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# Hydrological Characterization of Wadi Abu Maris Basin Using GIS and Digital Elevation Models

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**KEYWORDS**

Remote Sensing; Geographic Information Systems (GIS); ArcGIS Pro; Hydrological Analysis; Digital Elevation Model (DEM).

**ABSTRACT**

According to the results of this study, Geographic Information System (GIS) techniques and Digital Elevation Models (DEMs) are effective tools for analysing the hydrological characteristics of watersheds by understanding the behavior of surface runoff and its relationship with the topography of the study area. Wadi Abu Maris Basin was selected because no previous study had conducted a comprehensive hydrological analysis; most previous studies focused on the topography and surface features of the region. Given the variations in elevation and the presence of slopes within the basin, these factors play a key role in controlling the direction and distribution of surface runoff and in forming a natural stream network that progresses from small streams in higher areas toward lower areas, forming the main stream. This indicates a well-developed hierarchical drainage network. Hydrological analysis tools successfully delineated flow paths, flow direction, and runoff accumulation patterns. Through these tools, the number of sub-basins was identified, with variations in area and spatial distribution, resulting in differences in their contribution to the main drainage channel through surface runoff. In conclusion, the results indicate that the use of these techniques provides an important scientific basis for the study and analysis of watersheds and contributes to supporting water resource management, environmental planning, and flood risk reduction.

## 1. INTRODUCTION

Understanding watershed hydrology is fundamental for sustainable water resource management in arid and semi-arid regions. Its study is of paramount importance due to its impact on all aspects of life. Since water is never static, it is in a state of constant change depending on various conditions, most notably climate change. However, understanding its spatial behavior at the basin scale remains essential for effective water resource management.

This study will focus on Hydrological analysis, which quantifies watershed processes such as runoff generation, flow routing, and movement across time and space, characterizing spatial patterns of runoff and drainage, and determining the relationship between precipitation and surface runoff. This approach helps in identifying suitable measures for protecting environmental resources and mitigating future problems such as floods. [1]

Hydrological analyses and many other studies are conducted using digital elevation models (DEM), which are three-dimensional representations of the elevation of the Earth's surface relative to sea level, consisting of precise spatial digital data obtained from satellite imagery and ground surveys. They are widely used in terrain analysis and hydrological modeling. [2]

A watershed is a geographical area where rainwater collects and flows out through a single outlet, forming a river, lake, or reservoir. It encompasses various hydrological processes, such as precipitation, runoff, and flow. By understanding its characteristics, it is possible to estimate water availability, predict future behavior, and assess potential risks. By conducting a hydrological analysis of a watershed, key hydrological variables can be determined, such as the watershed boundaries, runoff volume, flow direction, and peak discharge. [3]

Geographic Information Systems (GIS) are among the most important tools used to study water resources and hydrology, and to analyze the spatial movement and distribution of water by integrating spatial data such as digital elevation models. This allows for the identification and analysis of watershed characteristics within the study area. [4], [5]

In addition to GIS, remote sensing technologies are among the most important tools used in hydrological studies. They allow the collection of spatial and temporal data over large areas without direct contact. This is achieved through the use of satellites and aircraft; these technologies enable the analysis of hydrological phenomena, as well as monitoring terrain and surface characteristics relevant to hydrological processes, and understanding their behavior and changes over time and their relationship to climate. With the recent advancements, Geographic Information Systems can be integrated with remote sensing, in addition to numerical models, to obtain the best possible results. [6], [7]

Wadi Abu Maris Basin was selected because no previous study has conducted a comprehensive hydrological analysis of the basin. In addition, the basin exhibits a relatively triangular geometry that promotes rapid runoff concentration during heavy rainfall events, making it a suitable case study for hydrological analysis and water resource management in southern Iraq.

This study aims to identify the characteristics of the study area by analyzing surface runoff patterns, drainage networks and flow directions, and evaluating water behavior for water resource management and environmental risk reduction by conducting hydrological analysis using Geographic Information Systems (GIS), remote sensing, and digital elevation models (DEM) of the area within the Abu Maris Valley basin, southern Iraq.

## 2. MATERIAL AND METHODS

### 2.1. Study Area

Wadi Abu Maris Basin covers an area of 332.148 km² and is located between latitudes 30°56′–31°22′ N and longitudes 44°30′–45°30′ E within the Southern Iraqi Plateau. The basin extends from the border between Al Muthanna Governorate and Najaf Governorate and is situated approximately 8 km from the Euphrates River to the east and northeast, as shown in Figs. 1 and 2.

