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GIS-BASED WATERSHED MORPHOMETRIC ANALYSIS USING DEM DATA IN DIYALA RIVER, IRAQ

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ABSTRACT

In this study, GIS and image processing techniques were employed to identify the morphological features and analyzing the basin properties of Diyala river. GIS hydrology tools were used for watershed delineation and analysis of the morphological features based on Shuttle Radar Topography Mission (SRTM) DEM data. Moreover, this study deals with the geometric characteristic, where it evaluates the sub-basins morphometric parameters such as area, perimeter, stream frequency, maximum width and length, drainage density and stream orders. The results led to delineate five sub-basins with five stream orders, the drainage density of these sub-basins are ringing between 0.47 to 0.99 km/km^2. Stream orders were calculated, where the number of streams is 41494 with a length 7040.44 km as first order, 10747 with a length 3540.58 km as second-order, 59 with a total length 622.55 km as third order, 13 with a total length 454.98 km as fourth-order streams, and 5 with a total length 340.7 km as fifth order. The stream length reaches the maximum in the first-order, and it decreases with increasing the stream order. This result could be valuable for regional planners and overall policy-makers for agricultural/ water management strategies.

Keywords: Morphometric analysis; Watershed; Water management; DEM

INTRODUCTION

Water is the most valuable resource on our planet; furthermore, it forms the foundation element of life and plays a social role and vital economic (Sanctuary and Tropp, 2005; Alwan *et al.,* 2019a). Watershed refers to the hydrological units that occur naturally determined by the border naturally occurring and is characterized by similar conditions of physical, topography and climatic. Watershed is defined as an area of land that contributes runoff to a mutual point along a water path. Accordingly, it is considered an ideal unit for restraining the flood hazards and manage water resources. Watershed management needs to employ the diverse aspects of landcover such as land, water, soil, and forest resources of a definite watershed for best production and minimum risk to natural resources (Biswas *et al.,* 1999). The morphometric analysis can be defined as the mathematical analysis of the configuration for Earth's surface, shape, and dimension of its landforms (Agarwal, 1998). The Morphometric analysis of drainage patterns are considered of inconceivable importance for suitable planning of watershed, according to its ability to extract information about the characteristics of the basin in terms topography, runoff characteristics, slope, surface water potential and soil conditions, and, etc. (Biswas *et al.,* 1999). In addition to its capacity to provides a quantitative description of stream systems (Strahler, 1964). The valuation of morphometric assist to elaborate an initial hydrological diagnosis to predict the approximate behavior of a watershed if correctly coupled with a geomorphological and geological setting (Esper, 2008).

Geographic Information System (GIS) considers being an effective tool in the study of water availability in the basins, delineation, morphometric analysis for the drainage basin (Abdulrazzaq *et al.,* 2018; Alwan *et al.,* 2019b; Hussein *et al.,* 2018), and water resources suitability analysis (Aziz *et al.,* 2018; Agbasi *et al.,* 2019). The application of remote sensing and GIS for analysis of the morphometric parameters consider being an immense utility in watershed prioritization for soil, water conservation, and natural resources management. The remote sensing satellite data is one of the most effective, time-saving, and accurate technique for morphometric basin analysis (Rai *et al*., 2014; Abdulrazzaq *et al.,* 2019). Digital elevation models (DEM) widely used in representing and analyzing surface topography and topographic analyses to determining topographic characteristics that are one of the most important exponents of hydrological attributes extraction, through analysis of DEM can identify the characteristics of dry valleys (basins and drainage systems). In the hydrological studies, DEM is frequently used to delineation the drainage network, catchment boundary and in the estimation, the hydrological descriptors (Hancock *et al*., 2006). The Shuttle Radar Topographic Mission (SRTM) provides a satellite DEM, which is widely used for watersheds delineation and hydrologic studies because of its global coverage of the surface of Earth with acceptable accuracy (Bhang and Schwartz, 2008). In the last decades, various studies discussed the algorithms of watershed characteristics extraction (e.g. Turcotte *et al.,* 2001; Jones, 2002; Zhang *et al.,* 2013). Wu and Huang (2008) discussed the derived topographic attribute of hydrologic applications using DEM. Zhang *et al.* (2013)

proposed a method to establish the networks using DEM. Too many GIS tools developed based on the previous researchers, Nevertheless, The Hydrology tools in ArcGIS, developed by ESRI (2004) consider being the common tool that used in DEM preprocessing and simulates the surface stream. Additionally, different studies focusing on the GIS-based morphometric analysis (e.g. Chandrashekar *et al.,* 2015; Abdulrazzaq and Aziz, 2016; Prakash *et al.,* 2019).

