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Fluvial Landforms Classification Using Geospatial Modeling of Al-Jazeera Eastern Region at Misan Governorate, Iraq

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ABSTRACT

In this paper, the landforms of Al-Jazeera Eastern Region at Misan Governorate, southeastern Iraq, are classified. An approach for regional geomorphological analysis is conducted using geospatial modeling and spatial analysis tools in a GIS environment. The reliance is mainly on SRTM digital elevation model data, LANDSAT and SASPLANET satellite images, as well as map data from the Iraqi Survey Authority. The landforms are investigated and classified according to the geomorphological classification system of the Dutch Geosciences Institute (ITC). The results indicate that the study area includes a large number of fluvial landforms (erosional and depositional) formed by the geomorphological activity of the river drainage basins that originated from Iranian territory. All landforms in the study area are a legacy of previous geomorphological conditions, most likely dating back to the Pleistocene era, which developed within six main geomorphological regions (Alluvial fans, Alluvial plains, Flood plains, Bad Lands, Pediments, and Hills). The importance of this study lies in the fact that it sheds light on the topographic features of Al-Jazeera Eastern Region at Misan Governorate, as it is one of the important regions in terms of natural resources in southern Iraq.

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تصنيف الأشكال الأرضية النهرية باستخدام النمذجة الجيومكانية لمنطقة الجزيرة الشرقية في محافظة ميسان، العراق

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الملخص

تم في هذا البحث تصنيف تضاريس منطقة الجزيرة الشرقية في محافظة ميسان جنوب شرقي العراق. تم تطبيق منهج التحليل الجيومورفولوجي الإقليمي باستخدام أدوات النمذجة الجيومكانية والتحليل المكاني في بيئة نظم المعلومات الجغرافية GIS. تم الاعتماد بشكل أساسي على بيانات نموذج الارتفاع الرقمي SRTM وصور الأقمار الصناعية LANDSAT ETM+8 وSASPLANET، بالإضافة إلى بيانات الخرائط من هيئة المساحة العراقية. تم مسح الأشكال الأرضية وتصنيفها وفقاً لنظام التصنيف الجيومورفولوجي التابع للمعهد الهولندي لعلوم الأرض (ITC). أشارت النتائج إلى أن منطقة الدراسة تضم عدداً كبيراً من التضاريس النهرية (التعروية والترسيبية) التي تكونت نتيجة النشاط الجيومورفولوجي لأحواض تصريف الأنهار التي تنبع من الأراضي الإيرانية. جميع التضاريس في منطقة الدراسة هي إرث لظروف جيومورفولوجية سابقة تعود على الأغلب لعصر البلايستوسين، والتي تطورت ضمن ستة مناطق جيومورفولوجية رئيسة هي: (المراوح الغرينية، السهول الغرينية، السهول الفيضية، الأراضي الوعرة، أقدام المنحدرات، والتلال). تتمثل أهمية هذه الدراسة في كونها تسلط الضوء على المظهر التضاريسي لمنطقة شرق دجلة في محافظة ميسان، حيث إنها إحدى المناطق المهمة من حيث الموارد الطبيعية في جنوبي العراق.

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Introduction

One of the crucial steps in understanding the elements of the geomorphological system of any location on the earth's surface is the classification of landforms. It provides a comprehensive understanding of how this area formed in conjunction with the other components of the prevailing environmental system (Sugita et al., 2019). Among these components are the present and previous climate, the geological structure, the river drainage system, the vegetation, and others. Geomorphologists have used to base their scientific findings on a distinct understanding of the geomorphological zones (Maaroof and Kareem, 2020). They didn't think these areas were interconnected. According to the integrated system of natural forces acting on the Earth's surface, geomorphological processes have an impact on the mechanism behind its genesis (Rong et al., 2022).

The constant interaction of internal and external forces results in landforms. Winds, rain, running water, and sea waves that pound the beaches and groundwater serve as metaphors for external influences (Maaroof et al., 2021). Along with the internal forces symbolized by gravity, earthquakes, volcanoes, and tectonic activity (Diniz et al., 2023). A thorough understanding of the principles underlying landform change as well as the procedures involved in creating geospatial models utilizing geoinformatics tools has sparked the growth of allied earth science disciplines. A dimension of disciplines (like hydrological,

geological, biological, etc.) is closely tied to geomorphological analysis, which is associated with the classification of landforms (Newman et al., 2022). Scholars in a variety of earth science fields have taken an interest in this issue, and numerous scholars from many different nations have started ground-breaking scientific efforts to categorize landforms in different parts of the world (Ghosh and Bera, 2023).

The creation of geomorphological categories for landform inventory utilizing cutting-edge geospatial methods is crucial. In the past, geomorphologists only used field evaluations to create classifications. Currently, the classification of landforms is done using digital methods that rely on satellite imagery and digital elevation models (DEMs). The most efficient method at the time for producing high-resolution maps and geospatial databases for the regions for which geomorphological classifications were to be generated was GIS, together with field reviews to match satellite data with field data (Dadson, 2022). The Digital Elevation Model (DEM) is a virtual digital simulation of the topographical reality of the Earth's surface. In the past two decades, earth scientists have been able to use it in many fields including the classification of landforms in the form of slope maps, river drainage networks, watershed derivation, land cover classification, etc. This relies on the use of many tools and procedures within a GIS environment (Lin et al., 2022).

In the current study, we focus on classifying the landforms of Al-Jazeera Eastern Region in southeastern Iraq, using the digital elevation model (DEM), satellite images, and topographic maps. The importance of this work comes from our belief that this region is characterized by diverse terrain and a complex topographic feature, and on the other hand, it is a promising land for economic investment due to its natural resources. Al-Jazeera Eastern Region is one of the distinct geomorphological regions in Iraqi territory, and the state has recently begun to realize its geographical, economic, and strategic dimensions. Development processes have begun to take place there because it contains many natural resources including oil reserves, water resources, and mineral wealth. The main objective of this study is to develop an integrated classification of landforms for Al-Jazeera Eastern Region according to the standards of the Dutch Institute of Earth Sciences (ITC), where landforms are classified according to the geomorphological processes that created them.

Classifying the landforms of Al-Jazeera Eastern Region leads to the production of the geomorphological map of the region, which leads to understanding the topographic system of the region and identifying the geomorphological processes that contributed to the formation of the terrain; as well as identifying the prevailing geomorphological processes in the region and predicting their development in the future. Also, using the geomorphological map of the region, it is possible to identify the types of deposits resulting from geomorphological processes and the types of ores and minerals that can be extracted and benefited economically. On the other hand, the geomorphological map can be used to understand the topographic system of the region and to employ this in the field of civil constructions such as roads, bridges, residential complexes, railways, airports, and other constructions.

Materials and Methods

Data Collection:

To conduct the study and complete its requirements, the regional approach is used, which includes an inventory of landforms and their classification according to the approved principles of the geomorphological classification system of the Dutch Institute of Geosciences (ITC). The study area represents a clear and defined territory containing many landforms, some are the product of erosion and sedimentation processes in river drainage basins, some others are the product of wind erosion and sedimentation processes, and some, are the product of tectonic activation processes in the region. In addition to the above approach, geospatial techniques have been widely used through the use of a digital elevation model (DEM)-type Shuttle Radar Topography Mission (SRTM) digital topographic data with a resolution of 30

m and the satellite image of the Landsat satellite ETM+8 with a resolution of 15 m. These layers are digitally processed using Arc GIS V.10.8, Arc GIS Pro V.2.8, Arc GIS Earth V.1.10, Q GIS V.3.12.1, Global Mapper V.11, Surfer V.21, and SAS Planet V.19.1 software.

A set of maps obtained from the Government Departments is also used, such as topographical maps on a scale of 1:100,000, geological maps on a scale of 1:250,000, and hydrological maps on a scale of 1:250,000. Carrying out the spatial matching process between the above layers and maps is very necessary, as it contributes to making final decisions about the classification of the landforms of the study area in a very accurate manner. After the above digital geoprocessing, the watersheds and their river networks are derived for the region using the hydrological analysis tools within the Arc Tool Box. Of course, river basins are independent geomorphological units, and their derivation with their sub-watersheds enhanced the analysis and interpretation of the emergence and development of landforms in the region, which contributed significantly to their classification according to the factors and processes that formed them (Fig. 1).