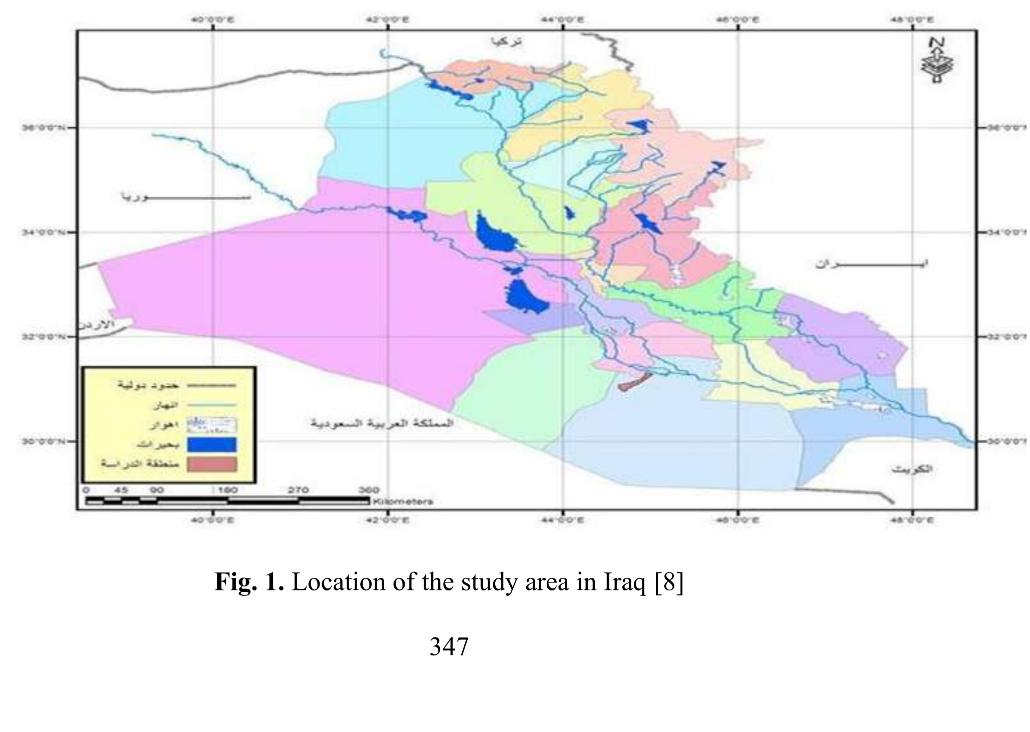


**Fig. 1.** Location of the study area in Iraq [8]

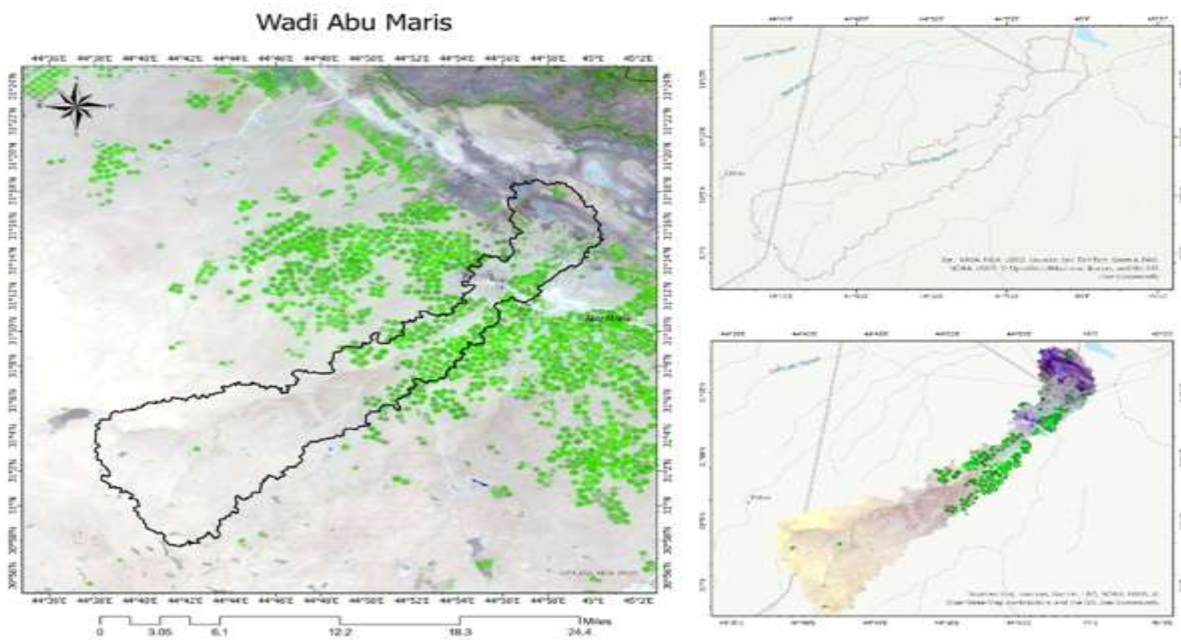


**Fig. 2.** Study area

The basin is characterized by low runoff because its main source of water is rainfall. The basin exhibits a relatively triangular geometry, with its apex at the headwaters and its base at the outlet. The basin geometry may facilitate rapid runoff concentration during intense rainfall events. The climate of the region is characterized by hot, dry summers and cold winters with little rainfall.[8]

To provide a comprehensive characterization of the study area and to better understand its hydrological response, several physiographic and environmental parameters were considered, including topography, geology, soil characteristics, mean annual rainfall, mean elevation, and mean slope. These factors play an important role in influencing runoff generation, infiltration processes, and stream network development within the Wadi Abu Maris Basin. Elevation and slope statistics were extracted from the DEM and calculated using ArcGIS Pro. The main characteristics of the study area are summarized in Table 1

