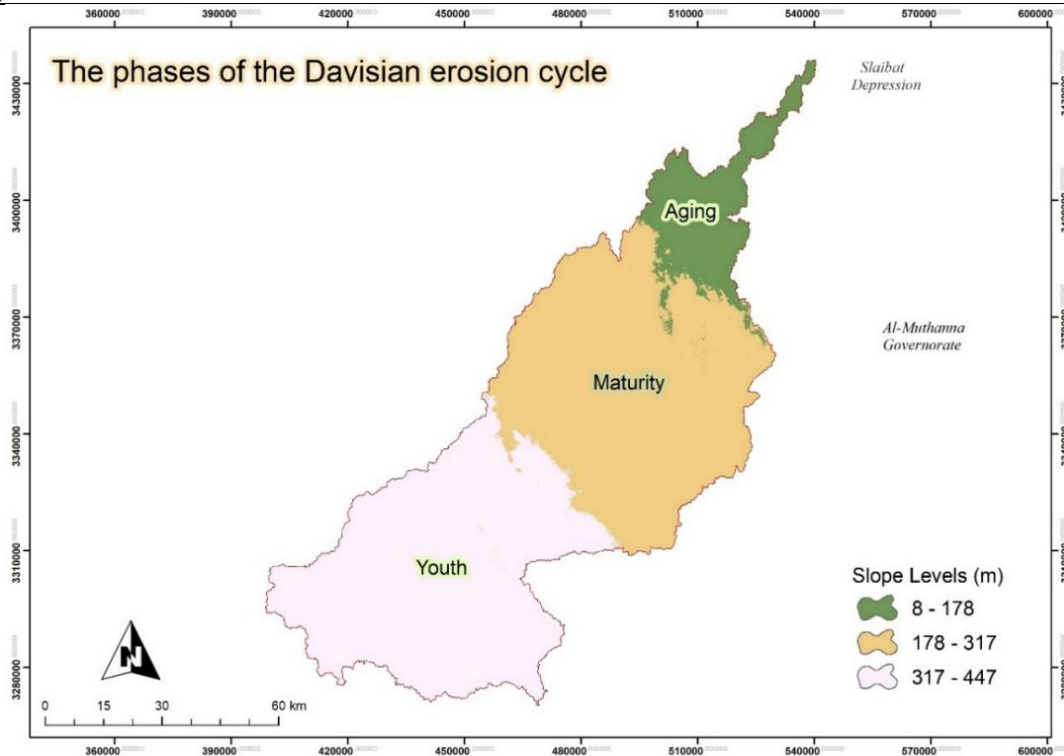


Figure 8. Spatial distribution of the Davisian cycle of erosion phases based on elevation (m) within the Abu Hadair watershed.