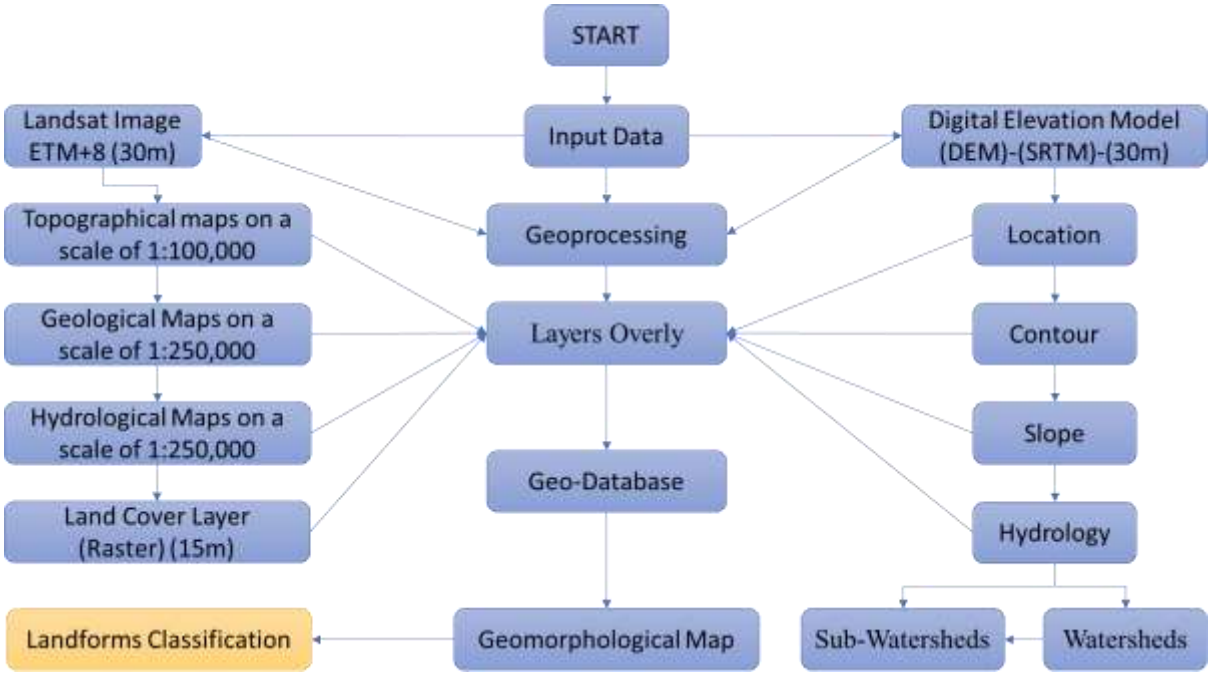

Fig. 1. Information flowchart of methodology.

Study Area:

The study area is located in the southeastern part of Iraq, and it extends widely within the East Tigris region in Misan Governorate. It is bordered to the north by Wassit Governorate, to the south by Basrah Governorate, to the east by the Iraqi-Iranian border, and to the west by the lands adjacent to the left bank of the Tigris River (Ali et al., 2023). The study area is located between latitudes (31°45′11.134″N - 32°51′3.852″N) north and longitudes (46°27′28.372″E - 47°51′15.884″E) east (Fig. 2). Its area is 5317.286 km2, its maximum length is 167.696 km, and its maximum width is 52.402 km. Many landforms are spread throughout the region including plateaus, hills, fault ridges, dunes, dry valleys, and others. Topographically, the study area is located within the southeastern part of the Mesopotamia Plain (Fig. 3). The general slope of the study area is from east to west; its highest elevation is 269 m a.s.l. in the eastern parts, and the lowest elevation reaches 10 m a.s.l. in the western and southwestern parts (Figs. 4 and 5). There is a clear effect of slope in the formation of the paths of the river basins spread in the study area, the general direction is with the slope of the region (Al-Salih and Al-Kubaisi, 2016).

In the study area, many river channels were formed by water erosion processes (Fig. 6). After the end of the rainstorm, water flows into the low-lying areas with a striped area, where streams are formed, rivers are formed that flow either into the Tigris River or into Al-Huwaizah and Al-Sanaf marshes. These river basins (seasonal or permanent) can be distinguished in most parts of the study area, especially in the northern and eastern parts (Maaroof, et al., 2023). These river basins represent independent geomorphological units separated by water-dividing lines. They are geomorphological systems (closed or open) to which several geomorphological processes contributed. Most of the sources of these river basins are in Iranian territory, and their mouths are in Iraqi territory. These basins represent a record of the geomorphological history of the region, which dates back to the Pleistocene period and passed through various geological and geomorphological phases that contributed to its formation (Maaroof and Kareem, 2022). These rivers played an important role in the geomorphological processes of erosion, transport, and sedimentation, which resulted in many landforms spreading throughout the study area (Al-Saady and Abdullah, 2014).

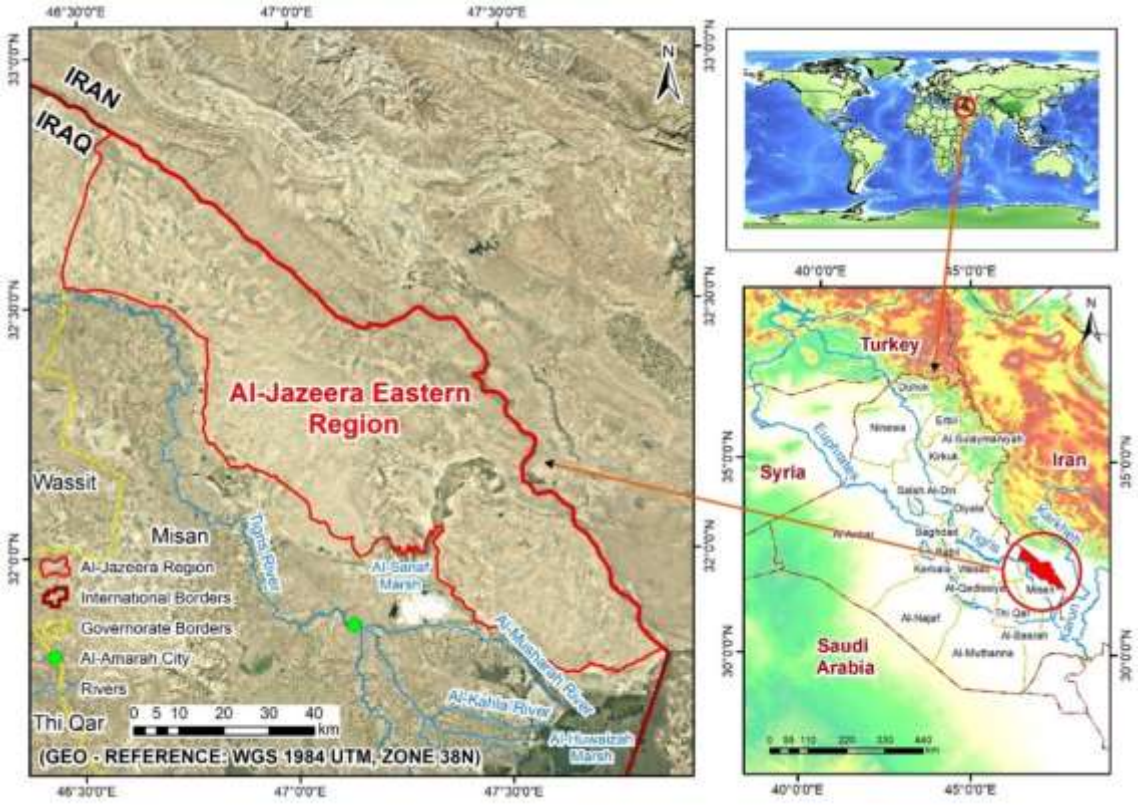

Fig. 2. Location of Al-Jazeera Eastern Region.