**Table 1.** Main Characteristics of the Wadi Abu Maris Basin

| Parameter | Description |
|---|---|
| **Mean annual rainfall** | 14.05 mm/year |
| **Mean elevation** | 95.73 m |
| **Mean slope** | 1.80° |
| **Geological formations** | Mesopotamian Foredeep Basin and Widyan Basin (Interior Platform) |
| **Soil types** | Yk, Yy, and Zo |

This basin was selected because previous studies of the area have addressed its morphological characteristics and drainage network, focusing on its morphometric aspects. However, no comprehensive hydrological analysis of the basin has been conducted. Other reasons include its proximity to agricultural areas and environmentally significant zones, as well as its relatively triangular geometry, which leads to rapid runoff concentration during heavy rainstorms

**2.2. Methodology**

All steps of the hydrological analysis were performed using the Model Builder tool in GIS software, as shown in Fig. 3

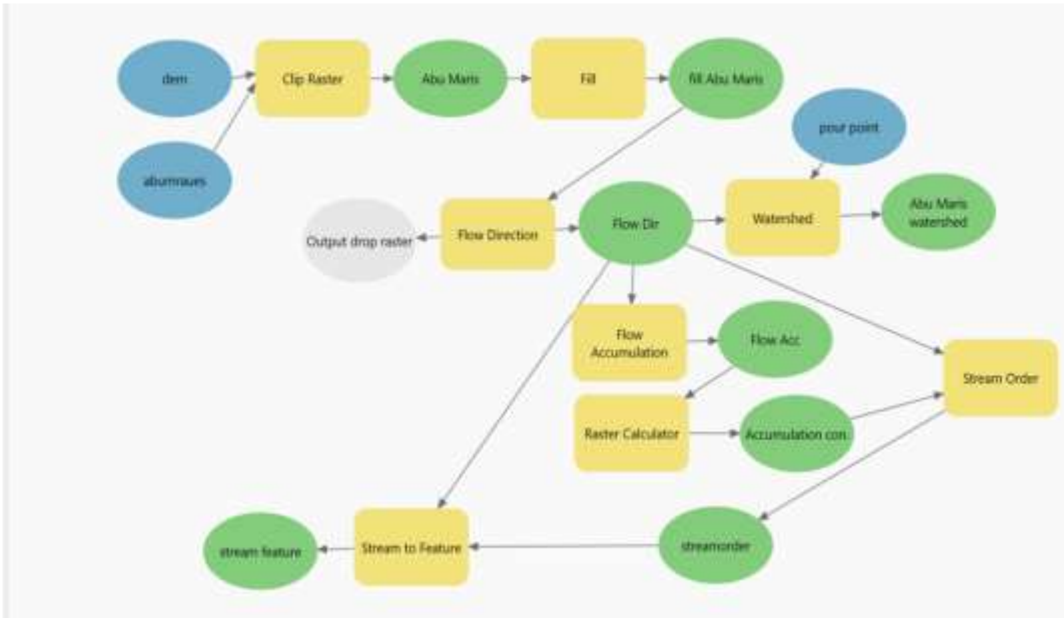


**Fig. 3.** Model Builder procedure for hydrological analysis

In this framework, GIS hydrological tools were used to map stream order and delineate the watershed. [6]

The Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) data were downloaded from the United States Geological Survey (USGS).[9]

No field verification was conducted, since the hydrological analysis was based entirely on the SRTM Digital Elevation Model (DEM) and GIS-based hydrological analysis tools. These data were used to generate thematic digital maps using GIS software (ArcGIS Pro 3.4.2). All maps are raster-based with a spatial resolution of 30 m × 30 m.

The hydrological analysis of the study area was conducted through a series of processing steps:

**2.2.1. Fill**

One of the essential steps in hydrological analysis is to eliminate artificial depressions resulting from data errors or numerical distortions when creating a digital elevation model of the study area to ensure that surface runoff paths are not interrupted by these depressions and that water movement within the basin continues. The Fill tool was applied using the default settings without specifying a sink depth threshold (Z-limit), allowing all spurious sinks in the DEM to be filled prior to hydrological analysis.

**2.2.2. Flow Direction**

This tool is used for finding the direction of surface water flow paths in the DEM of the study area based on the natural slope of the terrain. The Flow Direction tool applies the D8 (Deterministic Eight Direction) algorithm, which uses standard numerical values (1, 2, 4, 8, 16, 32, 64, 128) to represent the eight major and minor directions of flow and assign flow directions from each cell to its steepest downslope neighbor. When a direction of steepest descent is identified, the output cell is coded with the value representing that direction.

**2.2.3. Flow Accumulation**

This tool identifies areas where surface runoff accumulates, based on the results of the previous flow direction determination tool. Water flows from each area to the lower adjacent cells; therefore, higher values represent areas of water accumulation and main runoff paths.