In this study, an integrated remote sensing and GIS technique was used to delineate the watersheds, and to compute the morphometric parameters of Diyala river basin. The results of the morphometric analysis are helpful in predicting floods, their extent, and intensity. Additionally, it is very important to identify and plan the groundwater potential zones and watershed management, including the whole gamut of natural resources connected with the watershed. This study could be valuable for regional planners and overall policy-makers for agricultural/ water management strategies.

STUDY AREA

The study area represents Diyala river basin which located between Latitude 33^0- 35^0 N and Longitude 44^0- 46^0 E in the northeastern part of Iraq (Fig. 1), 40 km to the North-East of Baghdad which covers an area amounts about 17,685 km² which represent 4% of the total area of Iraq. It is sharing the eastern border with Iran, and internally bordered with four Governorates; Baghdad and Salah Al-Din westwards, Sulaymaniyah to the north and Wasit to the south. The geographical landscape is dramatically varying from Hamrin Mountain series and lakes in the North to the bare soil area near Wasit to the South. According to the Aridity index based on De Martonne's method Diyala Governorate, classify under arid climate class (Alwan, *et al.,* 2019c).

DATA AND METHODOLOGY

The morphometric computation was conducted using SRTM v3 DEM data with a spatial resolution of 90 meters (Fig. 2). SRTM data is a near-global digital elevation model using radar interferometry. The hydrology tool of Arc GIS 10.5 (spatial analyst) was used to delineate the sub-basins and the morphometric analysis such as linear and aerial aspects. Furthermore, DEM was employed to extracted hydrological information such as drainage networks and the boundary to delineate the watershed.