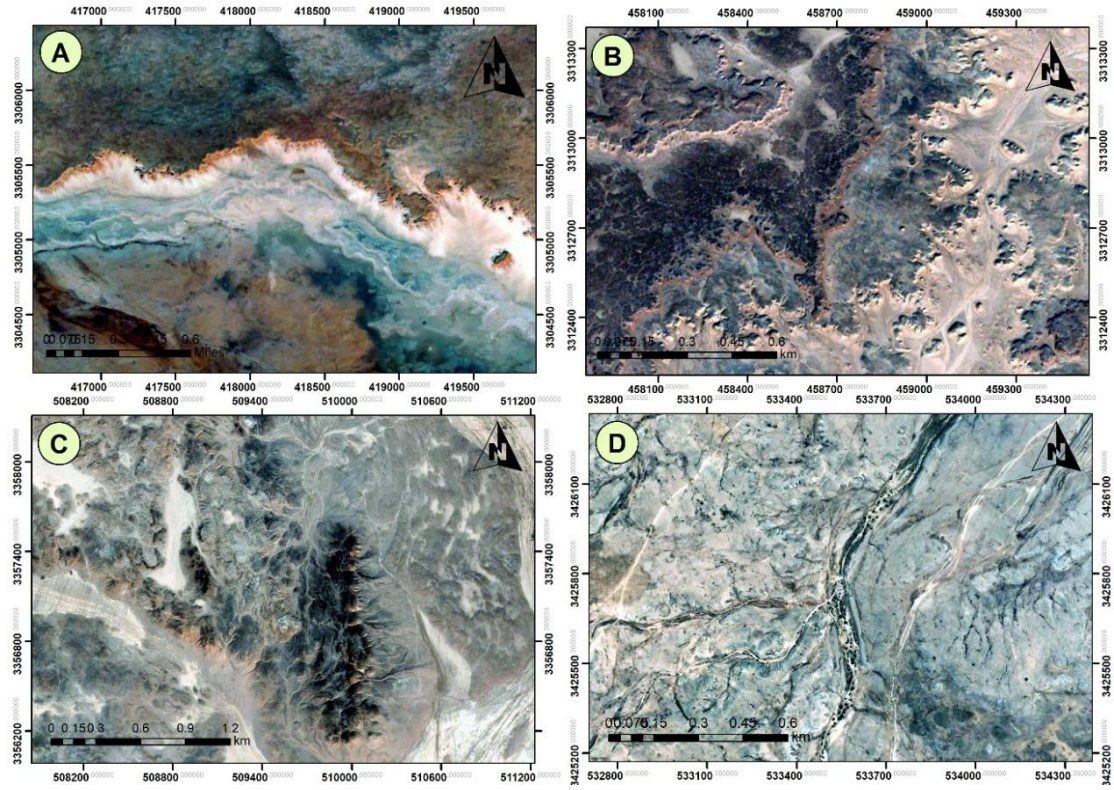


Figure 9. (a) The first stage of the watershed is called Youth, which is the highest elevation source area. (b) Badlands are youth analogs to the Davisian cycle and consist of no-man's monadnocks. (c) The second stage (Maturity) of the Abu Hadair watershed indicates a Davisian erosion cycle of late maturity. (d) The third stage (Aging) is characterized by low elevation and flat, even topography at the junction of sub-watersheds with the main valley.

3.2. Slope categories: Young's slope classification system categorizes the Abu Hadair watershed into seven distinct groups, with slopes ranging from 0 degrees to more than 45 degrees. These categories align with the geomorphological stages of the watershed (Wang et al., 2023). The distribution of these slope categories across the watershed shows significant variation. The 0–2 degree slope class covers an area of 2,870.55 km², making up 34.67% of the watershed and having the highest recorded slope rate (Table 4; Figures 10a and 11a). Conversely, the 45+ degree slope class spans 16.898 km², which is 0.204% of the total area, and has the lowest recorded slope rate (Table 4; Figures 10a and 11b).

Table 4. Area and percentage of slope groups in the study area according to Young's classification.

Slope Type	Slope Angle (degrees)	Area (sq. km)	Percentage (%)
Semi-flat lands	0 – 2	2870.55	34.670
Simple slope lands	2 – 5	2772.6	33.487
Light sloping land	5 – 10	1584.64	19.139
Moderate terrain	10 – 18	713.512	8.617
Steep terrain	18 – 30	257.152	3.105
Very steep terrain	30 – 45	64.188	0.775
Cliffs	45 +	16.898	0.204