### 2.2.4. Stream order

Stream ordering is a method used to assign a numerical order to streams within a drainage network. The classification is based on the number of tributaries connected to each stream. This method helps identify stream types and understand some of their characteristics. The stream network in the study area was classified according to the Strahler stream order classification system. A threshold value of 2000 was selected for stream network extraction based on the maximum flow accumulation value of 284,204. Considering the Wadi Abu Maris Basin area of 332.148 km², this threshold provided the most suitable representation of the stream network.

### 2.2.5. Watershed Delineation

One of the basic hydrological tools used in this study is watershed delineation, which represents the area where surface runoff is collected and directed toward a single outlet based on the natural topographic structure of the terrain [10]. The pour point was selected at the outlet of the main channel based on the flow accumulation raster and the extracted drainage network using the Snap Pour Point tool.

## 3. RESULTS AND DISCUSSION

To prepare the hydrological analysis maps, a Digital Elevation Model (DEM) of the study area (Fig. 4) was generated with a spatial resolution of 30 m and projected to the WGS 1984 UTM Zone 38N coordinate system to ensure accurate metric-based spatial analysis.

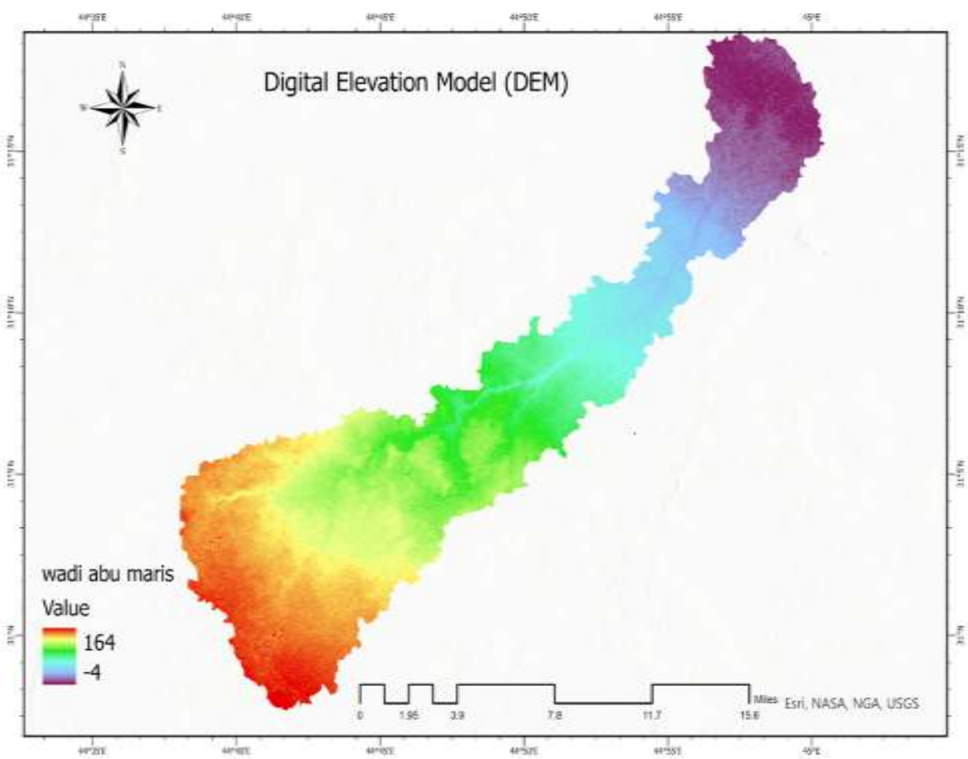


**Fig. 4.** Digital Elevation Model (DEM) of the study area

### 3.1. Fill

The Digital Elevation Model (DEM) of the study area after the removal of surface depressions (sinks) is shown in Fig. 5.