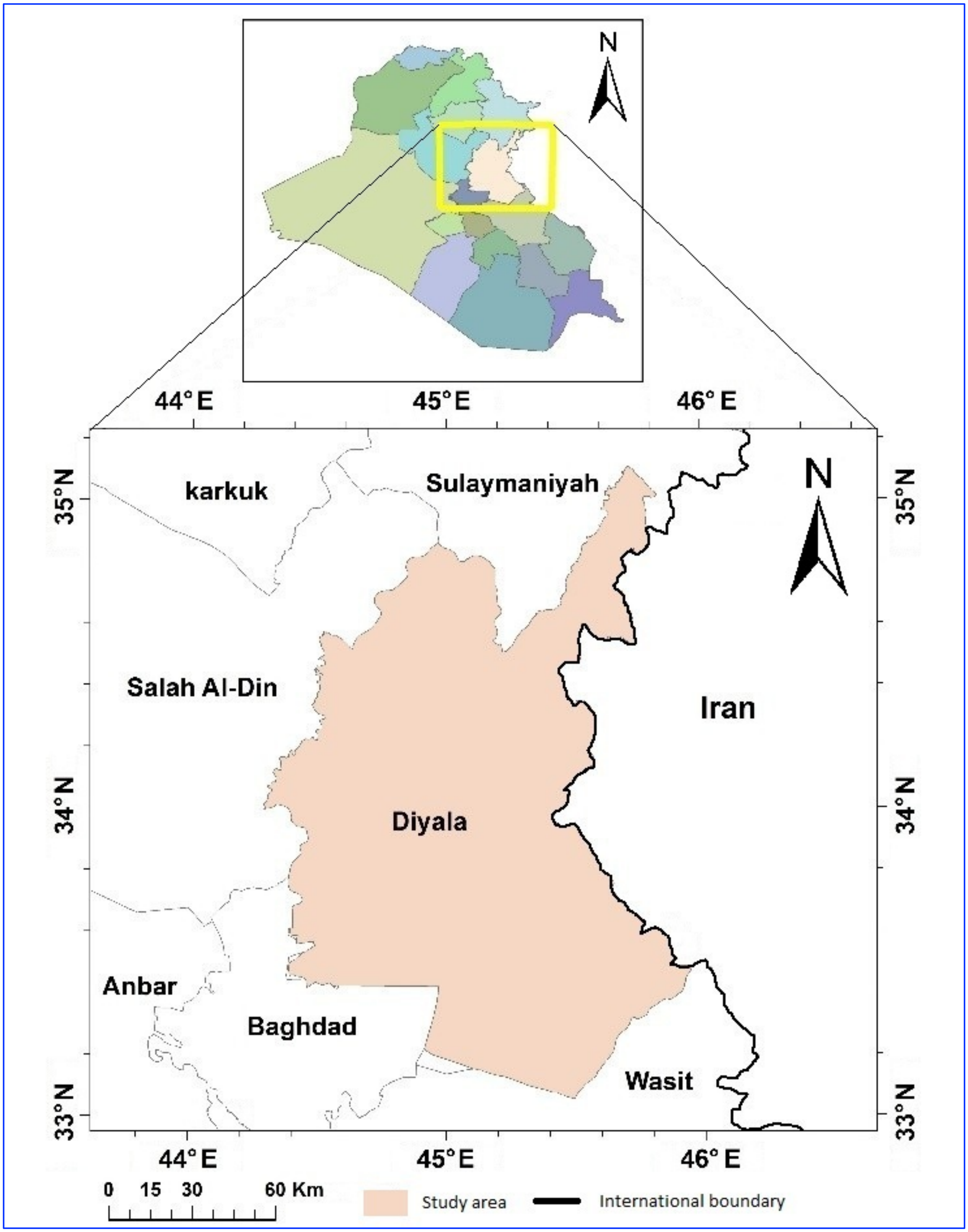

Fig. 1. Location of the study area

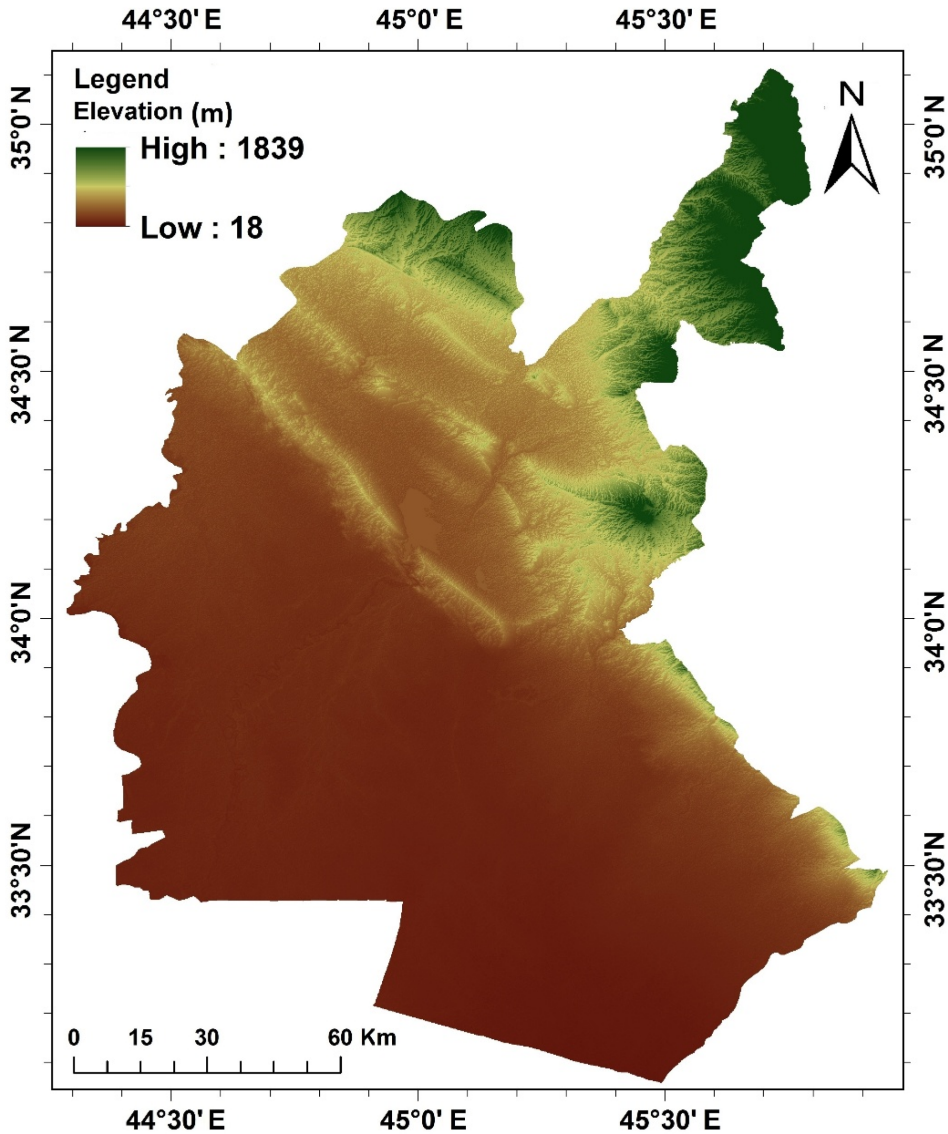

Fig. 2. SRTM digital elevation model (DEM)

DEM DATA PROCESSING

The major steps to process DEM to delineate a watershed as follows (Fig.3):

A. Fill the Depressions

In this step, the cells which have an elevation lesser than the bordering cells commonly, refer to the depressed cells. In this case, DEM will create depressed cells when extracting a watershed parameter from DEM data caused by the existing noise in sensors (Lindsay, 2016). In order to reduce the drainage discontinuities, the sinks were removed by the fill option (Fig. 4). The method of depression filling using an eight-flow direction matrix

(D8) to prepare valid DEM data. The D8 approach considers being one of the most common methods used to derive the drainage networks from DEM data (Lin *et al*., 2008).