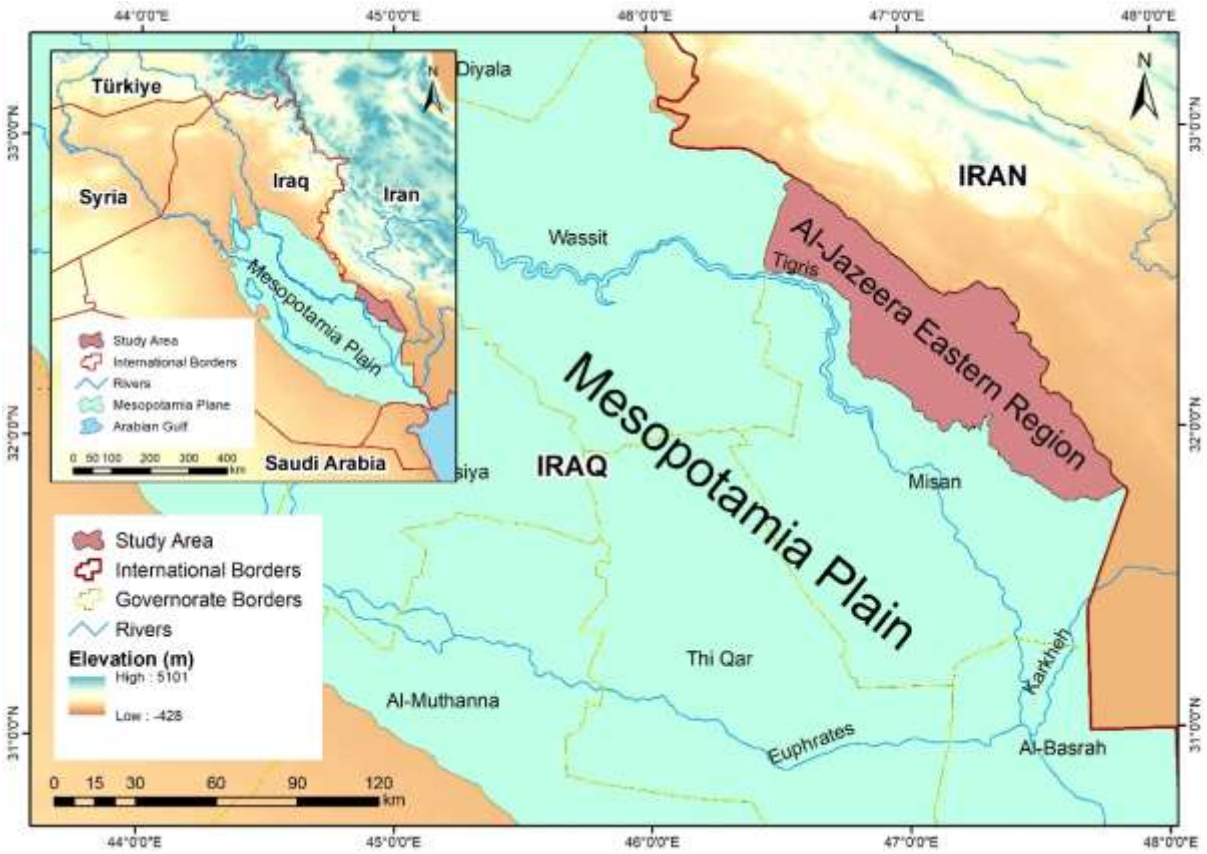

Fig. 3. Location of Al-Jazeera Eastern Region from Mesopotamia Plain.

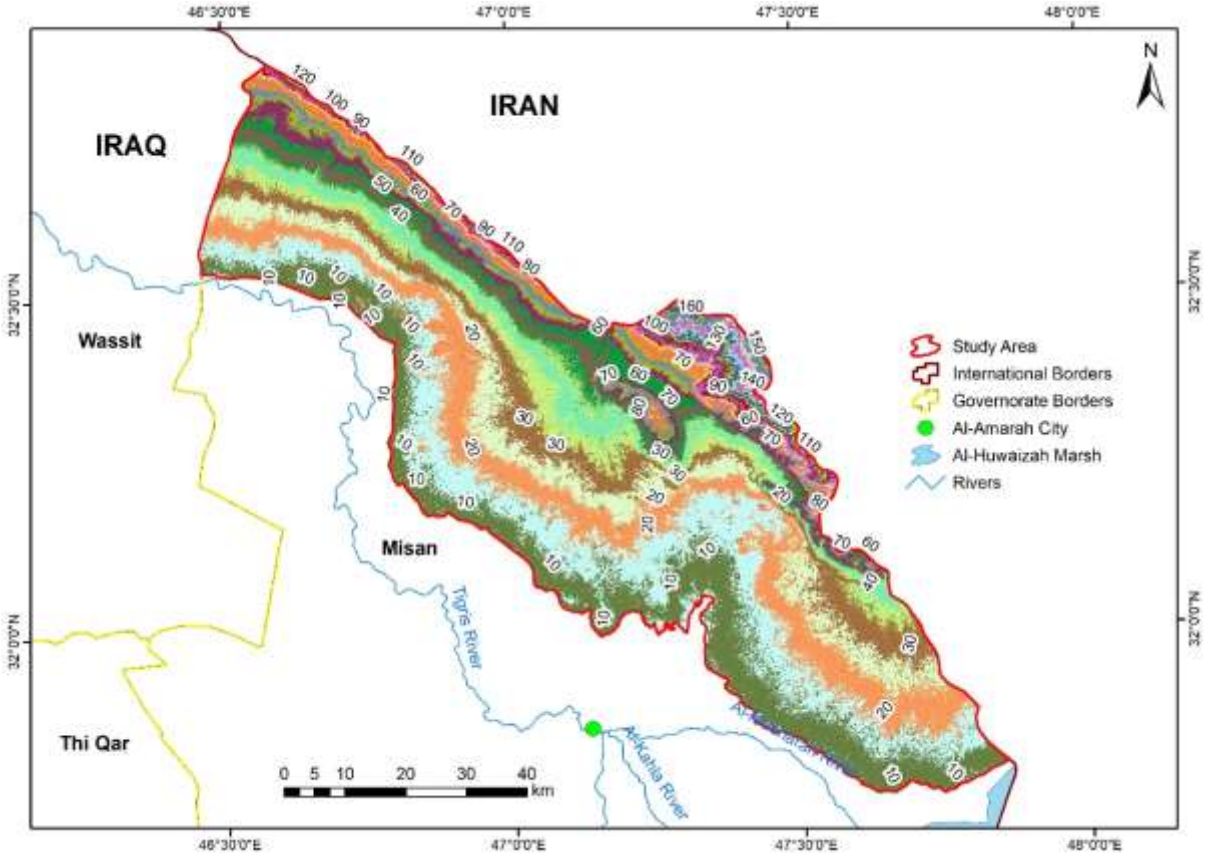

Fig. 4. Contour lines of Al-Jazeera Eastern Region.

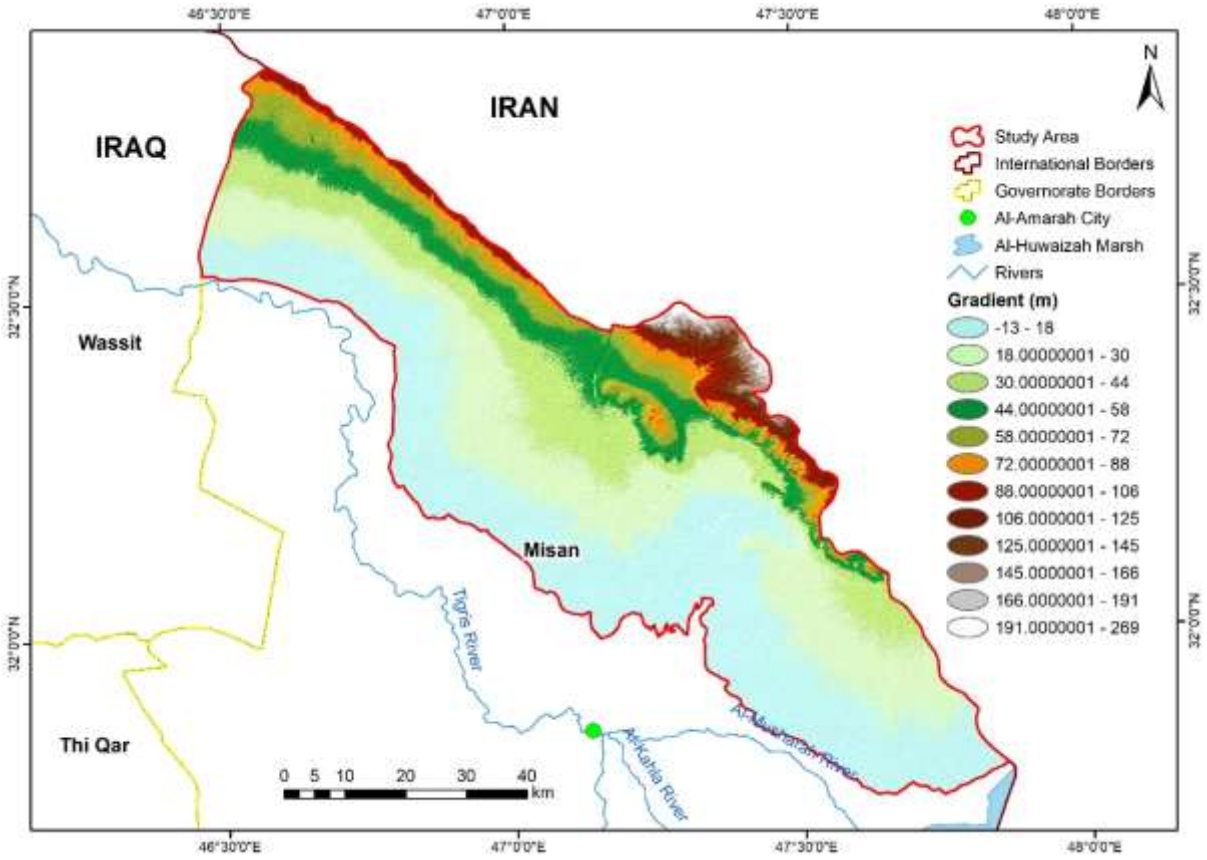

Fig. 5. Gradient levels of Al-Jazeera Eastern Region.