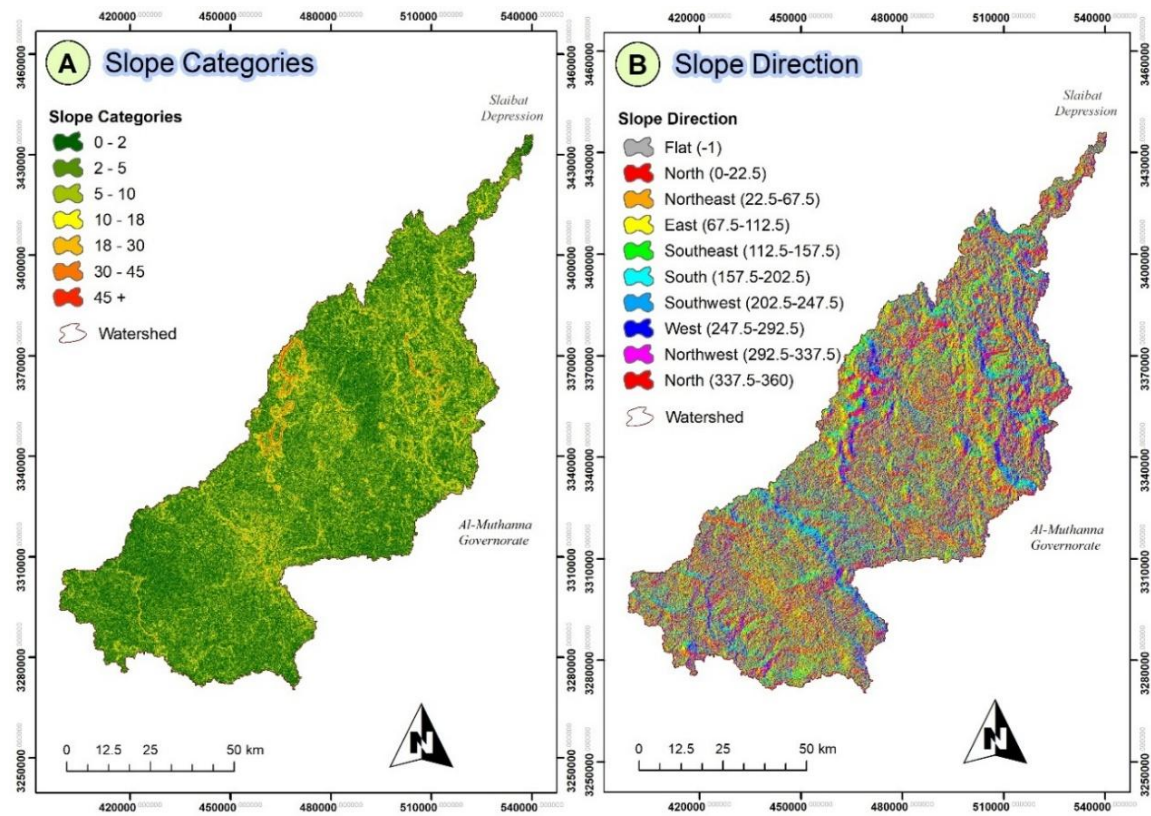


Figure 10. Slope Characteristics of the Study Watershed: (A) Slope Categories and (B) Slope Direction (Aspect).

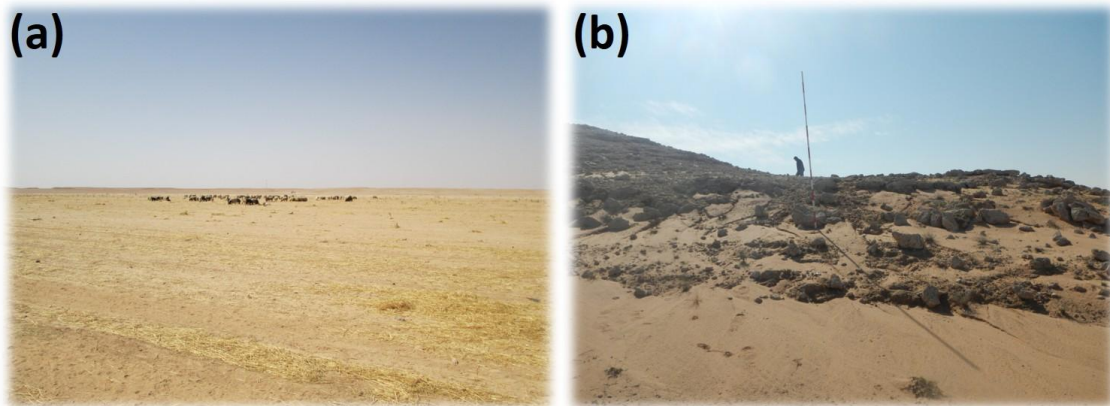


Figure 11. (a) Shows the extent of slope category 0–2 in the lower elevations of the dominant watershed, which is the most common. (b) Compared with slope category 45+, the most abundant category, this category covers a proportionally smaller area of the watershed.

3.3. Slope Aspect: The research area extended over a long stretch and featured a gentle incline from the southwest to the northeast, forming its primary gradient. It also incorporated local configurations, including both cardinal (north, east, south, west) and intercardinal directions. Notably, the watershed slope aspects varied significantly in terms of area and proportion. The

northern slopes covered 1,184.78 square kilometers, representing 14.309% of the total area, which was the highest percentage recorded. In contrast, the southeastern slopes encompassed 558,964 km², or 6.751% of the watershed, marking the smallest proportion found within the basin (refer to Table 5 and Figure 10b).

Table 5. Degree, area, and percentage of slope directions in the study area.