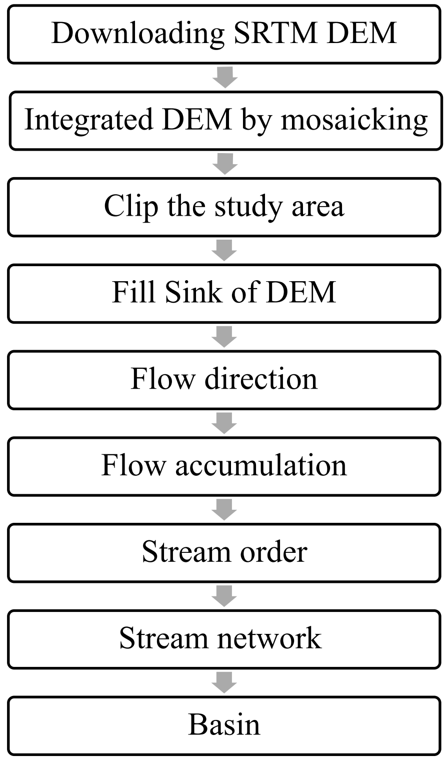

Fig. 3. The methodology flowchart of watershed delineation

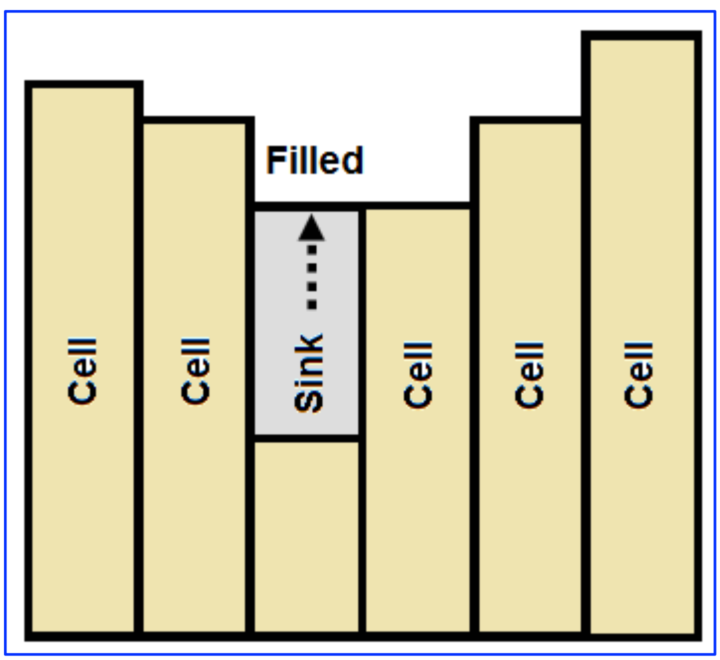

Fig. 4. The process of filling the sinks

B. Flow Direction

Flow direction is an important step in hydrologic modeling, which used to identify the direction of flow for each cell. The filling process must be done before identify the flow direction. In this study, the D8 approach has been used to identify the flow directions using the filled DEM, which is one of the simplest methods to appoint the direction of flow of each cell based on its eight-surrounding cells (Martz and Garbrecht, 1993). ArcGIS-hydrology tools allow water to flow from one cell to a single adjacent cell (Fig. 5a), along with the direction of the steepest descent encoded in different directions (Maidment, 2002).

C. Flow Accumulation

In this step, every cell assigned to a value equal to the number of cells that flow into it (O'Callaghan and Mark, 1984). The drainage network was generated using the flow accumulation process (Fig. 5b), which depends on the flow direction of every cell (Mark, 1983). The watersheds can be delineated by pour points (the deepest point in the boundary of the watershed), where water flows out of an area.