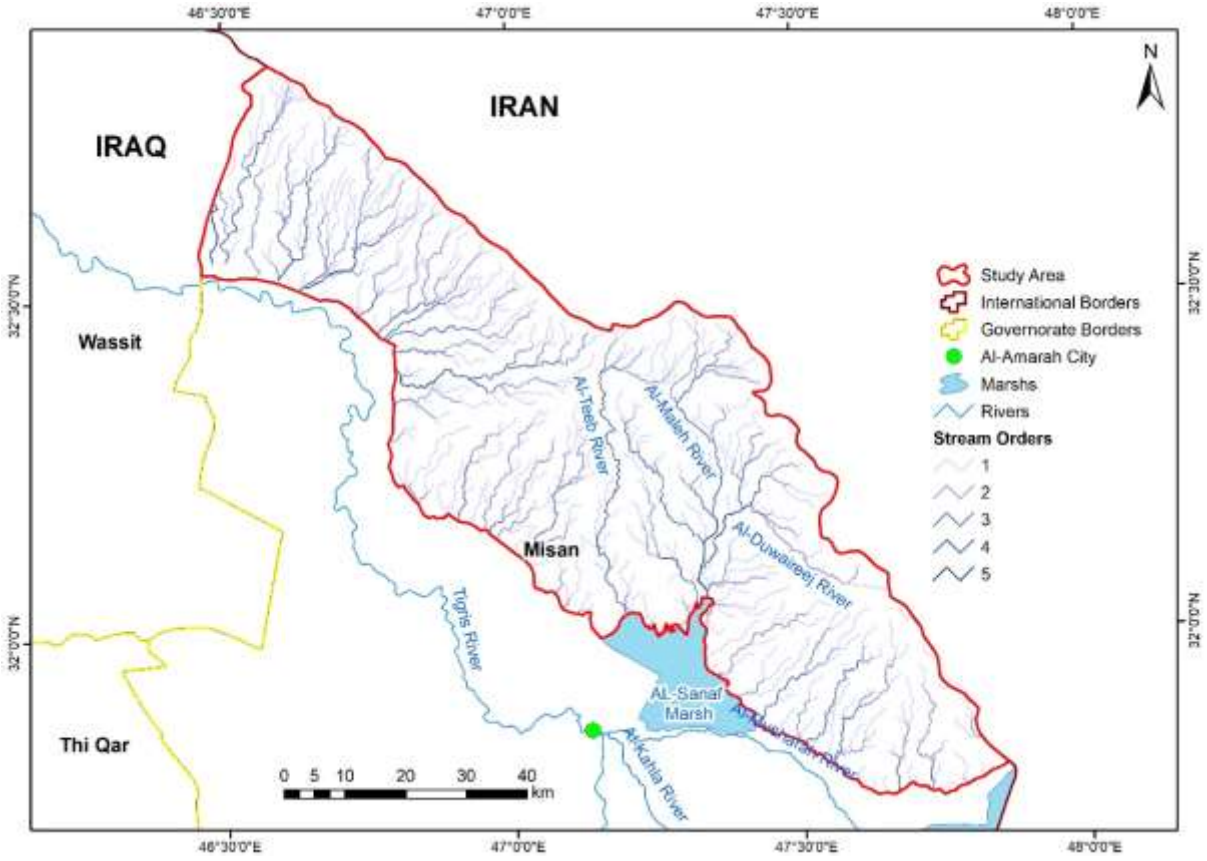

Fig. 6. Water bodies of Al-Jazeera Eastern Region.

Climatically, the study area is characterized by the presence of thermal extremes within two seasons of the year (Agha and Şarlak, 2016; Maaroof et al., 2023). In the summer (June, July, and August), temperatures are extremely high reaching 32.3, 36.5, and 38.3 °C respectively. The winter (December, January, and February) temperatures drop sharply reaching 13.9, 12.2, and 14.8 °C respectively. As for rain, it is characterized by its seasonal fall and its annual and monthly fluctuations, as it falls in relatively distant periods and is in the form of intense showers (Al-Hasani et al., 2023). Rainfall begins in November when the amount of rain reaches 36.6 mm and continues until May, when the amount of rain reaches 9.1 mm (Maaroof, 2022a). The annual average wind speed is 3 m/s, and this speed increases in the summer months reaching 5.1, 5.2, and 4.4 m/s respectively. The average wind speed decreases in the winter months reaching 2.6, 2.7, and 3.3 m/s respectively (Fig. 7).

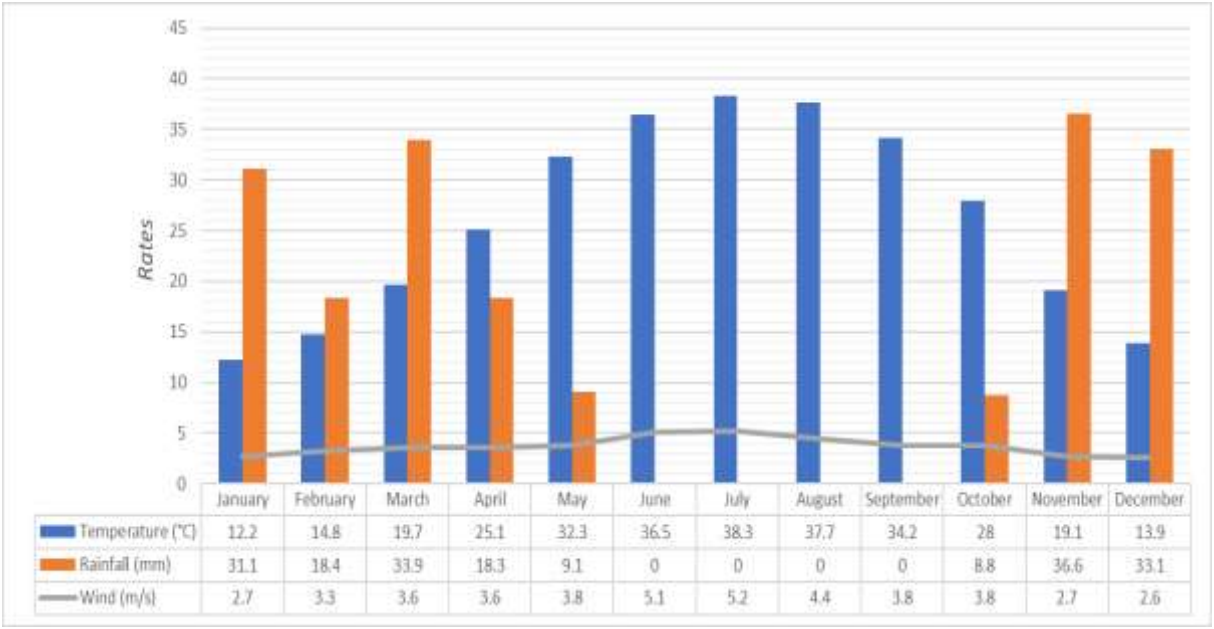

Fig. 7. Temperature, rain, and wind rates in the study area, according to Amarah Climatic Station data for the period (1990 - 2020). Iraq | World Meteorological Organization (wmo.int)

Geologically, the study area is located within the Mesopotamia Plain, which is part of the unstable range of the Persian Shield plate. The study area is characterized by the fact that most of its areas are covered by Quaternary sediments of mainly fluvial origin and partly of marine and aeolian origin (Yacoub, 2011). The Bai Hassan Formation is the most famous geological formation in the study area, it consists of a succession of layers of sandstone and mudstone, and the depositional environment, in which it is formed, is fresh river water (Hadi and Al-Zubaydi, 2019). Alluvial fan deposits are spread in a strip that extends along the northeastern areas of the study area. The deposits of this formation are located between Al-Teeb and Sheikh Saad, and its thickness reaches 15 m, where the gravel is its most important component (Al-Jiburi and Al-Basrawi, 2011). Aeolian deposits cover large parts of the study area and are in the form of spread sheets no more than 1 m thick, or spread in the form of dunes, whose thickness may reach 5 m. In addition to sediments from river basins, there are floodplain sediments and sediments filling depressions (Fig 8).