Direction	Degree	Area (sq. km)	Percentage (%)
Flat	(-1)	1067.25	12.889
North	0 - 22.5	1184.78	14.309
Northeast	22.5 - 67.5	1083.79	13.089
East	67.5 - 112.5	902.495	10.900
Southeast	112.5 - 157.5	558.964	6.751
South	157.5 - 202.5	602.487	7.276
Southwest	202.5 - 247.5	644.913	7.789
West	247.5 - 292.5	696.326	8.410
Northwest	292.5 - 337.5	803.076	9.699
North	337.5 360	735.633	8.884

3.4. Slope parts (segments): Across the study area, slope segments differ according to geomorphological contexts for each dominant period (refer to Table 6; also see Figures 12 and 13). E – F maturation: At its peak, this slope segment is the most densely packed, suggesting a more developed landscape form. The youth segment (C–D) is smaller, yet it is still large enough to demonstrate significant slope instability caused by current geomorphic activities. In contrast, during the aging phase (G–H), both the slope and segment length reduce significantly, indicating ongoing erosion and a relatively stable landscape that is regenerating. These characteristics highlight the geomorphological importance (or possibly the spatial extent) of the extremal longitudinal section A–B, which features an exceptionally high number and length of slope segments. This distinction highlights a dynamic and continuous energy exchange within a natural landscape.

Table 6. The length and slope parts of the cross-sections at the Abu Hadair watershed.

Cross-sections	Code	Length (km)	Slope parts (Segments)
Longitudinal	(A – B)	203.357	2388
Youth	(C – D)	63.672	729
Maturity	(E – F)	68.330	789
Aging	(G – H)	29.606	339

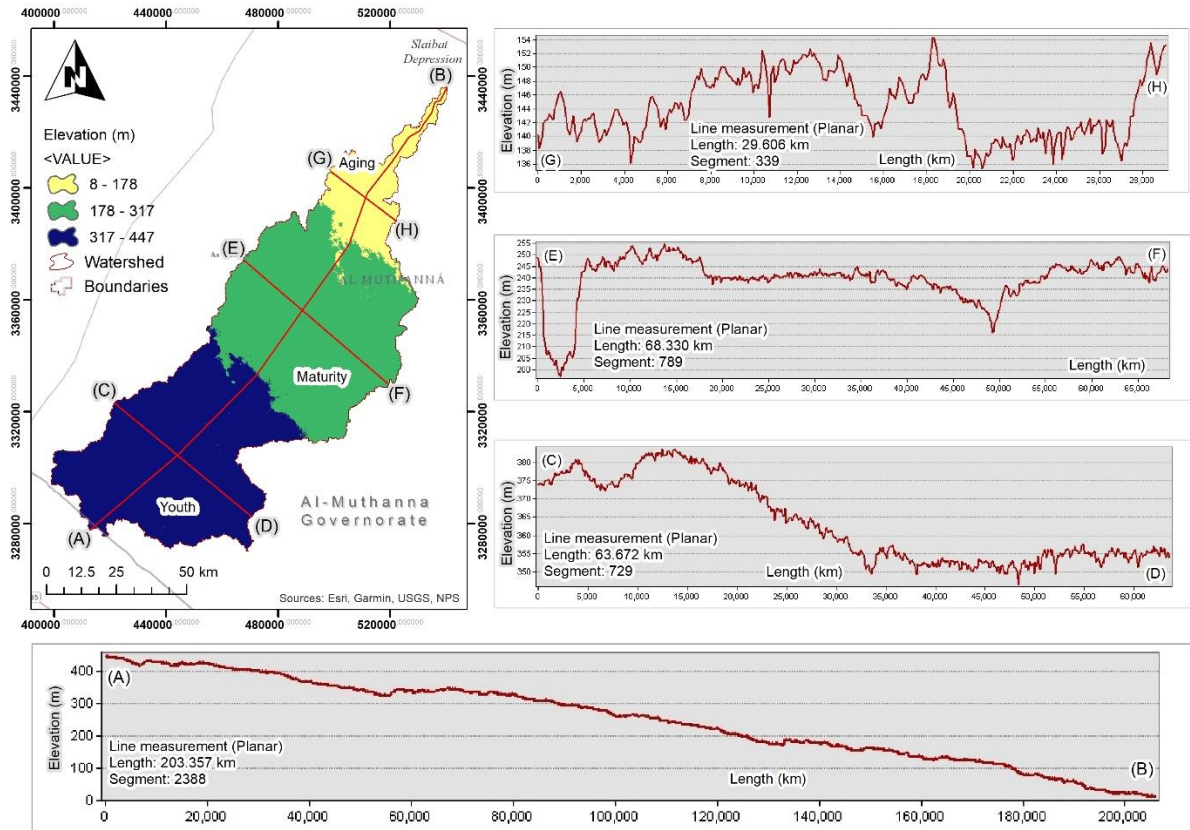


Figure 12. Spatial distribution of elevation and longitudinal topographic profiles across the sections of the Abu Hadair watershed, southern Iraq