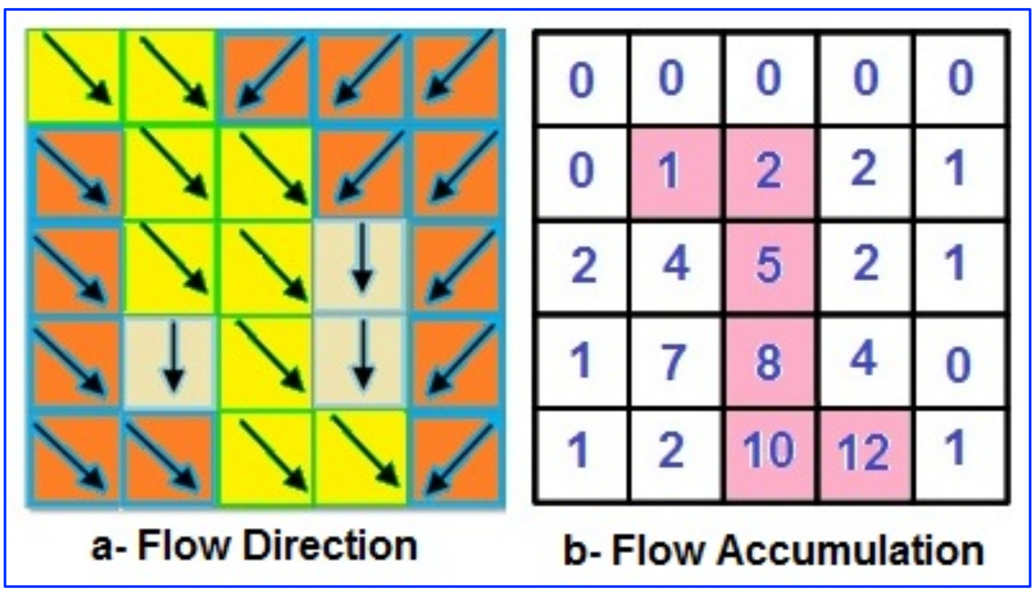

Fig. 5. Cell neighborhood showing flow direction (a) and flow accumulation (b)

MORPHOMETRIC ANALYSIS OF BASIN

Various morphometric parameters are described in the following paragraphs. Table 1 summarizes the morphometric parameters of the study area drainage basins.

A. **Stream Order:** According to Strahler's system, when two-channel of different orders join then the higher-order is maintained (Strahler, 1952). Strahler's system, which is a slightly modified Horton system (Horton, 1945) was used in this study.

B. **Stream Length:** The stream length was calculated based on the law proposed by Horton (Horton, 1945). Stream length considers being an important hydrological feature of the basin. Generally, the total length of the stream segments is a maximum in the first order and decreases as stream order increases.

C. **Drainage density:** Drainage density is the ratio of total channel segment length cumulated for all orders within a basin to the basin area that expressed in terms of Km/Km^2 (Strahaler, 1964). It is a significant indicator of the linear scale in the stream (Horton, 1932).

D. **Stream Frequency:** this parameter defined as the total number of stream segments of all orders per unit area (Horton, 1932).

Table 1. Morphometric Parameters of a Drainage basin

Type	Morphometric Parameters	Formula/Definition	References
Linear	Stream order	Hierarchical order	Strahler,1964
Linear	Stream Length	Length of the stream	Hortan, 1945
Aerial	Drainage density	$Dd = \frac{L}{A}$ L=Total stream length. A= The basin area.	Hortan, 1945
Aerial	Stream frequency	$Fs = \frac{N}{A}$ N=Total number of the stream. A= The basin area	Hortan, 1945

RESULTS AND DISCUSSION

GIS Hydrology tools were used to delineate the watersheds from DEM with a spatial resolution 90 m. The DEM is in Geo TIFF format referenced to UTM zone 38, WGS84 geoid. The DEM contained sinks that could vary between 0.1 m to 4.7 m in a 90m DEM (Tarboton *et al.,* 1991). The Hydrology tools were used to derive several datasets, the analysis was performed to recondition the DEM. Then to generate the flow direction, flow accumulation, streams order, and a watershed delineation, Figure 6 illustrates the watershed delineation and extraction of the basin boundary. This data then used to generate the vector representation of the basins and streams network. The data demonstrated a significant variation in the elevation of the study area; to determine the flow direction based on the DEM iterative process of the cell was conducted. The tool derives the flow direction creates a raster with values that range from 1 to 255, based on a D8 approach. Then, pour point is identified using the flow accumulation layer in the contributing a watershed. The sub-basins were delineated by pour point to computing the flow direction and using it in the watershed function. As a result, five sub-basins have been delineated in the study area (Fig. 7).