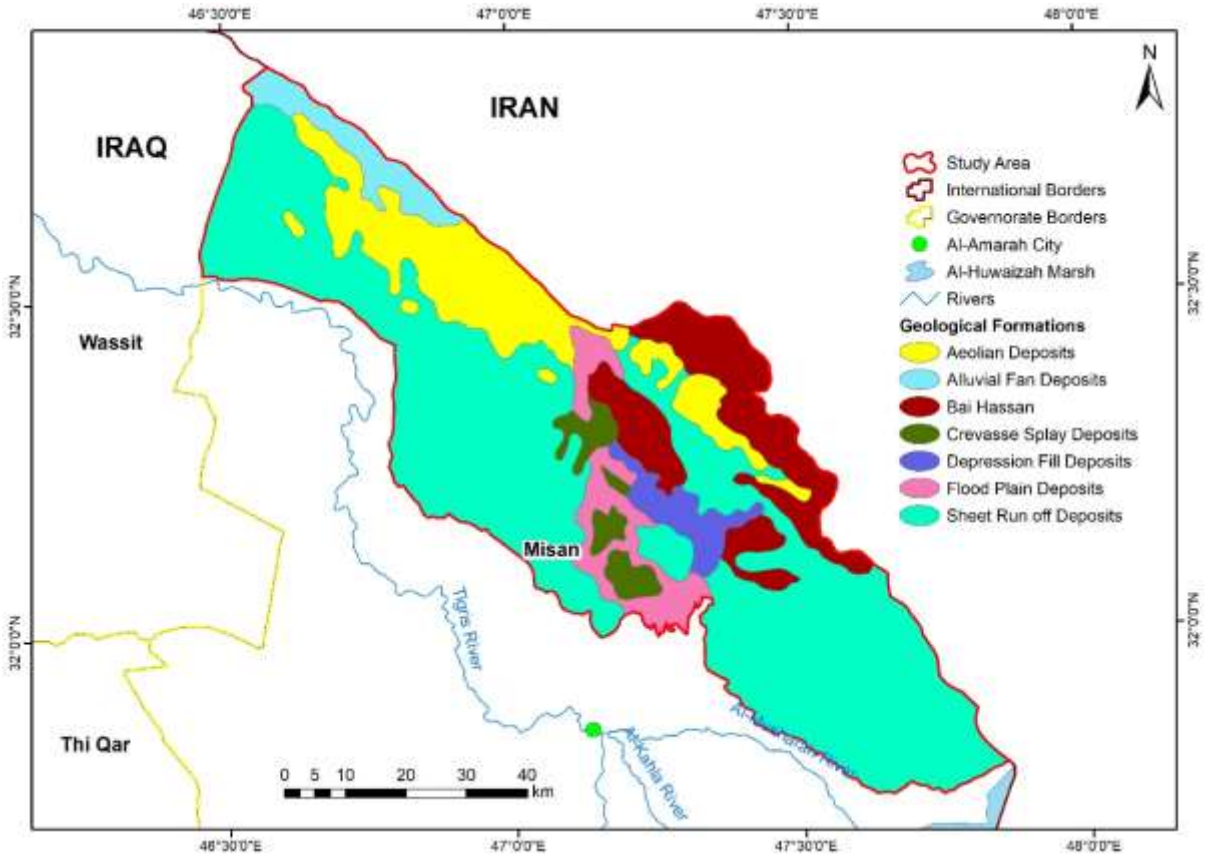

Fig. 8. Geological formations in the study area.

Results and Discussion

Erosional fluvial landforms:

1. Valleys:

The study area is traversed by many river drainage basins, both seasonal and permanent (Fig. 9). This led to the area being a scene of active hydro-geomorphological processes, which helped in any way to form a complex hydro-geomorphological system that contained many landforms (Fig. 10-a). Geospatial analysis of satellite images and geological, geomorphological, and hydrological maps indicates that the study area is divided by a giant network of waterways belonging to several river valleys (Table 1). These river basins are ancient geomorphological phenomena that were formed during the rainy times of the Pleistocene era. These valleys are characterized by drought at present, as the current climate conditions do not favor the formation of river valleys (permanent or seasonal) due to the prevalence of drought most days of the year (Yacoub, 2011).

Runoff surface water begins to move in the river basins of the study area after a rainstorm occurs and large amounts of precipitation fall. Water resulting from rain collects within the narrow passages in the deepest areas of the valley floors and flows in the general direction of the slopes, reaching the lowest area of the valley surface (Maaroof, 2022b). The process of water flow within the valleys results in the formation of streams that quickly grow into river channels, which expand over time with increasing river activity in terms of speed and quantity. The formation of these valleys is controlled by a group of geomorphological factors represented by the geological structure, rock types, faults, climate system, and the general slope of the area's surface. Most of the river basins in the study area originate from Iranian territory, and their general slope is towards the north and northeast (Maaroof and Kareem, 2023). Water flows into the valleys of the study area and passes through vast areas leaving several geomorphological traces represented by the fluvial landforms. Most of these

valleys empty their waters into the Tigris River and Al-Sanaf Marsh (Maaroof and Al-Musawi, et al., 2023).

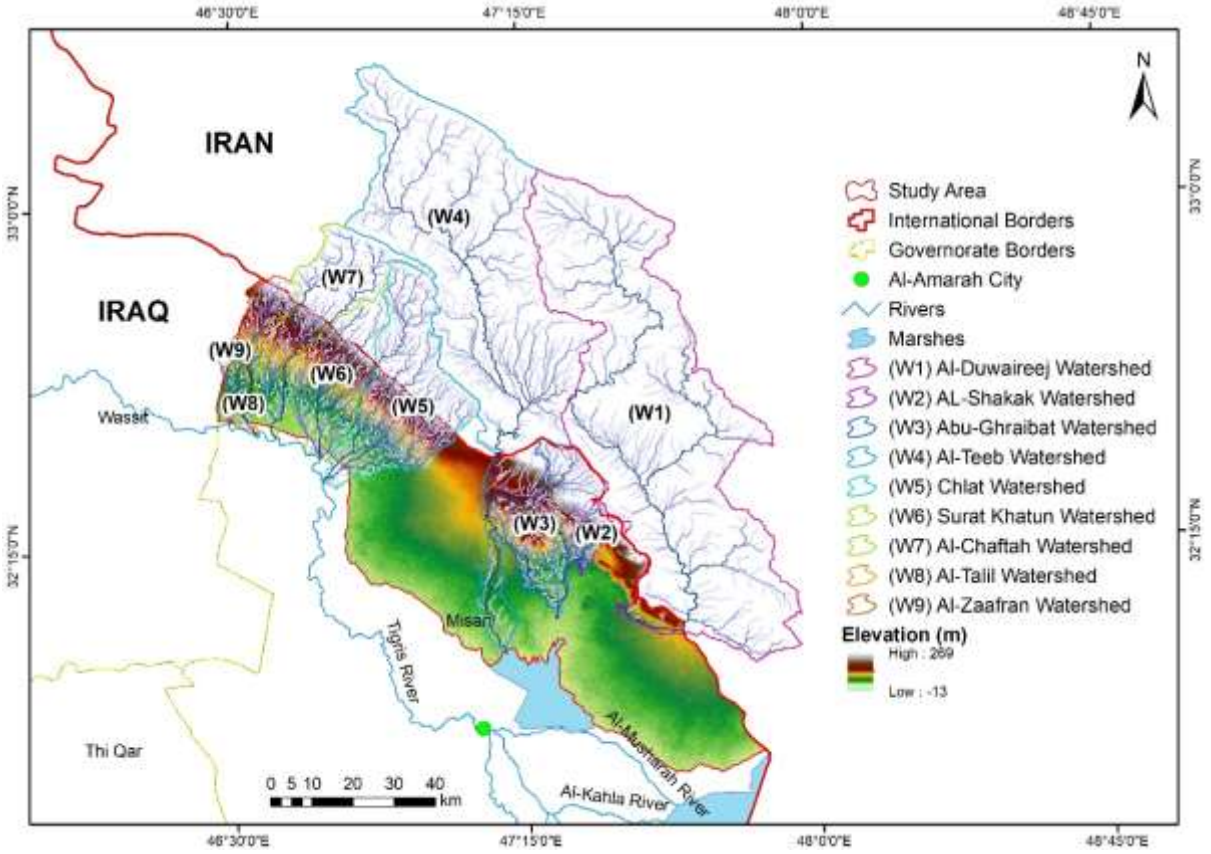

Fig. 9. A group of river drainage basins (seasonal and permanent) that cover the study area and whose sources are within Iranian territory.