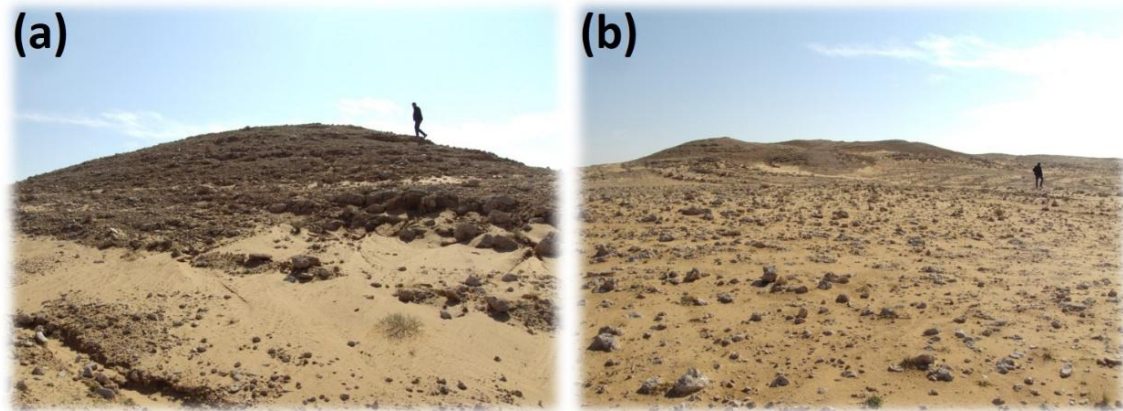


Figure 13. Various regression segments across the cross-section of the study area reveal unique geomorphological traits associated with each stage.

3.5. Slope types: The diversity of slopes within the study region is influenced by the characteristics of the slope components, which are defined as sections where the curvature coefficient remains consistent. An inclined element might be composed of a single sloped segment, as seen in linear and planar components, or it could comprise several sloped segments, as found in convex and concave components. On typical inclines, the sloped plane is consistent and lacks elevation variations, irrespective of the gradient's steepness (Bronguleyev, 2015). As a result, contour lines were aligned along these inclines. This type is clearly illustrated in the cross-section (E–F) (Figure 12). Concave slopes exhibit a noticeable steepness at the top and gentler gradients at the middle and lower ends. Consequently, near the summit, contour lines that are initially spaced apart converge more closely than those at lower and more central positions, with this gradient pattern becoming increasingly evident through the cross-section and in cross-section E–F. These slopes are concave outward, becoming less steep as they curve around their peaks, significantly steeper just below the summit, and gradually more tapered towards the base of the slope, where they widen considerably (especially in their lower sections). This phenomenon was observed only in limited areas of the study region, except in the eastern parts of the mid-basin cross-section (the maturity zone).

4. Discussion:

Spatial distributions of slope classes reveal a consistent variation in topographic characteristics that influence hydrologic and geomorphic processes at the watershed level. The Abu Hadair watershed predominantly features slope classes of 0–2, representing flat to gently sloping land, which is advantageous for agriculture and experiences minimal soil erosion (Figure 14). In contrast, slope class 45+ is anticipated to cover a limited horizontal area due to the small extent of steep terrain, which limits land use and is prone to erosion and landslides. These slope categories are vital for watershed management due to their geomorphological importance. Measures such as reforestation and terracing are implemented to mitigate erosion or shock effects on steeper slopes. Likewise, sustainable agricultural practices can boost productivity on flat terrain while preserving soil integrity. Considering slope distribution is crucial for land-use planning and environmental conservation in the Abu Hadair watershed, and thus, it was thoroughly analyzed (Larsen & Montgomery, 2012).