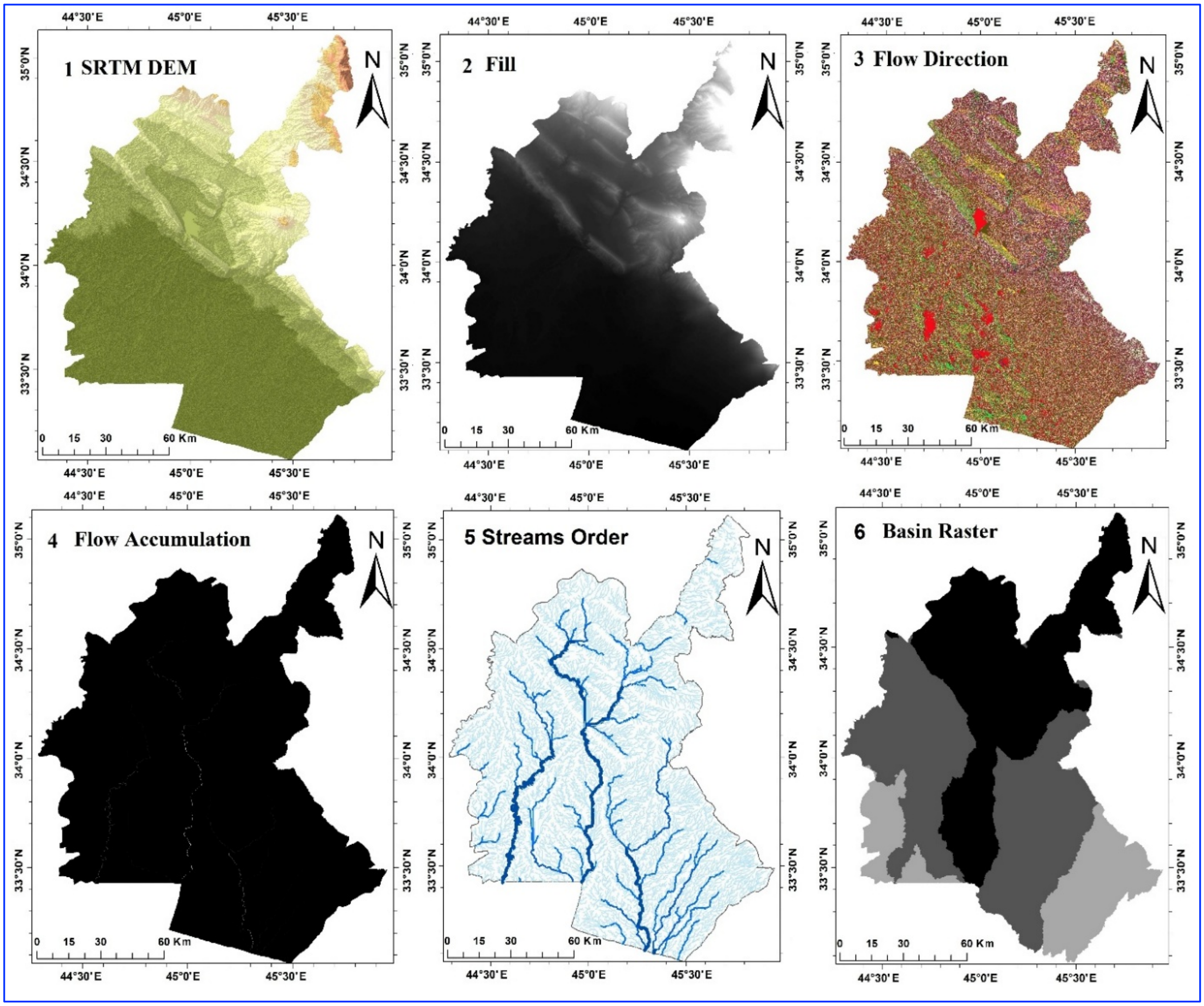

Fig. 6. Watershed delineation and the basin boundary extracted from DEM data

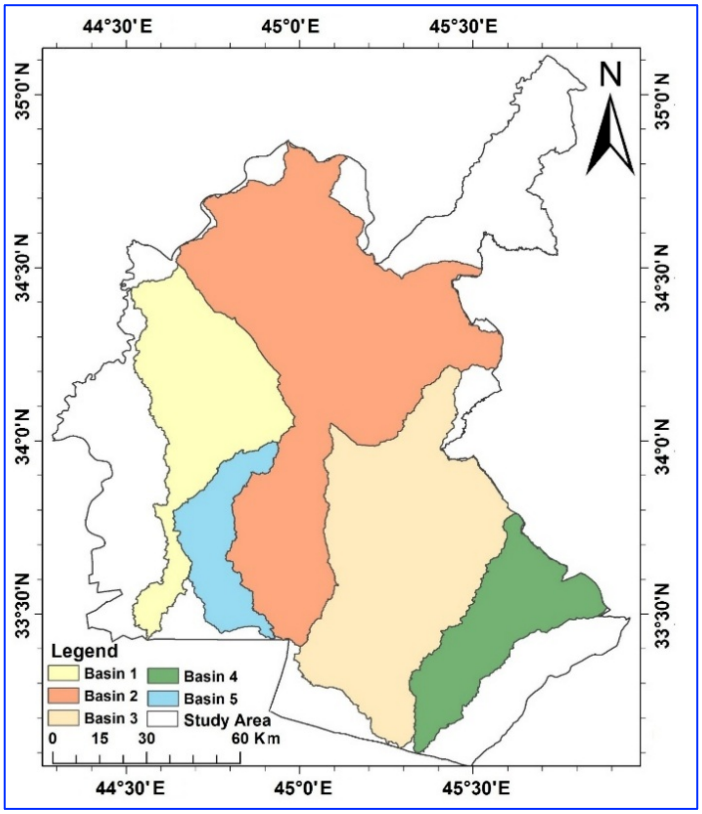

Fig. 7. The five sub-basins of the study area

STREAM ORDER

The stream order of the basin considers being an important parameter to study the amount of water discharge. The higher stream order in the study area is fifth-order; the figures below explain the streams order for all studied sub-basins (Fig. 8). This research represents the delineation and characterization of watersheds using ArcGIS software in a systematic methodology.

In this study, low-resolution DEM (90 m) was used to decrease the computational time and storage requirements. However, future studies are recommended to use high-resolution data, as it tends to provide more accurate results in terms of channel length and channel slope, especially in flat areas. This research provides a basis for delineation and characterization of watersheds; it can be extended to identify additional attributes of watershed polygons, including soil type and land use indicators, for enhanced results. The drainage network and watersheds have been delineated following the methodology as described above.