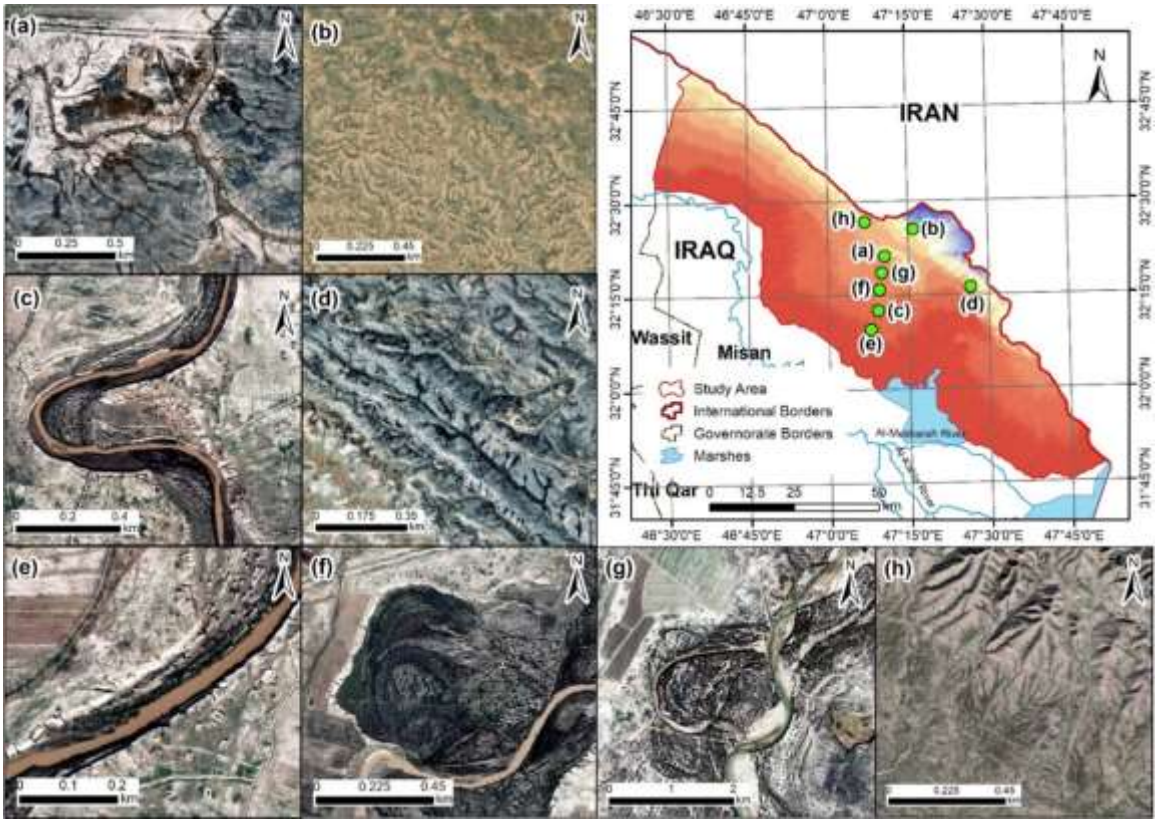

Fig. 10. Erosional fluvial landforms in Al-Jazeera Eastern Region: (a) Valleys; (b) Bad Lands; (c) Meanders; (d) Cliffs; (e) River Terraces; (f) Oxbow Lakes; (g) Braided Channel; (h) Pediment.

Table 1: Geo-spatial characteristics of the river drainage basins of the study area.

Watersheds	Status	Area (km^2)	Highest point (m) (a.s.l)	Lowest point (m) (a.s.l)	Length (km)	Width (km)	Estuary
Al-Duwaireej Watershed (W1)	Permanent	3666.456	1280	80	132.876	51.324	Al-Sanaf Marsh
Al-Shakak Watershed (W2)	Seasonal	53.949	240	20	18.975	9.860	Al-Sanaf Marsh
Abu-Ghraibat Watershed (W3)	Seasonal	554.751	160	10	43.573	20.630	Al-Sanaf Marsh
Al-Teeb Watershed (W4)	Permanent	3048.399	2020	10	155.027	41.468	Al-Sanaf Marsh
Chlat Watershed (W5)	Seasonal	970.516	1120	20	62.088	28.195	Tigris River
Surat Khatun Watershed (W6)	Seasonal	545.536	340	20	46.335	17.716	Tigris River
Al-Chaftah Watershed (W7)	Seasonal	629.610	1280	10	66.797	17.562	Tigris River
Al-Talil Watershed (W8)	Seasonal	89.428	60	10	32.352	4.548	Tigris River
Al-Zaafran Watershed (W9)	Seasonal	227.477	280	10	40.947	10.389	Tigris River

2. Bad Lands:

This type of landform results from a special type of erosion caused by rain and running surface water in arid and semi-arid areas. When rare, sometimes heavy rains fall, torrents quickly form, washing away shale, chalk, or gypsum deposits, which leads to the earth turning into a network of cracks and gorges interspersed with sharp rocky ledges (Mandal and Chakrabarty, 2021). This type of landform is spread in the northeastern parts of the study area, to the north of the Abu Ghraibat and Al-Shakak watersheds, and to the southwest of the Al-Duwaireej watershed (Fig. 10-b). Its area is 397.881 km2 and its percentage is 7.482 (Table 1). Its height ranges between 145 and 191 m (a.s.l.), and it is surrounded by rock debris over from the weathering and erosion processes to which this area was exposed, in addition to the succession of brittle and hard rocks. Exposed rocks are less hard, which helps with weathering and erosion (Fig. 11). The lack of vegetation cover helped the surface exposure in these areas to the processes of weathering and erosion directly without any obstacle, as natural vegetation, in turn, reduces the process of water erosion when rain falls over the study area.

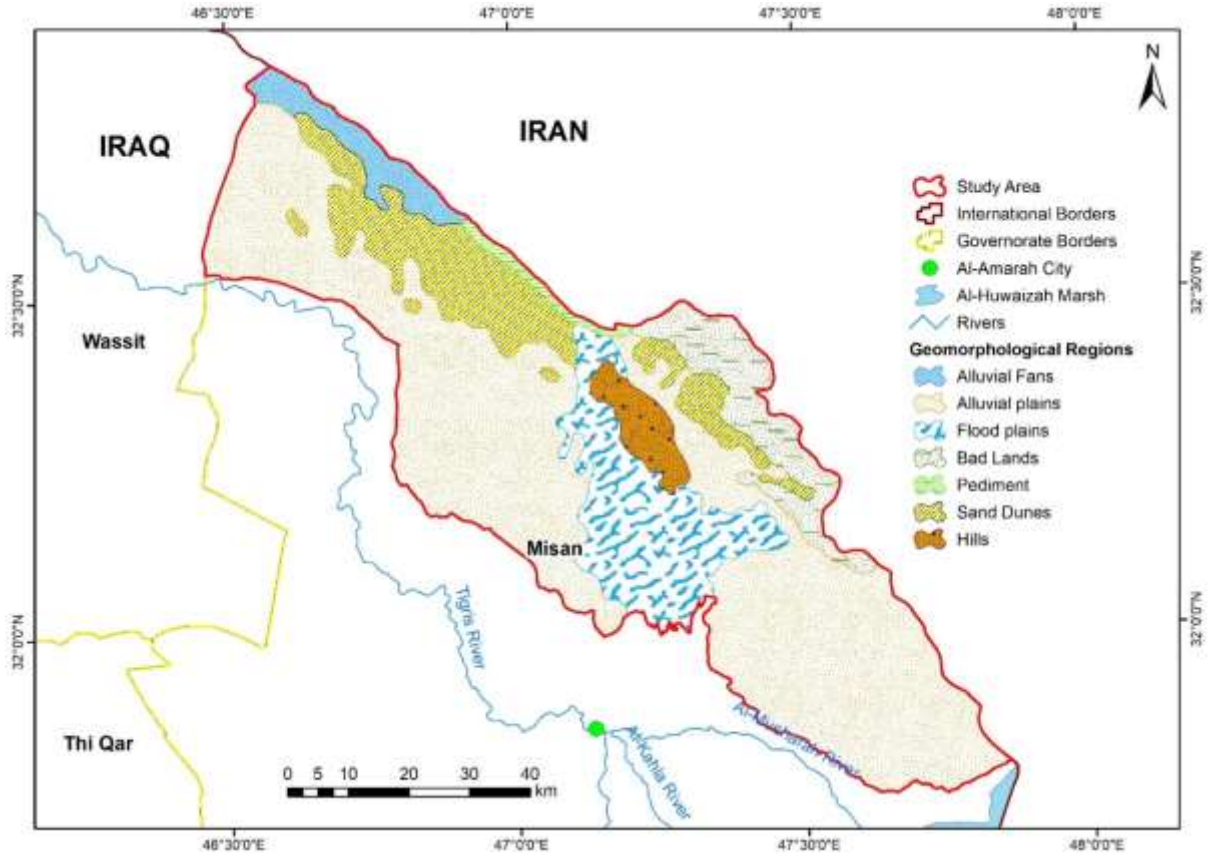

Fig. 11. Geomorphological regions of Al-Jazeera Eastern Region.