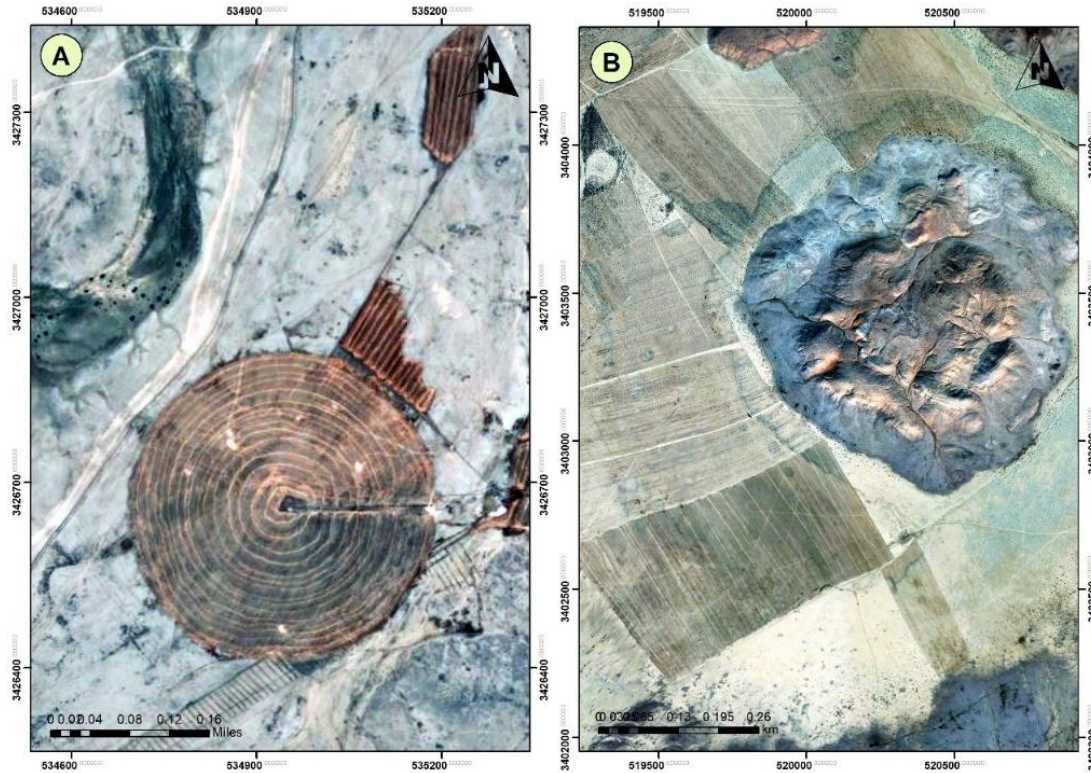


Figure 14. The dominance of slope category 0–2 highlights the prevalence of flat lands, which support agricultural practices and mitigate soil erosion.

Slope steepness is influenced by geological factors: it tends to rise in areas with hard rocks and significant faults, while it diminishes in regions with softer rocks. Semi-flat terrains, characterized by slope angles between 0 and 2°, show variations and are similar to the high Dammam formations and the upper Umm Er Radhuma. These formations are found on lands adjacent to highland foothills, which are significantly impacted by weathering, erosion, and sedimentation processes. Sandstone and mudstone, due to their weak structure and blocky nature, predominantly form in slope deposits as the gentler slope angles create calm earthen flood fans in these areas. On the other hand, slope angles ranging from 30 to 45°, indicative of very steep terrains, have been observed in the middle and upper Dammam formations (Al-Amar, 2024).

Variations in climate within the study area contribute to differences in slope morphology and affect the range of deposition and erosion processes. Geomorphological activities are linked to climate both directly and indirectly, impacting aspects such as the type, frequency, and intensity of these processes. Understanding the Earth's origin or development sometimes necessitates considering both past and present climatic conditions. Morphoclimatic processes involve mechanical and chemical changes that prepare surface materials for subsequent geomorphological actions, playing a significant role in altering the Earth's surface and shaping slopes. Vegetation strengthens surface materials like soil and other loose elements on sloped terrains. Plant roots penetrate soil and rock particles, creating a network that stabilizes the soil and often hinders the

movement of these materials, particularly on gentle to moderate slopes. The absence of vegetation on inclined surfaces is a key factor contributing to material displacement and sliding, a frequent phenomenon on most slopes in the studied region (Mohammed & Jawad, 2023).