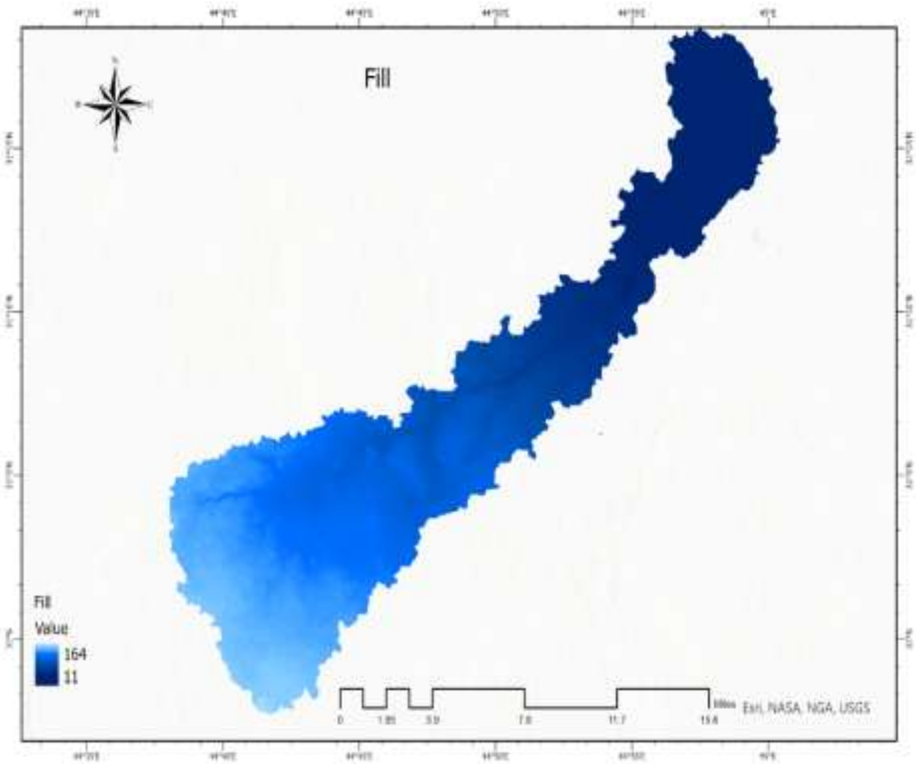


**Fig. 5.** Fill result of the study area

The results showed a clear gradient in elevation values within the basin, ranging from approximately 11 meters as the lowest elevation to approximately 164 meters as the highest elevation, a difference of 153 meters. The figure shows a color gradient indicating the variation in topography within the region. Darker colors appear in the northern and northeastern parts, representing the higher elevations from which surface runoff originates. Lighter colors appear in the southern and southwestern parts, representing the lower elevations where surface runoff accumulates due to gravity. The fill operation removed artificial depressions and ensured continuous flow routing, thereby ensuring the continuous flow of surface water within the study area.

### 3.2. Flow Direction

The directions of water movement in the digital elevation model of the study area were determined according to the (D8) algorithm, where each direction is represented by a numerical value. The directions are shown in Fig. 6 in different colors.

Figure 6 shows that the distribution of surface runoff in all directions within the basin is a result of topographical variation. It is noted that Northward flow appears visually dominant in several parts of the basin. This is followed by values (128) and (32), which clearly indicate northeastward and northwestward directions, respectively, in several locations. This demonstrates the diversity of slope directions. The greater the color variation, the greater the changes in runoff direction, while in areas with less variation, the runoff direction is more stable. Runoff pathways indicate progressive convergence toward the main drainage channel through a number of secondary channels, gradually merging to form an interconnected stream network primarily influenced by topography and slope. The flow direction was compared with Wadi Hasab Basin in Al-Najaf and the Al-Najaf–Karbala Plateau in southern Iraq; both studies reported that flow direction is primarily controlled by topography and slope, which is consistent with the results of the present study. However, the dominant flow directions differ among basins due to variations in geomorphological characteristics [11], [12]. This indicates that flow-direction behavior is a common hydrological response in southern Iraq basins, while the specific directional pattern is site-dependent.

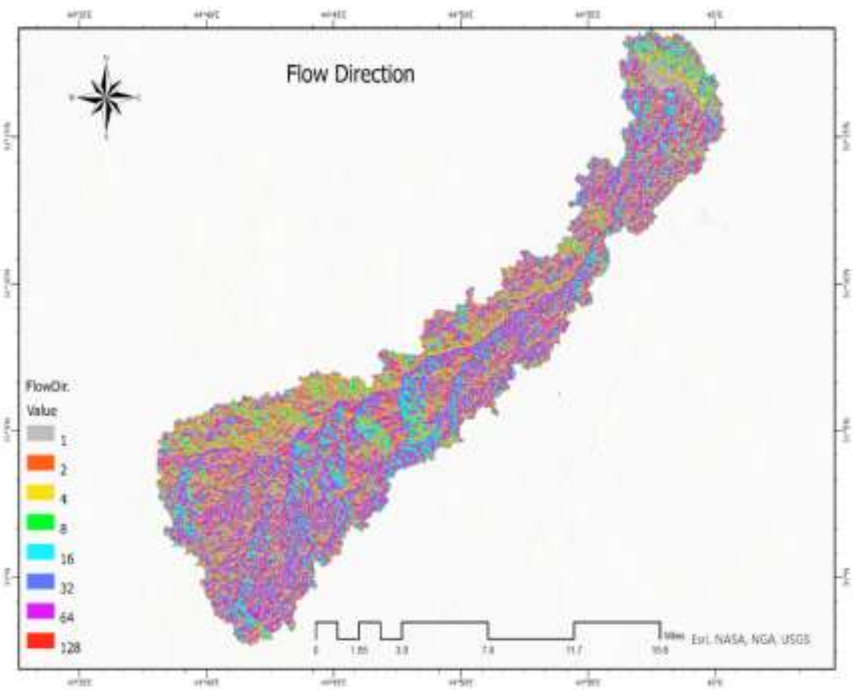


**Fig. 6.** Flow directions in the study area

### 3.3. Flow Accumulation

The Flow Accumulation result identifies areas where surface runoff accumulates within the study area, as shown in Fig. 7.