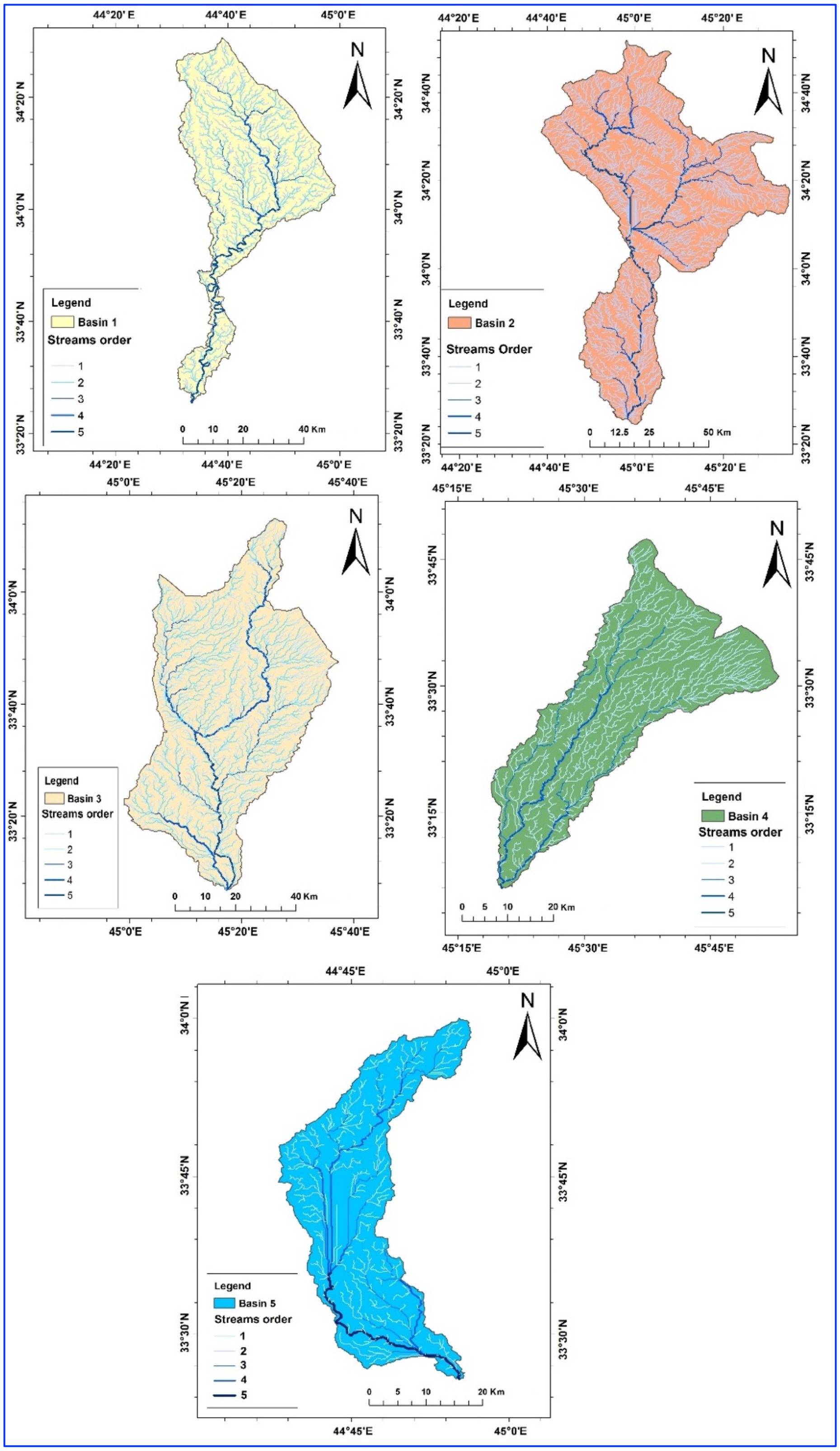

Fig. 8. Streams order of the sub-basin 1, 2, 3, 4 and 5

MORPHOMETRIC ANALYSIS

Five sub-basins have been delineating with five streams order for each one, the drainage density for the five sub-basins are 0.99, 0.47, 0.85, 0.88, and 0.88 km/km^2 (respectively). Table 2 summarized the morphometric analysis result. Moreover, the streams order was calculated. The number of streams is 41494 with a length 7040.44 km as first order, 10747 with a length 3540.58 km are second-order, 59 with a total length of 622.55 km are third order, 13 with a total length of 454.98 km are fourth-order streams, and 5 with a total length 340.7 km are fifth-order (Table 3).

Table 2. The morphometric analysis result

Basin No.	Area Km^2	Perimeter km	Length Km	Max Width km	No. of order	Sum No. of the streams	Sum of stream length Km	Drainage density	Stream frequency
1	2105.25	355.95	115.31	35.15	5	8025	2077.58	0.99	3.81
2	5478.27	548.41	160.89	70.92	5	19860	4070.66	0.74	3.63
3	3641.61	369.67	122.95	50.05	5	15725	3082.16	0.85	4.31
4	1368.54	242.422	80.55	35.15	5	5867	1206.2	0.88	4.29
5	777.32	203.22	77.24	16.28	5	2841	687.66	0.88	3.65

Table 3. Characteristics of drainage the sub-basins and streams

Basin	No. Stream of 1st order	Stream Length of 1st order (km)	No. Stream of 2ed order	Stream Length of 2ed order (km)	No. Stream of 3ed order	Stream Length of 3ed order (km)	No. Stream of 4th order	Stream Length of 4th order (km)	No. Stream of 5th order	Stream Length of 5th order (km)
1	6676	1130.31	1338	650.2	8	131.03	2	36.6	1	129.44
2	15226	2915.8	4613	875	18	68.5	2	108.69	1	102.67
3	12472	1876.9	3236	832.05	13	162.56	3	141.3	1	69.35
4	4906	741.43	953	235.71	5	143.06	2	84.05	1	1.95
5	2214	376.01	607	72.62	15	117.4	4	84.34	1	37.29
Sum	41494	7040.44	10747	3540.58	59	622.55	13	454.98	5	340.7

CONCLUSIONS

In this study, an integrated remote sensing and GIS technique was used to delineate the watershed and to compute various morphometric parameters of Diyala river basin. Five sub-basins were delineated with five streams order for each one, the drainage density for the five sub-basins is 0.99, 0.47, 0.85, 0.88, and 0.88 km/km^2 respectively. Additionally, streams order was calculated where the number of streams is 41494 with a length 7040.44 km as first order, 10747 with a length 3540.58 km are second-order, 59 with a total length of 622.55 km are third order, 13 with length reach to 454.98 km are fourth-order streams, and 5 with a total length 340.7 km are fifth order. The derivation of data (flow direction, flow accumulation, basin, and sub-basins), in addition to the morphometric parameters using GIS, would be very valuable in water harvesting site selection with minimum cost and time compared to the traditional methods; moreover, it is giving acceptable results. The delineate and characterize of watersheds provided by a systematic procedure is provided, which is then applied to a case study.

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