Table 2: Area and percentage of each geomorphological region.

Geomorphological regions	Area (km)	Percentage (%)
Alluvial Fans	194.674	3.661
Alluvial plains	3163.560	59.495
Flood plains	687.438	12.928
Bad Lands	397.881	7.482
Pediment	55.493	1.043
Sand Dunes	671.713	12.632
Hills	146.525	2.755

3. Meanders:

They are curvatures in river courses that are due to the stage nature of the river passing through. These curvatures are often slight in youth and early maturity and are most severe in the old stage. The meander is created in the study area by the influence of the prevailing geomorphological processes, as there is a variation in the amount of resistance of the banks to the erosion process, as the river creates the meander by the effect of lateral erosion (Langbein and Leopold, 1966). The formation of the meander in the study area is mainly due to the presence of a bank consisting of a high percentage of sand and silt and a small percentage of clay (Fig. 10-c). There is a high response of this bank to the lateral erosion processes that are destroying it leading to the formation of what is called the (external arch) or (concavity), which is a narrow bank characterized by its great depth and slope. The activity of geomorphological processes at concavities is destructive, while the opposite occurs at the bank opposite the peaks of the meander, where the speed of water currents decreases, leading to the dumping of sediments into it and then forming a convex bank called (the internal arch).

4. Cliffs:

The formation of cliffs is linked to the horizontal rock layering system, as well as to the alternating rock structure between hard and brittle layers of varying thicknesses. In addition, they are associated with vertical and lateral erosion factors of running water (Flor-Blanco et al., 2022). Cliffs are spread over large parts of the study area, especially in the eastern parts (Fig. 10-d). Geospatial analysis and monitoring indicate the spread of this geomorphological feature in the upper parts of the Al-Shakak and Abu Ghraibat watersheds. The spread of this landform in these two regions indicates that they are affected by the process of regressive erosion, and the processes of rockfall and sliding that are active on these cliffs and on the sides of the main river valleys.

5. River Terraces:

They are strips of land with a flat surface of varying sizes extending along the sides of some river valleys for different distances as terraces at levels higher than the current floodplain levels (Nandy et al., 2021; Al-Auqadi, et al., 2023). These terraces represent the remaining traces of former floodplains, in which rivers have deepened their courses to lower levels, due to the rejuvenation of river drainage basins. Most likely, the river terraces were formed in the study area as a result of the process of rejuvenation of the valley streams, which resulted either in a change in the general base level or due to a change in the local base level due to changing climatic conditions and tectonic movements (Oldknow and Hooke, 2017; Tian et al., 2023).

The study area is spread across a group of river terraces, and this indicates that the region witnessed changes in the amount of received rain, as well as being affected by base-level oscillations (Fig. 10-e). The river terraces extend along the Al-Teeb drainage basin, as well as some of its tributaries. The height of these terraces does not exceed 2 m above the level of the valley floor. River terraces are also found to the north of the Abu-Ghraibat drainage basin within the Bai Hassan Formation. Like other terraces, they are subjected to severe erosion and their levels decreased. This appears clear through the interpretation of

satellite images. River terraces are also found in the lower parts of the Al-Duwaireej drainage basin to the east and southeast of Al-Sanaf Marsh.

6. Oxbow Lakes:

They are a type of landforms associated with rivers that are characterized by an abundance of meanders, especially in the lower parts of their courses. The formation of ox-bow lakes is the result of extensive erosion activity on the sides of the riverbed (Chukwuka and Adeogun, 2023). When the river current is faster in the concave parts, erosion processes are more active, which leads to an increase in the width of the stream, and this represents the first stage of the formation of ox-bow lakes (Ghosh and Donselaar, 2023). Ox-bow lakes develop over time when the river can cut off part of its meandering course, especially after severe floods. Ox-bow lakes often turn into shallow swamps filled with weeds and aquatic plants. Over time, as a result of the river and wind sediments deposited in the ox-bow lakes, they dry up and disappear and turn into semi-flat areas, and then they are known as meander scars (da Silva et al., 2013).

There are many ox-bow lakes spread throughout the study area, but the most obvious of them is found in the central parts of Al-Teeb River, north of the mouth of Al-Sharhani watershed (Fig. 10-f). This ox-bow lake is large compared to its counterparts in the study area. Its length is (4.163) km, its average width is (154) m, and its concavity is directed towards the east. The two sides of this lake are ox-bow away from the main riverbed by a distance estimated at (2.025) km. This lake is characterized by its shallow water and high salt content making it a suitable environment for the growth of submersible plants such as algae and sedges.

7. Braided Streams:

This geomorphological phenomenon often occurs in rivers running in floodplain areas. It is one of the types of river channels that occurs due to the lack of slope of the river channel, its increased meandering, or the presence of some obstacles in the river channel (Bertoldi et al., 2009; Gran and Paola, 2001). This phenomenon is widespread in several locations in the study area, but the most famous is what is observed in the central parts of Al-Teeb River course to the west of Al-Sharhani watershed (Fig. 10-g). What is observed is the division of the river channel into many sections as a result of the growth of sand barriers and the changes that occurred in the channel bed. In addition, the slight slope of the riverbed in this location facilitated sedimentation and the dumping of large amounts of sediment. The variation in the quality of river bank rocks and their response to erosion processes directly contributed to the occurrence of divisions in the river course. The riverbed at this site is relatively widened due to the activity of riverine erosion processes, which led to the formation of middle barriers that led to the bifurcation of the riverbed. As the width of the river channel increases and the sediment amounts increase, the number of river islands increases, which is accompanied by the bifurcation of the river course.

8. Pediment:

It is an erosional plain found below the highlands and has a rocky floor that was carved by regressive erosion of rock ridges in arid and semi-arid areas. The pediment is also formed by the merging of a group of ancient erosional plains located in the upper parts of the watershed (Guerrero et al., 2023). The pediment is characterized by its striped extension and limited width. Sometimes it extends for hundreds of kilometers and is connected in a direction parallel to the general extension of the adjacent highlands (Ghosh and Bera, 2023). The pediment plains in the study area extend in a longitudinally extended strip located below the slopes of the Iranian Zagros Mountains, within the area extending between Al-Teeb River in the east and the alluvial fan region in the west, for a distance of up to 31 km (Fig. 10-h). The

width of these plains varies from one location to another and is almost similar in most parts ranging between 2 - 3 km.

Depositional fluvial landforms:

1. Alluvial fans:

They are sedimentary formations composed of various rock materials that were deposited by running water, and sometimes by landslide processes (Zhang et al., 2020). Alluvial fans often occur at transition zones between regions with a steep slope and the adjacent low-lying regions, which are characterized by their lack of slope (Jiang et al., 2021). This phenomenon is widespread in arid and semi-arid areas including the study area, as the rivers that flow there are usually temporary or seasonal (Fig. 11). When they flow quickly over steep areas, these rivers carry large amounts of sediment resulting from various weathering processes. The flow speed of these rivers suddenly decreases as they move towards the adjacent low-lying areas resulting in most of the sediments being dumped over the transition zone (Singh et al., 2022). Most coarse sediments are deposited first, especially in the middle of the stream creating barriers that force the river to divide into several sections. Over time, as rivers become more branched, the amount of water and their sediments decrease as they move away from the higher areas, they come from (Hashemi et al., 2018).

The study area is spread across many alluvial fans, which extend longitudinally in the northeastern parts adjacent to the Iraqi-Iranian border (Fig. 12-a). The surfaces of these alluvial fans are flat, with ripples and cracks resulting from rain and wind erosion activity. The shape and size of alluvial fans in the study area vary depending on the size and area of the river drainage basins where they formed, and the degree of slope of the surface, on which they were deposited, as well as the number of sediments they carry with them.