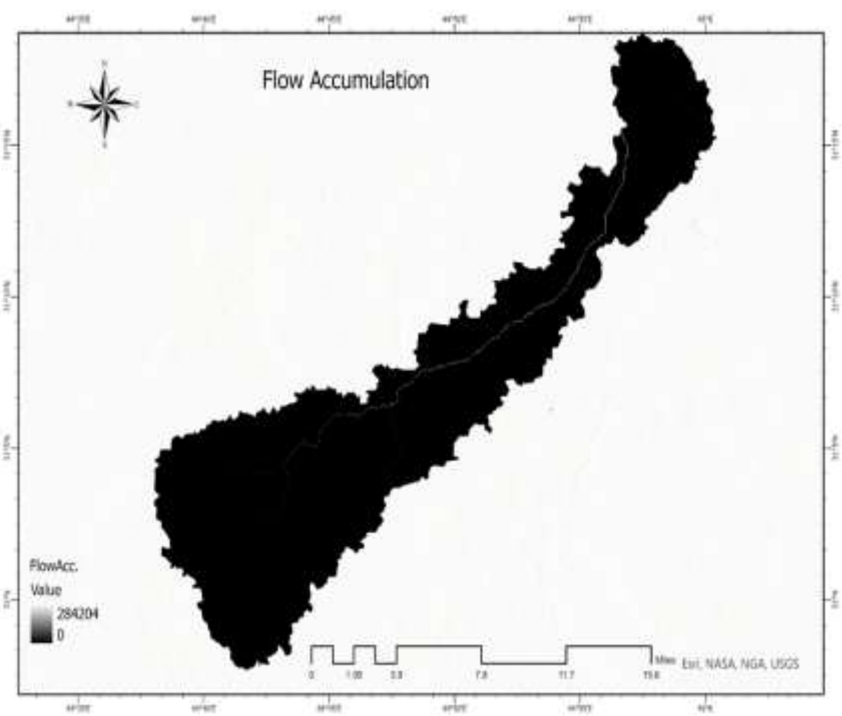


**Fig. 7.** Flow Accumulation of the study area

The runoff accumulation pattern illustrates the distribution of water accumulation within the basin, depending on the area's topography. Values ranged from 0 to 284204, indicating a clear variation in the area's surface runoff collection and reception. Low values are found in elevated areas, which represent the initiation of runoff, as the contribution of upstream cells is limited. Conversely, high values are concentrated in continuous lines representing drainage paths. A clear main channel exhibits the highest accumulation value within the basin, receiving water from tributaries and secondary channels. This represents the maximum accumulation value (284204), indicating major runoff convergence zones for collecting surface runoff and transporting it towards the main outlet. This value represents the number of upstream raster cells contributing flow to the corresponding cell and was not converted into a contributing area.

### 3.4. Stream Order

The tool for classifying the stream network in the study area according to Strahler's classification, as shown in Fig. 8.