At the study location, elevation decreased progressively from west to east. The area shared similar local orientations, encompassing both cardinal (north, east, south, and west) and intercardinal directions. There was significant regional variability, particularly in the orientations of the slopes depicted. This gradient resulted in varied hydrological features, such as surface runoff and subsurface flow. Rainwater gradually collected on the moderate incline, creating rills that traversed the terrain. Variations in slope orientations and watershed boundaries affected the moisture retention capacity, which in turn influenced the distribution of plant species across the area. Regions with north-facing slopes developed abundant hydrophilic vegetation, sustained by ongoing topographical wetness due to continuous water flow from higher elevations (Alsultan et al., 2025).

Conversely, regions facing the southwest experienced drier conditions due to reduced rainfall, which favored the growth of plants adapted to drought. The merging of minor streams into larger bodies of water has transformed the terrain. As the streams wound their way through the area, they shaped the land and formed microhabitats that accommodated a diverse array of aquatic and terrestrial life. Lakes and wetlands emerge from shallow ponds that form where streams converge in low-lying regions; these wetlands have long served as essential habitats for both flora and fauna. Acting as natural purifiers, wetlands enhance water quality and supply essential nutrients to wildlife.(Ethaib et al., 2026)

Although slope segments are indeed linked to geomorphological changes, this connection would not be present without the roles of weathering and erosion, which alter and reshape slopes, and sediment transport, which carries fine particles away from slopes via river systems. C – D Juvenile Substage: the slope serves as an active and crucial transitional area for newly formed features. These newly developed slopes offer significant insights into active geomorphic processes, setting the stage for evolutionary paths during landscape development. The subsequent articles delve into the relationships between erosional and depositional processes along slopes with multiple segments during this maturity phase (E – F). This stage reveals a landscape in a state of quasi-equilibrium, where ongoing erosion is counterbalanced by sediment accumulation, resulting in a slope form that reflects both resilience and fragility. As biological activity and human actions become more influential in this phase, they can greatly impact the natural erosion processes across slope segments. The decline in slope-segment activity as the landscape transitions to the aging phase (G – H) might coincide with ecological and physical stabilization.

The terrain has been somewhat cultivated, shaped gradually over time, largely due to the persistent influence of natural forces. Remnants of past geomorphic activities are still visible, though they are interwoven with signs of aging and deterioration, reflecting a post-disaster contemplation over an extended period of chaotic transformation. Furthermore, a branching

section (A – B) with diverse slope characteristics might document the geomorphic development of this area. This not only demonstrates the impact of geomorphological processes but also highlights regions that warrant further investigation. Insights from this segment could provide information about historical climate conditions, sediment transport routes, and the landscape's broader resilience to ongoing environmental changes.

5. Conclusions:

The watershed's rugged terrain is indicative of the early phase of the Davisian erosion cycle, where initial dissection is evident. As the cycle progresses to maturity, the drainage system becomes intricate, yet there are expansive flat regions with sparse vegetation. The ultimate phase of erosion is characterized by the deposition of state-range sediment onto basin-flat landscapes with minimal uplift, influenced by geological factors that drive aging. The spatial and temporal distribution of slopes can significantly influence watershed dynamics. In the study area, runoff from slopes and groundwater flow diminish from the southwest to the northeast. While slope orientation and basin boundaries initially signal hydrological patterns, they are followed by species distribution and microhabitat development. Wetlands serve as natural filtration zones, where streams merge and deposit nutrient-rich soils on lower lands, supporting abundant wildlife. Slope components are crucial for detecting geomorphological changes. The juvenile stage, marked by gradual contours (C – D), signifies the onset of emerging features. During the maturity phase (E – F), the proximity of erosion and deposition is most pronounced, creating a distinct landform signature. The transition to age (G – H) involves ecological and physical stabilization, resulting in a more refined and time-shaped landscape. We propose that the longitudinal stretch of A – B serves as an external record of geomorphic evolution, capturing paleoclimate, sediment transport, and landscape resilience to environmental shifts. Therefore, assessing slope destabilization is crucial for sustainable land use and environmental policy development. These slope variations influence hydrological processes through pathways like overland flow, leading to runoff, siltation, and erosion. Concurrently, management strategies could enhance soil conservation at intermediate scales, with significant potential for improving water-use relevance.

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