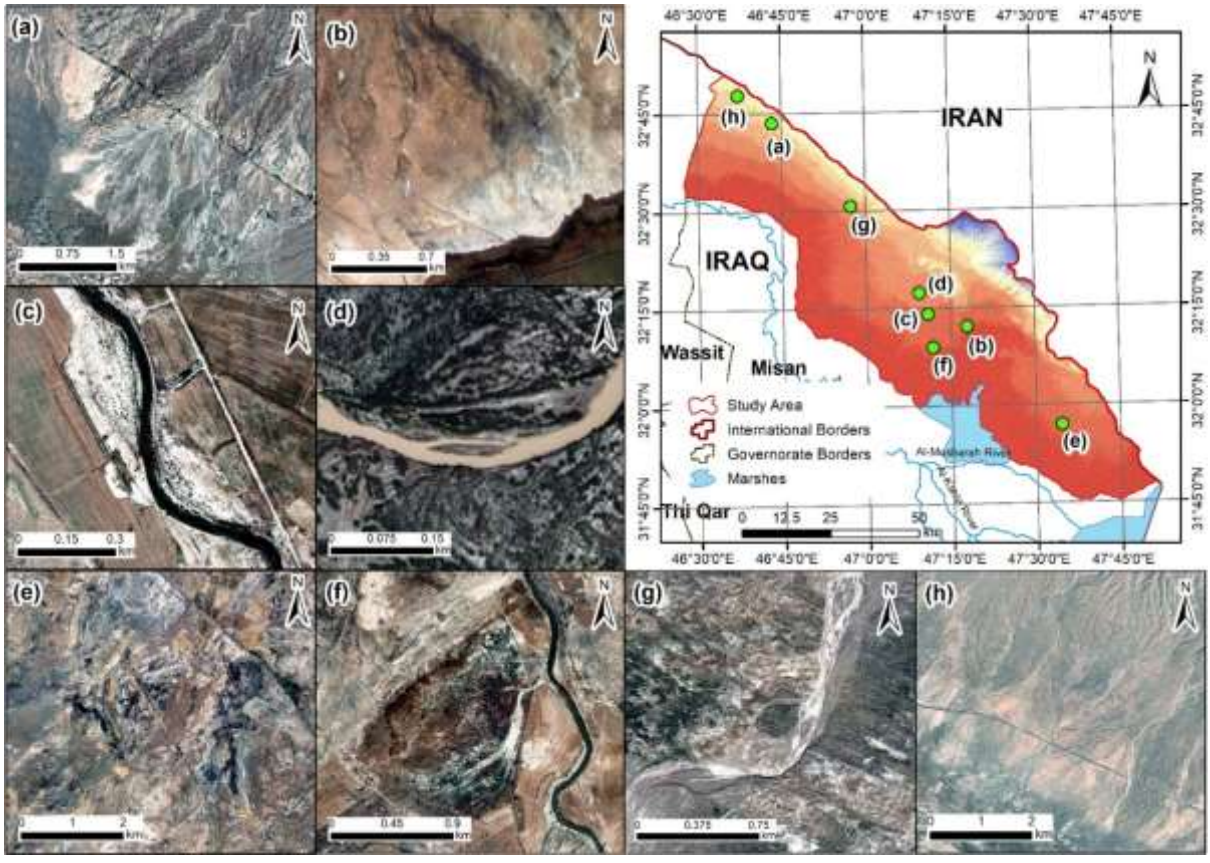

Fig. 12. Fluvial landforms in the Al-Jazeera Eastern Region: (a) Alluvial fans; (b) Flood Plains; (c) Natural levees; (d) River Islands; (e) Alluvial Plains; (f) Crevasse Splay; (g) Valleys Deposits; (h) Depressions.

2. Alluvial Plains:

It is the flattest surface feature in the study area. These planes were formed by sediments transported by river drainage basins coming from the neighboring highlands of Iran (Al-Bdaiwi, 2014). The steep slope of these lands helped in increasing speed up the flow of the water current, which led to increased erosion of these areas. When the slope decreases as a result of the river drainage basins crossing high areas with a steep slope and then moving to flat areas, the speed of water flow decreases, which leads to the deposition of their transported sediment load (Fig. 12-e). Therefore, the formation of these plains is linked to the occurrence of surface runoff at successive times.

3. Flood Plains:

The floodplains in the study area are characterized by low elevations fairly close to the base level. These planes were formed as a result of the accumulation of alluvial sediments on the bottoms of the valleys that they expanded (Sissakian and Fouad, 2015). These plains are characterized by their low degree of slope, and many landforms are spread over them such as meanders, ox-bow lakes, swamps, and others. A group of depressions are spread over the various parts of the floodplain, which are formed as a result of the irregular sedimentation process (Fig. 12-b). Some areas receive large amounts of sediments, while others receive only a small number of sediments and turn into depressions. These depressions and other landforms can arise as a result of changes that occur to the courses of some rivers during a flood or the development of meanders.

4. Natural Levees:

They are high ridges that separate the floodplain from the riverbed. These levees are formed as a result of the deposition of clay materials on both sides of the river due to the slow movement of water on both sides (Yang and Tsai, 2020). Sometimes, these levees collapse due to the pressure of floodwaters that flow into the floodplain (Ohtsuka et al., 2021). The height of these levees in the rivers of the study area reaches 15 feet (4.57 m) above the level of the floodplain on both sides of the river. It is noted that the natural levees in the study area are often linked to the meander phenomenon and have not been observed in the case of braided rivers that deposit their load of gravel and coarse sand within their courses rather than on their sides (Fig. 12-c).

5. River Islands:

They are areas of land surrounded by water at all sides, which are formed due to sedimentation within the riverbed (Raslan and Salama, 2015). The emergence of river islands is related to the accumulation of sedimentary materials of clay, silt, sand, and gravel in the form of layers starting from the bottom of the riverbed to the surface of the water (Sadek, 2013). The development of river islands in the study area is associated with an increase in river-borne sediments. When the river has less capacity to carry these sediments, it is forced to deposit its load on the bottom, which leads to the emergence of barriers within the riverbed. Over time, these barriers grow and expand as a result of the continuing sedimentation process, thus turning into islands within the river course. It is noted that most of the river islands in the study area were formed at the meander range due to the low velocity of flowing water in these areas, which leads to sedimentation and the formation of this type of landform (Fig. 12-d).

6. Bajada:

This phenomenon reveals the interconnection of the alluvial fan plains, which form an alluvial range extending several kilometers above the band separating the river drainage basins and the adjacent highlands (Schumm, 1993). The bajada grows through sediments carried by seasonal valleys coming from the eastern side and dumping them in the region of alluvial fans extending in the northeastern part of the study area. It is noted that the bajada

facies in the study area are interrupted by river channels with a radial drainage pattern. These river channels tend to change their locations during flood seasons, and most of the waters of these rivers sink into their gravel bottoms and become groundwater. The degree of slope of the Bajada surfaces in the study area varies greatly reaching 10 degrees near high areas, while it reaches 1 degree near valley bottoms.

7. Crevasse Splay:

This phenomenon occurs when there is weakness in the river banks. The water flowing from it is a secondary system for discharging some of the flood waters within the general river system (Nienhuis et al., 2018). The probability of their occurrence increases as the river approaches base level as the stream widens and the speed of the water slows down, so sedimentation at the floor increases, the height of the bank's decreases, and their size and breadth decrease leading to their easy collapse and water emanating from them to neighboring areas. Crevasse splay forms on the concave sides of valleys as a result of erosion of natural levees. The water flowing from the crevasse splay has a high velocity and carries sand and silt deposits, which are coarser than the natural levee deposits.

8. Valleys Deposits:

When the river load increases and the volume of the transported sediments exceeds the river's sufficiency limit, the river will deposit this load. Sedimentation occurs gradually along the river course depending on the volumes of the transported large-sized sediments that make up a large proportion of the bed load being deposited first. As for the fine sediments, they remain suspended in the river water until they reach the estuary (Yacoub, 2011). The valley bottoms of the study area contain large amounts of sediments varying in size and distribution. Boulders are found with unsorted sandy clastic deposits in the upper reaches of the valleys, and some areas of the valleys are devoid of sediment due to the slope and high speed of flow. While sand, silt, and small gravel deposits are found in the lower parts of the valleys and at their mouths. All evidences indicate that these deposits occurred over long periods during Pleistocene time meaning that they are formed under conditions relatively different from today's climate conditions.

Conclusion

Many river drainage basins are spread across the Al-Jazeera Eastern Region, which plays a major role in the formation and development of its fluvial landforms. In the study area, many landforms are a product of geomorphological processes (erosional and depositional), as well as the conditions of the geographical environment of the Pleistocene era. The floodplain region is one of the most important geomorphological regions in the study area, because it contains many Fluvial landforms, and this region is the product of complex geomorphological and geological conditions. The geomorphological development of the alluvial fans in the study area is a legacy of ancient climatic conditions dating back to climate changes during the Pleistocene era, and they were formed by sedimentation processes of several rivers coming from Iranian lands. The alluvial plains' region is one of the largest geomorphological regions in the study area, it was formed by sedimentation processes for many river drainage basins, the most important of which are the Al- Duwaireej, Al-Teeb, and Abu Ghraibat watersheds.

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Conflict of Interest

The author declares that there are no conflicts of interest regarding the publication of this manuscript.

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