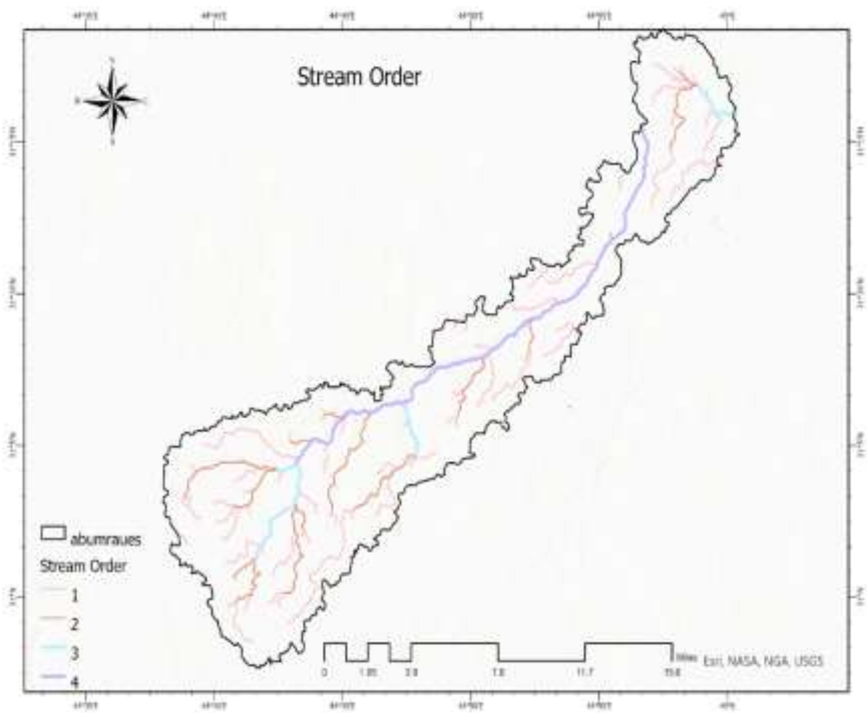


**Fig. 8.** Map of stream order in the study area

The figure shows that the order of streams in the study area ranges from first to fourth order, the highest stream order within the basin. First-order streams represent headwater channels that combine to form higher-order streams that collect surface rainwater and runoff. After the merging of two watercourses of the same order, a higher-order watercourse is formed, capable of transporting and receiving larger quantities of runoff from smaller tributaries. The fourth-order stream extends across the basin, forming the main drainage channel that serves as the primary channel of the drainage network, carrying collected water toward the basin outlet. Thus, we conclude that the basin has a well-structured drainage network, possessing a well-organized stream network that begins with smaller streams and culminates in the main fourth-order stream. A comparison with Wadi Hasab Basin and the Al-Najaf–Karbala Plateau shows that stream-order analysis has also been used to describe the drainage network and its hydrological characteristics in these basins. Although the maximum stream order differs among the three basins (fourth order in Wadi Abu Maris, fifth order in the Al-Najaf–Karbala Plateau, and seventh order in Wadi Hasab), this difference can be attributed to variations in basin size and geomorphological characteristics. Nevertheless, stream-order classification provided a clear description of the drainage network in all three studies [11,12].

### 3.5. Watershed Delineation

The watershed delineation process identified several sub-basins within the Wadi Abu Maris Basin, as shown in Fig. 9. The reported sub-basin areas presented in this section correspond only to the major sub-basins selected for detailed hydrological analysis and do not represent the total area of the Wadi Abu Maris Basin (332.148 km²). The area of each selected sub-basin was calculated, as shown in Table 2.

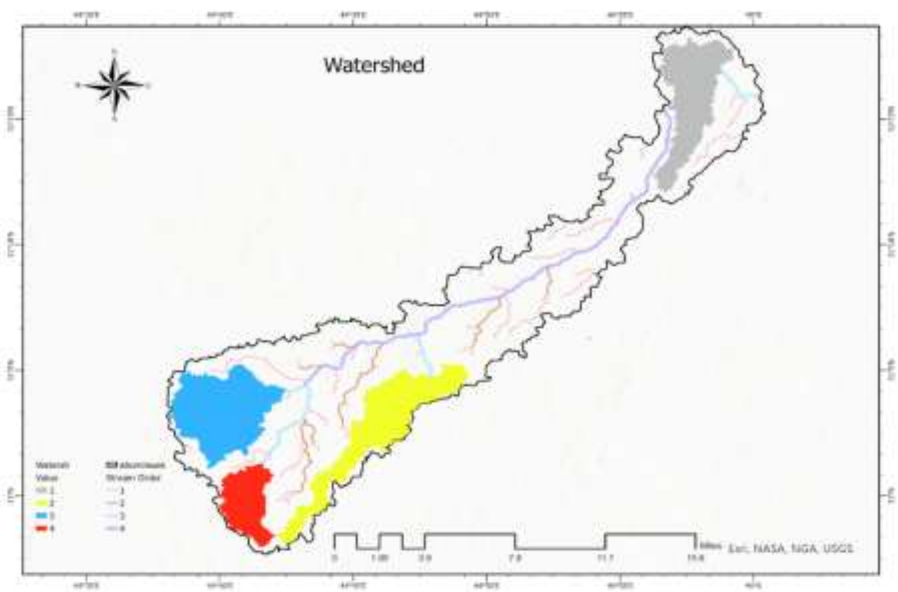


**Fig. 9.** Watershed map

**Table 2.** Area of the Sub-Basins

| value | count | Area $km^2$ |
|---|---|---|
| **1** | 30162 | 27.1458 |
| **2** | 35825 | 32.2425 |
| **3** | 37516 | 33.7644 |
| **4** | 15484 | 13.9356 |

The sub-basin map shows four major sub-basins selected for detailed hydrological analysis within the Wadi Abu Maris Basin. The area calculations show that sub-basin No. (3) represents the largest sub-basin, with an area of 33.7644 km², followed by sub-basin No. (2) with an area of 32.2425 km², then sub-basin No. (1) with an area of 27.1458 km², while sub-basin No. (4) represents the smallest of the sub-basins with an area of 13.9356 km². The sub-basins also differ in their spatial distribution within the study area, with sub-basin (1) extending across the northern and northeastern parts of the study area, while the other three sub-basins are located in the southern part. This indicates that the northern sector of the basin occupies a larger spatial extent than the southern sector. The map shows that all sub-basins are connected to a single integrated drainage network. Surface runoff from each sub-basin collects via first-, second-, and third-order tributaries, forming the fourth-order main channel, which is the foundation of the basin's drainage network. Due to the varying sizes of the sub-basins, the amount of surface runoff contributed by each sub-basin will also vary. Larger sub-basins have a greater capacity to collect water and a greater number of associated tributaries. Since sub-basins (2) and (3) are the largest in area, their contribution to the main channel is expected to be the largest.

## 4. CONCLUSIONS

This study illustrates the applicability of Geographic Information Systems (GIS) and Digital Elevation Model (DEM) data for hydrological analysis of the Wadi Abu Maris Basin. The Wadi Abu Maris Basin faces two major interconnected challenges: flash flood hazards during short-duration, high-intensity rainfall events and desertification resulting from continuous water and wind erosion due to sparse vegetation cover. Therefore, rainwater harvesting and the potential use of small water-harvesting structures may contribute to mitigating these challenges and improving water resource management in the basin. The results showed significant topographic variation, with elevations in the area ranging from 11 meters to 164 meters. This indicates a slope that directly affects surface runoff in the study area. Furthermore, the fill operation removed artificial depressions within the DEM, ensuring continuous surface runoff routing during the hydrological analysis. The results of the flow direction analysis revealed variations in flow direction within the basin due to differences in slopes, the influence of topography, and the direction of water toward low-lying areas. Meanwhile, the runoff accumulation results indicated the presence of an interconnected stream network where water from secondary streams converges and flows into the main channel with the highest runoff accumulation value, indicating the major runoff convergence zones within the basin. From the results of classifying streams according to the Strahler system, we concluded that the stream network ranges from first-order streams—which constitute the largest proportion of the network—to fourth-order streams, represented by the basin's main channel. This indicates a well-structured drainage network. After obtaining the results for the sub-basins, we found that the basin is divided into four sub-basins that differ in area and spatial distribution. Sub-basin No. 3 had the largest area, at 33.7644 km², followed by sub-basin No. (2) with an area of 32.2425 km², while sub-basin No. (4) was the smallest with an area of 13.9356 km². This suggests that Sub-basins (2) and (3) may contribute larger runoff volumes because of their larger drainage areas to the main channel. Thus, the study illustrates the applicability of ArcGIS Pro and DEM data for watershed analysis for understanding surface runoff patterns, supporting future water resource management and environmental planning.

## 5. RECOMMENDATIONS

Based on the analysis results, Future studies may evaluate the suitability of water harvesting structures using integrated hydrological and geotechnical analyses .In addition, the implementation of rainwater harvesting techniques is recommended to enhance groundwater recharge and support sustainable water resource management. Establishing a hydrological monitoring network is also suggested to improve flood prediction and water resource assessment. Furthermore, afforestation and vegetation restoration programs should be promoted to reduce soil erosion and mitigate desertification. Finally, future studies are encouraged to incorporate climate change scenarios and advanced hydrological modeling techniques to improve the accuracy of water resource planning and management in the study area.

### Abbreviations

GIS: Geographic Information Systems.

DEM: Digital Elevation Model.

SRTM: The Shuttle Radar Topography Mission

USGS: United States Geological Survey.

D8: Deterministic Eight Direction.

ArcGIS Pro: Geographic Information System Software.

### Conflict of Interest

The authors declare that they have no conflict of interest.

### Consent for Publication

All authors have read and approved the final manuscript for publication.

### Availability of Data and Material

All data generated or analyzed during this study are included in this manuscript.

### Authors' Contributions

S.Y.H., M.M.Y., M.A.A.H., Y.Y.K., and T.S.H. contributed to the conception and design of the study, data collection, hydrological analysis, interpretation of results, manuscript preparation, and revision. All authors read and approved the final manuscript.

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# التوصيف الهيدرولوجي لحوض وادي أبو مريس باستخدام نظم المعلومات الجغرافية ونماذج الارتفاع الرقمية

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**الملخص**

وفقًا لنتائج هذه الدراسة، تُعد تقنيات نظام المعلومات الجغرافية (GIS) ونماذج الارتفاع الرقمية (DEM) أدوات فعالة لتحليل الخصائص الهيدرولوجية لأحواض المياه من خلال فهم سلوك الجريان السطحي وعلاقته بالتضاريس في منطقة الدراسة. وقد تم اختيار حوض وادي أبو مريس نظرًا لعدم وجود دراسة سابقة أجرت تحليلًا هيدرولوجيًا شاملاً؛ حيث ركزت معظم الدراسات السابقة على التضاريس والخصائص السطحية للمنطقة. ونظرًا للتباينات في الارتفاع ووجود منحدرات داخل الحوض، تلعب هذه العوامل دورًا رئيسيًّا في التحكم في اتجاه وتوزيع الجريان السطحي، وفي تشكيل شبكة مجاري مائية طبيعية تتقدم من الجداول الصغيرة في المناطق المرتفعة نحو المناطق المنخفضة، لتشكل المجرى الرئيسي. ويشير ذلك إلى وجود شبكة تصريف هرمية متطورة. وقد نجحت أدوات التحليل الهيدرولوجي في تحديد مسارات التدفق واتجاهه وأنماط تراكم الجريان السطحي. ومن خلال هذه الأدوات، تم تحديد عدد الأحواض الفرعية، مع وجود تباينات في المساحة والتوزيع المكاني، مما يؤدي إلى اختلافات في مساهمتها في قناة الصرف الرئيسية من خلال الجريان السطحي. وفي الختام، تشير النتائج إلى أن استخدام هذه التقنيات يوفر أساسًا علميًا مهمًا لدراسة وتحليل احواض المياه، ويساهم في دعم إدارة الموارد المائية والتخطيط البيئي والحد من مخاطر الفيضانات.

**الكلمات المفتاحية**

الاستشعار عن بُعد؛ نظم المعلومات الجغرافية؛ التحليل الهيدرولوجي؛ نموذج الارتفاعات الرقمية؛ ArcGIS Pro.